sustainability

Sustainable Development and Higher Education Institutions

Acting with a purpose

Edited by
Göran Finnveden, L.A. Verhoef and Julie Newman

Printed Edition of the Special Issue Published in *Sustainability*

www.mdpi.com/journal/sustainability

MDPI

Sustainable Development and Higher Education Institutions

Sustainable Development and Higher Education Institutions

Acting with a purpose

Special Issue Editors

Göran Finnveden
Leendert Verhoef
Julie Newman

MDPI • Basel • Beijing • Wuhan • Barcelona • Belgrade

Special Issue Editors
Göran Finnveden
The Royal Institute of Technology (KTH)
Sweden

Leendert Verhoef
Delft University of Technology
and Amsterdam Institute for Advanced
Metropolitan Solutions (AMS Institute)
The Netherlands

Julie Newman
Massachusetts Institute of Technology
USA

Editorial Office
MDPI
St. Alban-Anlage 66
4052 Basel, Switzerland

This is a reprint of articles from the Special Issue published online in the open access journal *Sustainability* (ISSN 2071-1050) from 2018 to 2019 (available at: https://www.mdpi.com/journal/sustainability/special_issues/Higher_Education_Institutions).

For citation purposes, cite each article independently as indicated on the article page online and as indicated below:

LastName, A.A.; LastName, B.B.; LastName, C.C. Article Title. *Journal Name* **Year**, *Article Number*, Page Range.

ISBN 978-3-03921-904-9 (Pbk)
ISBN 978-3-03921-905-6 (PDF)

Contents

About the Special Issue Editors

Göran Finnveden is Professor of Environmental Strategic Analysis and Vice-President for Sustainable Development at KTH Royal Institute of Technology. As Vice-President, he is responsible for the integration of sustainable development in education, research, and collaboration across the whole university. He is also a member of KTH's management council. His main research interest is in the use and development of lifecycle assessment and other sustainability assessment tools. His contributions include both methodology development and case studies. He also works with environmental policy and futures studies for sustainable development. Application areas include buildings, energy, ICT, transportation, urban development, and waste management. He is a member of the editorial boards of seven scientific journals and the board of the International Sustainable Campus Network.

Leendert Verhoef is Program Lead Living Labs at AMS Institute and Partner in New-Energy-Works. He is strongly motivated when it comes to bridging the gap between science and society by implementation and transdisciplinary and transformative approaches. Over his career, he has developed multidisciplinary system integration and circular economy programs and living lab frameworks, integrating mobility, sustainable energy, buildings, and other sustainability issues. He has worked with municipalities in national and international projects, conducted seminars and training sessions, and published about these in books, including "SunCities—Reflections", "Our Car as Power Plant", and "Campus as Living Lab" for sustainability. In addition to this, he has started several companies and broadly advised in the field of sustainability, innovation, and strategic marketing, helping start-ups, multinationals, local governments, and international institutes such as European Commission and the World Bank. He serves in the advisory boards of the German Network of Sustainable universities (HOCH-N) and the International Sustainable Campus Network, where he leads in city–university partnerships and Living Lab approach development.

Julie Newman joined MIT as the Institute's first Director of Sustainability in the summer of 2013. She has worked in the field of sustainable development and campus sustainability for twenty years. Her research has focused on the intersection between decision-making processes and organizational behavior in institutionalizing sustainability into higher education. In 2004, Julie was recruited to be the founding Director of the Office of Sustainability for Yale University. At Yale, Julie held a lecturer appointment with the Yale School of Forestry and Environmental Studies. Julie lectures and consults for universities both nationally and internationally, participating on a variety of boards and advisory committees, and has contributed to a series of edited books and peer-reviewed journals. Julie holds a BS in Natural Resource Policy and Management from the University of Michigan, an MS in Environmental Policy and Biology from Tufts University, and a Ph.D. in Natural Resources and Environmental Studies from the University of New Hampshire.

Preface to "Sustainable Development and Higher Education Institutions"

This volume includes papers from the Special Issue on Sustainable Development and Higher Education Institutions: Acting with a Purpose. This includes papers presented at the 2018 annual conference of the International Sustainable Campus Network (ISCN) at KTH, together with additional contributions. We would like to thank all authors, reviewers, and editors involved in this Special Issue. Thanks also to all participants at the conference, the members and secretariat of the ISCN, and local organizers at KTH.

Göran Finnveden, Leendert Verhoef, Julie Newman
Special Issue Editors

sustainability

MDPI

Editorial

Sustainable Development and Higher Education: Acting with a Purpose

Göran Finnveden [1,*], Julie Newman [2] and Leendert A. Verhoef [3]

1 Department of Sustainable Development, Environmental Science and Engineering, The Royal Institute of Technology (KTH), 10044 Stockholm, Sweden
2 Office of Sustainability, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
3 Amsterdam Institute for Advanced Metropolitan Solutions, 1018 JA Amsterdam, The Netherlands
* Correspondence: goranfi@kth.se; Tel.: +46-8790-7318

Received: 7 July 2019; Accepted: 9 July 2019; Published: 12 July 2019

Keywords: Higher Education Institutions; Education for Sustainable Development; Campus; Sustainable Development Goals; Research

---

Higher Education Institutions (HEIs) have a unique role and responsibility for the future and for driving the development of a sustainable society. HEIs are charged with the task of fostering sustainability in the leaders of tomorrow, developing solutions and methods to address a sustainable future, and ensuring that we contribute knowledge to society. HEIs must also ensure that our everyday operations and practices are consistent with a sustainable future and that we work to holistically integrate sustainability into both the mission of a university and our daily tasks.

This Special Issue builds on papers presented during the 2018 International Sustainable Campus Network Conference [1] and also includes other contributions. The articles reflect the many aspects of Sustainability in Higher Education Institutions and illustrate innovation in approach, outcomes, and impact. From a geographical point of view, the papers originate from twelve different countries across four continents. The papers cover a range of perspectives on sustainability both on and around campuses. These include organization and management issues, networking and city partnerships themes, and metrics and indicators related to Sustainable Development Goals. The Special Issue also includes papers on education, student involvement, and gender issues. Select articles include results from surveys and desktop research; others depict approaches on experimentation, living labs, and action research.

The implementation and expansion of sustainability requires an openness to new ways of operating and new ways of partnering. These new ways are conducted on campus, in networks among universities, within relations between the city and the university, and in challenges within cities themselves [2–4]. Bracco et al. [5] write about organising in Living Labs on a campus in Genoa. They describe promising achievements on energy (self-)generation and waste collection as well as recycling. Networking and cross-university learning is important to overcome the numerous, significant challenges. Kahle et al. [6] provide a systematic study of networks, including the open national German Network of Higher Education Institutions for Sustainability (HOCH-N) and the smaller international University Alliance for Sustainability (UAS). Whitycombe Keeler et al. [7] describe a study of city–university partnerships in four countries, developing key contextual factors that may determine the effects of a city–university partnership: interest, individual competences, collective competences, and actions. Fuso Nerini et al. [8] examined how cities can contribute to decarbonising societies and what role research and innovation institutions can play, showing the complicated and large challenges in cities. They emphasize that innovation is required in technology, governance, and on a social level. Leveraging our campuses as living labs is an approach that could tackle these issues simultaneously.

Organizational transformation for sustainability is complex. As demonstrated in this Special Issue, to transform an institution of higher education requires a commitment to consider the role of course offerings, research, and operational impacts. The articles in this Issue capture and relay this challenge via case examples and in-depth analysis of universities around the globe. What emerge from these papers are the common points of entry, challenges, and opportunities, regardless of one's location in the world. Akins et al. [9] seek to understand the barriers examining Kennesaw State University as a case example. Their observations are shaped and grounded in a literature review that seeks to provide a series of lessons learned and categorization that may be shared with institutions in a similar stage of organizational transformation for sustainability. Similarly, Oyama et al. [10] articulate a methodology by which to assess a campus-wide approach to sustainability via an in-depth analysis of sustainability courses, research, campus operational commitments, and land holdings. They also outline overall obstacles and barriers to implementation that mimic those seen in Kennesaw State University; however, the institutional context is quite different. One of the Sustainable Development Goals (SDGs) concerns Gender Equality. Hansman and Schröte [11] describe how mid-career scientists evaluate the impact of gender and age on their career possibilities.

At the case-specific level, Dehghanmongabadi et al. [12] outlines the challenges of transportation demanded management at Eastern Mediterranena University. Their case example is insightful for universities that are seeking to develop comprehensive transportation systems on university campuses in a move away from expanded parking. Another type of travel that universities are seeking to model and develop a more in-depth understanding of is air travel, specifically, its relationship to greenhouse gas emissions. Given the global nature of faculty research and the student body, universities are more readily grappling with these implications. Ciers et al. [13] provide insight into how École Polytechnique Fédérale de Lausanne (EPFL) is measuring and accounting for these Scope 3 emissions. This will provide insight for universities around the world grappling with the same challenge. Hopff et al. [14] bring forth an emergent model for HEIs grounded in the principles of a circular economy. The case looks at Dutch universities and explores how the principles of a circular economy may manifest within a university campus. Uehara and Ynacay-Nye [15] looked into the willingness to pay to use water bottle refill stations at a Japanese university. Hugo et al. [16] used an action research method focussed on community participation to develop their university in Ecuador. The goal was to integrate the main university campus within a framework which guarantees sustainability and allows innovation in the living lab.

Transforming our world, which is the name of the 2030 Agenda for sustainable development, may require also a change in education practises. Troft et al. [17] describe experiences with participatory action research for undergraduates. In many ways, Brugmann et al. [18] is a unique paper because it describes an undergraduate project written mainly by students. It describes inventories of courses and other university activities based on key words. This also addresses the important aspect of monitoring and measuring, which may be necessary for transforming universities. Körfgen et al. [19] have also developed lists of key words for mapping universities research on the global sustainable development goals. This could possibly be integrated into the sustainability assessment tools of higher education institutions reviewed by Findler et al. [20], which concluded that there is a need for further development of these tools. Finally, the essay by Sonetti et al. [21] discusses the context in which universities can collaborate and contribute to triggering sustainability values, attitudes, and behavior within future regenerative societies.

Universities worldwide seek and provide common frameworks for understanding, applying, evaluating, and advancing the principles of sustainable development on campuses today. The papers in this Special Issue provide an overview of many of the aspects that higher education institutions are working with while promoting sustainable development. The value proposition of integrating these principles into institutions of higher education is clear as they will be tied to the educational outcomes of their graduates.

Author Contributions: All authors contributed to conceptualization, writing of original draft and editing.

Funding: This work received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. ISCN 2018 Conference Summary Report. Available online: https://www.international-sustainable-campus-network.org/conferences/stockholm-2018/2018-conference-summary (accessed on 7 July 2019).
2. Verhoef, L.A.; Graamans, L.; Gioutsos, D.; van Wijk, A.J.M.; Geraedts, J.; Hellinga, C. ShowHow: A Flexible, Structured Approach to Commit University Stakeholders to Sustainable Development. In *Handbook of Theory and Practice of Sustainable Development in Higher Education*; Walter, L.F., Azeiteoro, U.M., Molthan-Hill, F.A., Eds.; Springer: Berlin/Heidelberg, Germany, 2017; Volume 4, pp. 491–508. [CrossRef]
3. Verhoef, L.A.; Bossert, M.; Newman, J.; Ferraz, F.; Robinson, Z.P.; Agarwala, Y.; Wolff, P., III; Jiranek, P.; Hellinga, C. Towards a Learning System for University Campuses as Living Labs for Sustainability. In *Universities as Living Labs for Sustainable Development: Supporting the Implementation of the Sustainable Development Goals—Volume 2*; Springer: Berlin/Heidelberg, Germany, 2019.
4. Verhoef, L.A.; Bossert, M. *University Campus as Living Lab for Sustainability—A Handbook and Practitioners' Guide*; TU Delft: Delft, The Netherlands, 2019; ISBN 978-3-940670-68-7.
5. Bracco, S.; Delfino, F.; Laiolo, P.; Morini, A. Planning & Open-Air Demonstrating Smart City Sustainable Districts. *Sustainability* **2018**, *10*, 4636.
6. Kahle, J.; Risch, K.; Wanke, A.; Lang, D.J. Strategic Networking for Sustainability: Lessons Learned from Two Case Studies in Higher Education. *Sustainability* **2018**, *10*, 4646. [CrossRef]
7. Withycombe Keeler, L.; Beaudoin, F.D.; Lerner, A.M.; John, B.; Beecroft, R.; Tamm, K.; Wiek, A.; Lang, D.J. Transferring Sustainability Solutions across Contexts through City–University Partnerships. *Sustainability* **2018**, *10*, 2966. [CrossRef]
8. Fuso Nerini, F.; Slob, A.; Engström, R.E.; Trutnevyte, E. A Research and Innovation Agenda for Zero-Emission European Cities. *Sustainability* **2019**, *11*, 1692. [CrossRef]
9. Akins, E., II; Giddens, E.; Glassmeyer, D.; Gruss, A.; Kalamas Hedden, M.; Slinger-Friedman, V.; Weand, M. Sustainability Education and Organizational Change: A Critical Case Study of Barriers and Change Drivers at a Higher Education Institution. *Sustainability* **2019**, *11*, 501. [CrossRef]
10. Oyama, K.; Pasquier, A.G.; Mojica, E. Transition to Sustainability in Macro-Universities: The Experience of the National Autonomous University of Mexico (UNAM). *Sustainability* **2018**, *10*, 4840. [CrossRef]
11. Hansmann, R.; Schröter, D. Equal Opportunities in Academic Careers? How Mid-Career Scientists at ETH Zurich Evaluate the Impact of Their Gender and Age. *Sustainability* **2018**, *10*, 3343. [CrossRef]
12. Dehghanmongabadi, A.; Hoşkara, Ş. Challenges of Promoting Sustainable Mobility on University Campuses: The Case of Eastern Mediterranean University. *Sustainability* **2018**, *10*, 4842. [CrossRef]
13. Ciers, J.; Mandic, A.; Toth, L.D.; Op't Veld, G. Carbon Footprint of Academic Air Travel: A Case Study in Switzerland. *Sustainability* **2019**, *11*, 80. [CrossRef]
14. Hopff, B.; Nijhuis, S.; Verhoef, L.A. New Dimensions for Circularity on Campus—Framework for the Application of Circular Principles in Campus Development. *Sustainability* **2019**, *11*, 627. [CrossRef]
15. Uehara, T.; Yancay-Nye, A. How Water Bottle Refill Stations Contribute to Campus Sustainability: A Case Study in Japan. *Sustainability* **2018**, *10*, 3074. [CrossRef]
16. Hugo, H.; Espinoza, F.; Morales, I.; Ortiz, E.; Pérez, S.; Salcedo, G. Delta Project: Towards a Sustainable Campus. *Sustainability* **2018**, *10*, 3695. [CrossRef]
17. Trott, C.D.; Weinberg, A.E.; Sample McMeeking, L.B. Prefiguring Sustainability through Participatory Action Research Experiences for Undergraduates: Reflections and Recommendations for Student Development. *Sustainability* **2018**, *10*, 3332. [CrossRef]
18. Brugmann, R.; Côté, N.; Postma, N.; Shaw, E.A.; Pal, D.; Robinson, J.B. Expanding Student Engagement in Sustainability: Using SDG-and CEL-Focused Inventories to Transform Curriculum at the University of Toronto. *Sustainability* **2019**, *11*, 530. [CrossRef]
19. Körfgen, A.; Förster, K.; Glatz, I.; Maier, S.; Becsi, B.; Meyer, A.; Kromp-Kolb, H.; Stötter, J. It's a Hit! Mapping Austrian Research Contributions to the Sustainable Development Goals. *Sustainability* **2018**, *10*, 3295. [CrossRef]

20. Findler, F.; Schönherr, N.; Lozano, R.; Stacherl, B. Assessing the Impacts of Higher Education Institutions on Sustainable Development—An Analysis of Tools and Indicators. *Sustainability* **2019**, *11*, 59. [CrossRef]
21. Sonetti, G.; Brown, M.; Naboni, E. About the Triggering of UN Sustainable Development Goals and Regenerative Sustainability in Higher Education. *Sustainability* **2019**, *11*, 254. [CrossRef]

sustainability

MDPI

Article

Planning & Open-Air Demonstrating Smart City Sustainable Districts

Stefano Bracco [1], Federico Delfino [1,2], Paola Laiolo [1,*] and Andrea Morini [1]

[1] DITEN—Department of Naval, Electrical, Electronic and Telecommunication Engineering, University of Genoa, 16126 Genova, Italy; stefano.bracco@unige.it (S.B.); federico.delfino@unige.it (F.D.); andrea.morini@unige.it (A.M.)

[2] CENS—Management Center of Savona Campus, University of Genoa-Savona Campus, 17100 Savona, Italy

* Correspondence: paola.laiolo@edu.unige.it

Received: 30 October 2018; Accepted: 4 December 2018; Published: 6 December 2018

Abstract: The article is focused on the "demonstration" activities carried out by the University of Genoa at Savona Campus facilities in order to implement the "Living Lab Smart City". The idea is to transform the Savona Campus in a Living Lab of the City of the Future: smart technologies in Information and Communication Technology (ICT) and energy sectors were installed in order to show a real application of the Smart City concept to population and external stakeholders. Moreover, special attention was given to the environment, personal wellbeing, and social equalities. The sustainable energy Research Infrastructures (RIs) of Savona Campus allowed enhancement of the applied research in degree programs and the collaboration with several companies. In particular, an important partnership with the Italian electric Distribution System Operator (DSO), ENEL S.p.A., started in 2017 to test the capability of these RIs to operate disconnected from the National Grid, relying only on the supply of renewables and storage systems. The "Living Lab Smart City" is an important action to reduce the carbon footprint of the Savona Campus and to increase the awareness of students, teachers and researchers towards Sustainable Development in Higher Education Institutes.

Keywords: smart city; living lab; sustainability; sustainable energy; sustainable environment; wellbeing

1. Introduction

During the last two decades, many cities around the world started to improve their urban infrastructures and services by resorting to the opportunities offered by state-of-the-art innovative technologies and according to the "sustainability" paradigm in order to offer higher life quality conditions to their citizens [1–5]. These efforts have been generally focused both on specific redevelopment operations on underused or decaying suburban areas and on the redesign of city centers from a traditional urban core, very often overcrowded, to a more environmentally sustainable and comfortable space, where the public community can work and spend free time, even experiencing a healthy lifestyle. This is the concept of the new sustainable smart cities [6–9], intended as urban spaces highly permeated by the contribution of a citizen and society oriented technology [10]. The so called "smartization process" includes interventions on different sectors of everyday life, based on a wide application of Information and Communication Technology (ICT) to both monitoring how the city is evolving and to connect, protect and enhance the lives of citizens [6,11,12]. Consequently, IoT (Internet of Things) sensors, video cameras, social media, and smart devices act as an urban nervous system, providing a constant information to local institutions and to the community. In particular, they allow, at any time, to manage, optimize and control all the urban activities according to people need [13–15].

Smart cities today stand for a multidisciplinary subject of interest with several sectors of development, namely energy [16], intelligent buildings, mobility, environment, low-impact infrastructures, participated governance, education, healthcare and wellbeing, and sustainable tourism.

As a result, these intelligent and sustainable urban areas have been studied not only by scholars in architecture and urban planning, but also by other disciplines, such as the social sciences (economy, geography), and the technical ones (computer science, electrical and civil engineering) [17,18].

It should be noticed that universities can play an active role in facilitating the deployment at a wide scale of the smart city concept, strictly cooperating with government and local institutions [19–21]. Academic players, indeed, can address innovation projects to the real experimentation at the campus level of smart city "pilots" in order to show "open-air" innovative technologies and increase the public awareness about the topic [20]. Following this path, university campuses can become Living Labs [22–24], open-innovation environments typically characterized by private—public partnerships (research institutions, industry, SMEs) aimed at implementing and demonstrating new services, products and systems for urban applications [24]. In this context, the University of Genoa (UNIGE), Italy, recognizes, in its Charter, sustainability as one of the main pillars for its future evolution, in strict connection with the development lines of the surrounding territory (Liguria Region, the North West Italian district), such as tourism, green & blue economies, hi-tech/hi-skills industries and health, wellbeing & sport activities. In particular, UNIGE is strongly committed in following an innovation path towards the paradigms of "Zero Emission Campus" and "Smart City Living Lab" at its premises located in the city of Savona (about 45 km from Genoa) [21,25–27]. UNIGE idea is to make the Savona Campus a model of sustainable district for local society and institutions through the real demonstration of the best available technologies in the environmental, energy and wellbeing sectors.

The present paper describes the projects and activities conceived by the University of Genoa with the specific intention to transform the Savona Campus into a demo site of a sustainable smart urban district, namely the "Living Lab Smart City", characterized by the most relevant city features, such as residences, offices, green/recreational areas, food service, and educational activities.

It is important to underline that planning and implementing a smart city is not simple because cities are made up of multitudes of individuals and entities that are difficult to coordinate. However, this process inside Savona Campus has been carried out with the active involvement and empowerment of all the Campus community components (students, faculty, and employees).

This article is organized as follows. Section 2 gives an overview about the Campus, while Section 3 describes the material and methods used to implement the "Living Lab Smart City" in different sectors. The performance evaluation metrics and the results of the projects are described in Section 4. Finally, Section 5 presents our discussion and conclusions.

2. Savona Campus Overview

From 1930 to 1990, the whole area, of about 55,000 sqm (Figure 1), hosted a military compound of the Italian Army. The barracks were delimited by a high wall, still present outside the current university campus. Afterwards, in the 1990s, an urban regeneration accommodated the University facilities into the pre-existing seventeen buildings. Nowadays, more than 2000 students attend here both B.Sc./M.Sc. programs and professional masters in Engineering (environment and energy sectors), Health & Sport Sciences, Nursing, Media Sciences, and Sustainable Tourism. About 185 persons (15 employees and 170 academics) are part of the University staff located inside the Savona Campus. Moreover, the area includes 15 SMEs (Small and Medium Enterprises) with about 130 workers. Many services for both students and workers are present as well: a library, a cafeteria, a canteen, study halls, sports facilities, green areas and student accommodations. Therefore, the Campus can be compared to a small city district since the most relevant city features are represented. For this reason, the University of Genoa decided to focus the research inside Savona Campus on Sustainability and Smart City topics in order to create a "Sustainable and Innovative Campus" able to increase the private and public awareness about the aforementioned themes. Great efforts were made to enhance green areas, increase sustainable mobility, and implement a waste-recycling program. Since 2011, an innovation project, named "Energia 2020" [21,26,28], allowed to create two important Research Infrastructures (RIs) integrating renewable energy sources and system automation in order to reduce the carbon footprint and to create a high-comfort environment for the Campus: the "Smart Polygeneration Microgrid" (SPM) and the "Smart Energy Building" (SEB) [21,28,29]. These RIs allowed, in 2017, to start a collaboration with a multinational energy company, Enel S.p.A. This brought to the creation of an "Open Innovation Lab" aimed to test the Smart City technologies in ICT and energy sectors [21]. Moreover, UNIGE is developing projects and programs related to sport in order to improve health and wellbeing of students and Campus users. In particular, a cooperation with Savona Municipality was put in place to design and create a National Sport Hub for sea and water activities.

The many actions developed on sustainability and smart city topics at Savona Campus, allowed to join, in 2016 and 2017, two important global networks about "Sustainable University Campuses". The first is the International Sustainable Campus Network (ISCN), a non-profit association of globally leading colleges and universities working together to holistically integrate sustainability into campus operations, research and teaching [30]. The second is the UI Greenmetric, a university ranking platform established with the aim to evaluate and rank universities all over the world according to their current condition and policies related to green campus and sustainability activities [31].

Figure 1. Satellite map of Savona Campus area from Google Earth 2018 (Google Earth V 7.3.2.5491. (23 July 2018). Savona Campus—University of Genoa, Savona, Italy. 44°17′54′′ N, 8°27′01′′ E, Eye Alt 215 m. Available online: https://earth.google.com/web/). The yellow line represents the Campus wall.

3. Materials and Methods

In the recent years, the research of the University of Genoa inside Savona Campus has been devoted to engineering topics such as sustainable energy & environment, smart buildings and electric mobility. Recently, health and sport sciences studies on wellbeing and healthy ageing have been developed as well, making the Campus an example of a healthy and innovative district inside the city of Savona.

In this context, it is worth mentioning the "Energia 2020" project of the University of Genoa, an important Research and Development (R&D) project related to the concepts of Sustainable Energy and Smart City [21,26,28]. The project, designed in 2011 and developed thanks to public financing, planned to install within the Savona Campus innovative energy systems aimed at both reducing operating costs and CO_2 emissions. Additionally, particular attention has been paid to create a comfortable environment for the Campus users. Energia 2020 consists of three different actions: (i) Smart Polygeneration Microgrid (acronym: SPM); (ii) Smart Energy Building (acronym: SEB);

(iii) Energy Efficiency Measures (acronym: EEM). The SPM, an "intelligent" and sustainable microgrid providing electricity and thermal energy to the Campus [21,26], started to operate in 2014. In 2017 both the SEB and the EEM were implemented; the first is an "intelligent" and active ZEB (Zero Emission Building) interacting in real-time with the Energy Management System of the SPM, while the second deals with a series of actions aimed at reducing the consumptions and the energy dispersions at the building level. These three interventions contributed to start, at the end of 2017, an important collaboration with the Italian electric Distribution System Operator (DSO), Enel S.p.A. The purpose of this public-industrial partnership is to develop research projects in the fields of sustainable energy, smart mobility and islanded microgrids. For that reason, the "Living Lab Microgrid" national laboratory was created [21].

Over the last three years, health & wellbeing topics are strengthening inside Savona Campus. From an educational point of view, one B.Sc. in Sport and Health Sciences and one Master's of Rehabilitation of Musculoskeletal Disorders are present. These programs benefit from several sport infrastructures within the Campus to practice what taught during the lessons. In particular, inside the area of the Campus it is possible to train specific sports as tennis and football or to practice a total-body training inside a smart Gym (U-Gym) or outdoors over a 1 km open-air fitness trail, named U-Trail. U-Gym and U-Trail were specifically designed to be used for individual wellbeing of students, university staff and personnel of the SMEs located inside the Campus, but also as Sport and Health Laboratories to performance studies on sport and rehabilitation programs.

Figure 2 shows some photos of the Savona Campus about green areas, renewable energy technology and outdoor sport infrastructures.

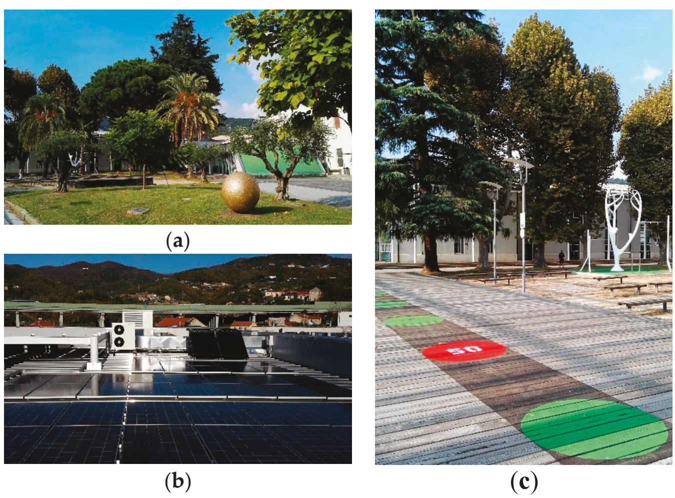


Figure 2. The figure shows some photos of Savona Campus: (**a**) the garden near the canteen and students accommodations; (**b**) the photovoltaic plant and the solar thermal collectors above the Smart Energy Building; (**c**) part of U-trail, a 1 km outdoor fitness trail, with one training station at the top right of the photo.

The following sub-sections describe in detail the Smart City sectors developed inside the "Living Lab Smart City" of Savona Campus. Moreover, Table 1 summarizes all the achievements obtained inside Savona Campus in the main Smart city sectors.

Table 1. Smart City achievements of Savona Campus—University of Genoa.

Smart City Sector	Achievements of Savona Campus
Sustainable Energy	• Creation of a Smart Microgrid managed by an Energy Management System • Energy production from renewable sources and cogenerating units • Energy-efficiency interventions in public buildings
Smart Mobility	• 4 charging stations (2 Grid to Vehicle and 2 Vehicle to Grid) • 4 electric vehicles (2 bikes and 2 cars) • 73 bike parking lots
Smart Buildings	• Construction of a Smart Energy Building managed by a Building Management System • Automatic light and presence sensor systems in all the buildings
Sustainable Environment	• Improvement of green areas and biodiversity • Vertical hydroponic garden • Smart garden irrigation system • Rainwater collection • Improvement of waste collection
Health, Wellbeing and Social Integration	• Creation of a technological gym with some instruments able to produce electricity • Creation of an outdoor fitness trail • Projects, at the design phase, to enhance the actual football field and to create a National Sport Hub for sea and water activities • Planning for special programs for the sport training of disabled people

3.1. Sustainable Energy

The need for a more efficient, reliable and sustainable energy production inside the Savona Campus paved the way for the design of a smart microgrid. Smart Grids are modern "active" grids designed to gather and exchange both information and energy. Among Smart Grid solutions, Microgrids are considered to be ones of the most interesting applications of this concept. They can be defined as localized aggregations of generating units (from renewable or traditional sources), loads as well as storage systems (electrical and thermal) related to a restricted area. The aforesaid infrastructures need to be daily managed by a so called EMS (Energy Management System) that usually aims at minimizing operating costs and/or emissions, also considering the possibility to apply demand response strategies [32,33]. In this context, the SPM pilot project has been developed by the University of Genoa with the purpose to efficiently and economically manage the energy produced and distributed within the Campus, optimizing the contributions coming from renewable sources and thus reducing the pollutants emissions [25–27]. The SPM is composed of an electrical and a thermal grid, both managed by a central brain, the Energy Management System (EMS), in charge of real-time checking the functional status of all the grid's elements and informing in case of problems or breakdowns [34]. The EMS allows also to forecast the energy consumptions to optimally schedule the operation of dispatchable sources, also planning the exchange with the public grid, with the goal of minimizing operational costs and reducing carbon dioxide emissions [28].

The main energy components of the SPM are: two photovoltaic plants (PV), three solar thermodynamics dishes, two cogenerating micro-turbines, two gas boilers, two absorption chillers and one electrochemical storage system. Furthermore, an additional PV plant, two solar thermal collectors and a geothermal heat pump are present in the new Smart Energy Building of the Campus.

Most of the electricity needs of the Savona Campus are satisfied by the generation from both solar power and cogenerating micro-turbines fed by natural gas. These high efficiency cogeneration units allow to exploit the primary energy to produce simultaneously two types of energy: electrical energy, injected into the distribution grid, and thermal energy, used to integrate the boilers' production during coldest months and as feeding source for the absorption chillers (in order to produce cooling energy) during warmer months. It is important to underline that the electrical energy generated by PV fields can be stored inside the electrical storage system, under the supervision of the EMS developed by the University of Genoa. The following table (Table 2) summarizes the sizes of the plants present inside the Savona Campus.

Table 2. Size of the energy production plants inside Savona Campus.

Energy Production/Storage	Installed Power/Storage Capacity
Electricity	120 kW (PV plants) 130 kW (Cogeneration units)
Thermal energy	900 kW (Boilers) 224 kW (Thermal power – cogeneration units) 220 kW (Cooling power– absorption chillers) 45 kW (Geothermal heat pump) 2 kW (Solar Thermal collectors)
Electrical storage	140 kWh

Due to the EEM project, the Campus end-user consumptions and the energy dispersions at the building level have been reduced. In particular, new window fixtures have been installed the air conditioning system has been improved and led lamps have been included in both the internal and external light systems.

3.2. Smart Mobility

UNIGE owns two electric bikes and two Li-ion batteries cars, whose technology guarantee a long life cycle, high performances, high efficiency, and no toxic components. The benefits given from the usage of electric vehicles are first of all environmental: indeed, there is no emission of local atmospheric pollutants and no acoustic noise.

Electric vehicles can be recharged inside the Campus since four charging stations, connected to an E-car Operation Center platform, are present. Two of them allow the Grid to Vehicle (G2V) technology, while the other two are also Vehicle to Grid (V2G). The latter, installed in 2017, use the batteries of the electric cars as support storages to the electric grid. Indeed, V2G is a technology that allows a full integration of electric vehicles into the electricity grid and a more efficient management of renewable energy. Through a V2G station, drivers can charge their batteries during off-pick periods (low demand), with the option to use the energy stored in the vehicles' batteries at home/office or even feed back to the grid during peak hours, when the costs are higher, becoming therefore "prosumers" (producer and consumer).

Another type of zero emission vehicle enhanced inside the Campus is the bike. Nowadays, about 73 bike parking lots are available for free inside the area; moreover, bicycles are available, upon request, for students staying at the Campus accommodations.

3.3. Smart Buildings

Several technological and smart devices are present within the buildings of Savona Campus in order to improve both safety and life quality of students and workers. Some examples are automatic lights, presence sensor systems, video surveillance system and automatic door sensor system to enter into the Library. Moreover, the entrance into the U-Gym is guaranteed by using a RFID (Radio Frequency Identification) bracelet or a specific smartphone app (Virtual Badge) and the environmental comfort inside the Smart Energy Building has been increased thanks to a controlled mechanical ventilation system.

In 2017, the SEB was built to be an innovative and high performance smart construction to meet goals of zero carbon emissions, energy and water efficiency, and automation [25–27]. It acts as the first smart city urban infrastructure in Italy as it is directly connected to the SPM. This connection, guaranteed by the BMS (Building Management System) of the SEB and the EMS of the SPM, allows the SEB to be an "Energy Prosumer" able to produce energy (thermal and electrical) for its own and, in case of need, to recall it from the SPM. Moreover, the BMS can optimally manage the electrical and thermal performances of the SEB, but also the led lamps intensity, the indoor temperature, the building blinds and the water consumptions.

The building has two floors covering a total area of 1000 m^2. The heating and the air-conditioning are provided only by a geothermal heat pump and solar thermal collectors, while the electricity is supplied by the photovoltaic panels mounted on its roof and by SPM storage batteries. In addition, the energy efficiency performance of the SEB are improved thanks to the high performance thermal insulation materials (cladding and ventilated facades) of the external walls and the low consumption led lamps.

3.4. Sustainable Environment

Environmental protection is one of the main pillars of sustainability. The technological development should protect ecosystems, air quality, and sustainability of natural resources. Following this direction, it becomes very important to enhance the surrounding environment to make it clean and livable. For this reason, UNIGE decided to improve the green areas of Savona Campus, obtaining a covering of about the 23% of the global area. The biodiversity is preserved since different trees species can be found: pine, palm, olive, cedar, and plane trees. In addition, a vertical hydroponic garden, fed only by water, is present inside the SEB. Lawns and gardens inside Savona Campus are irrigated by a smart irrigation system which runs automatically but can be optimally managed by the use of a web application also available on smartphones. The web application allows to monitor the garden irrigation status, to set different irrigation programs, to detect problems in the system, to see the irrigation schedule in a selected period, and to generate reports about the use of water. Moreover, the gardens near the SEB are irrigated by the use of recycled rain water. The water collected from the roof, conveniently filtered, is stored inside an underground 5000 liters storage tank and it is used, in case of need, for garden irrigation and toilet flushing. This system allows to have both economic and environmental benefits. Other examples of water saving technologies are the dual-flush toilets and low flow taps and showers in the buildings.

Great efforts were also made in relation to urban waste and recycling. The Savona Campus wants to raise awareness on the issue of urban waste and to be a model of environmental impact reduction for population and institutional stakeholders (e.g., municipalities) in the surrounding area. For this reason, appropriate waste containers were located into all the buildings and in the main external areas. It is possible to recycle paper and cardboard, plastic, glass, cans, organic waste, used electrical batteries, toners and cartridges, and also street sweepings. All the waste fractions, including the street sweepings, are collected and sent to different treatment plants.

3.5. Health, Wellbeing, and Social Integration

Many more people today are living healthier lives than in the past decade. Nevertheless, the economic growth and high workloads can often cause health diseases and psychological disorders [35]. A possible way to increase the personal wellbeing is to practice regular sport. Sport activities, together with technological innovation, can facilitate a transition to a world of reduced environmental stress and enhanced human wellbeing. For these reasons, the University of Genoa decided to invest some of its funds, not only in the energy and environment sectors, but also in the sport one, improving and creating new facilities inside the Savona Campus following the smart city concept.

From 2017, the Smart Energy Building hosts a digital and technological Sport Science Lab, named U-Gym, available for students and Campus workers. It is a cutting-edge gym with particular equipment for indoor training with LCD displays for the interaction with a virtual coach by the use of a Cloud platform. Each sport equipment allows the user to access a personal account in which historical training program results, favorite websites, and social networks are present. Moreover, some of these instruments (bikes, tapis roulant, and elliptical machines) are able to produce electricity thanks to the "human movement"; this energy is injected into the Smart Energy Building and used inside offices, laboratories and also into the gym. The access to U-Gym is automatically controlled by a virtual gap: the door can be opened by the use of a special bracelet (the same used for sport equipment) or by using Android or iOS Apps.

In 2018, a 1 km fitness trail, named U-Trail, was created. The path includes three different workout stations for a total body outdoor training. The exercise options can be learned on a smartphone App available both on IOS and Android platforms.

In the near future, two other projects will be put in place. The first one, U-Field, is devoted to roof the existing football field to create an indoor multi-purpose field to train football, volleyball and basketball. The second is aimed to establish, in collaboration with Savona Municipality, a National Sport Hub for sea and water activities (e.g., open water swimming, surf, rowing, sailing, stand up paddle, beach volley, beach soccer) on the beach in front of the Campus (about 800 m far from the University). This water sport center could be used by the Campus population (students and workers) but also by the Olympic athletes for their training.

Finally, special attention was given to the generation of a comfortable environment for people with disabilities. In particular, wheelchairs ramps were built outside the buildings and suitable lifts were inserted inside. Moreover, a recent project, named "Sportability", planned special programs for the sport training of disabled people (also for Paralympic athletes) by the use of Savona Campus facilities.

4. Results

The "Living Lab Smart City" of Savona Campus allowed to implement several projects in different smart city sectors such as energy, smart buildings, sustainable mobility, and wellbeing. These activities produced many benefits both from educational and government/industrial perspectives. All the developed infrastructures and facilities helped the University to fill the gap between theoretical lessons and the real world applications, allowing the students both to make an experience of applicative research during their degree programs and to have a direct insight of what explained during the lessons.

The following sub-sections are related to the results obtained, respectively, in the energy sector, in the waste management area and about the health and sport facilities use.

4.1. Energia 2020 Project's Results

The Energia 2020 actions, that is the SPM, the SEB, and the EEM, allowed to reduce, in 2017, the energy bill (electricity and thermal energy) of the Campus of about the 30% (81,000 € saved in one year). Moreover, different companies are developing Research and Development (R&D) activities in collaboration with the University researchers with the goal of creating innovative hardware and software products for smart microgrids and smart buildings. In particular, the "Living Lab Microgrid" has been conceived by the University of Genoa, in collaboration with the Italian DSO, Enel S.p.A, to develop research projects in the fields of sustainable energy, smart mobility, and islanded microgrids (electrical networks which are able to work only by the use of renewable sources and storage systems, without being connected to the national grid). Enel S.p.A. works together with Savona Campus researchers on SPM and SEB infrastructures to test smart city technologies in order to create a springboard for their development and widespread implementation. Moreover, research activities focused on innovative technical solutions for the residential sector will be also build up, in the domain of smart electrical homes/ appliances and devices related to the Internet of Things. The results derived from the Living Lab Microgrid will be used to develop guidelines for the implementation of the smart city concept in urban areas; besides, the Savona Campus will become a demo site where the technologies of the smart city will be available to the community. The sustainable energy research team operating at the Campus is heavily committed in sharing results, field experiences, techniques and strategies with researchers operating in energy and sustainability topics around the world, through bilateral cooperation, framework agreements between Universities, participation in European projects, etc. This because the University firmly believes that, in a world characterized by tight economic constraints and technical complexity, important results can be achieved only by sharing different experiences and joining research efforts. It is also for this reason that both the SPM and the SEB were conceived as test-beds for the Smart City paradigm, open to research activities carried out by industries and other Universities.

The implementation and the study of the SPM and SEB infrastructures at the Savona Campus defined several sustainability best practices to be reproduced at the city level designing residential, tertiary and industrial districts characterized by distributed generation units and efficient buildings. The best practices are the following ones:

- production of sustainable energy to satisfy the Campus needs;
- use of Combined Cooling, Heating and Power (CCHP) systems to reduce primary energy consumptions and CO_2;
- implementation of Energy Management Systems to optimally manage the energy production and distribution;
- use of electrical storage systems to compensate the fluctuations of power production from renewable sources;
- promotion of the use of sustainable mobility by enhancing the electrical vehicle charging stations with two different technologies (G2V and V2G);
- creation of a sustainable urban energy island with buildings fed only by renewables with no connection to the public electric grid;
- use of energy efficient appliances such as LED lamps automatically controlled according to available natural light and occupancy levels;
- use of water efficient appliances and water recycling programs to reduce the waste of water;
- use of ventilated facades and high thermal/acoustic insulation systems to reduce thermal dispersions;
- implementation of Building Management Systems to optimally manage building consumptions and performances to guarantee both a maximum comfort level and high efficiency.

In order to better analyze the energy performance of the "Living Lab Smart City", that is the combination of SPM and SEB, six Key Performance Indicators (KPIs) were considered. Three of them evaluate the electric performance (Electrical self-production—ESP, Electrical production from renewable sources-EP_R and Electrical production from CCHP—EP_CCHP), while the other three consider the thermal ones (Thermal self-production-TSP, Thermal production from boilers-TP_B and Thermal production from CCHP—TP_CCHP). The equations used to calculate these indexes are the following ones.

$$\mathrm{ESP} = \frac{\text{Electrical energy production}}{\text{Total electrical demand}} \cdot 100 \tag{1}$$

$$\mathrm{EP\_R} = \frac{\text{Electrical energy production from renewables}}{\text{Electrical energy production}} \cdot 100 \tag{2}$$

$$\mathrm{EP\_CCHP} = \frac{\text{Electrical energy production from CCHP}}{\text{Electrical energy production}} \cdot 100 \tag{3}$$

$$\mathrm{TSP} = \frac{\text{Thermal energy production}}{\text{Total Thermal demand}} \cdot 100 \tag{4}$$

$$\mathrm{TP\_B} = \frac{\text{Thermal energy production from boilers}}{\text{Total Thermal demand}} \cdot 100 \tag{5}$$

$$\mathrm{TP\_CCHP} = \frac{\text{Thermal energy production from CCHP}}{\text{Total Thermal demand}} \cdot 100 \tag{6}$$

The following spider graph (Figure 3) summarizes the energy KPIs of Savona Campus from 2015 to 2017. It can be noticed that both the electrical self-production, taking into account the electricity produced by the cogenerating micro-turbines and the PV plants, and the electrical production from renewables have been increased from 2015 to 2017 (the electrical self-production in 2015 was about

36%, while in 2017 it was 49%). This is due, basically, to the new PV fields installed over two buildings: in 2015 only one PV field was present, now they are three. The Electrical production from CCHP remained almost constant at about 60%. As per the thermal performance, it is important to underline that all the energy needed to heat or cool the buildings is produced inside the Campus by the geothermal plant in the SEB and by cogenerating micro-turbines with absorption chillers and, when necessary, by the boilers. In 2016, a very cold winter caused a bigger use of the boilers with respect to years 2015 and 2017. The thermal production from renewables in 2015 and 2016 was 0%, while in 2017 it was 5% since the geothermal plant of the Smart Energy Building started to operate.

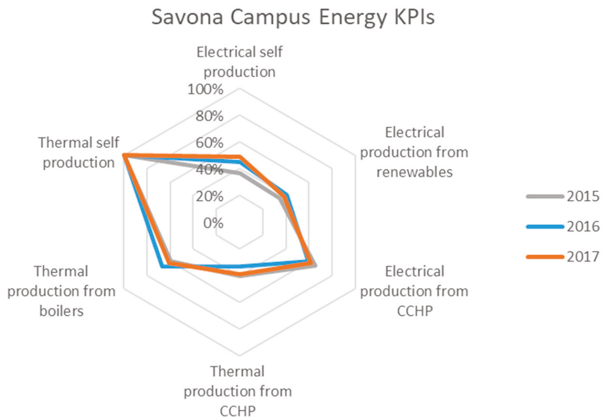


Figure 3. The spider diagram summarizes the values of the six Energy Key Performance Indicators of Savona Campus RIs. The performances were evaluated for three different years: 2015 (grey line), 2016 (blue line) and 2017 (orange line).

4.2. Results about the Recycling Program

The implementation of the recycling program inside the Savona Campus generated benefits for the environment because the recycling rate reached the 75%. The total amount of waste produced inside Savona Campus is about 100 tons per year. The recycling plants guarantee a 100% recycling for paper, plastic, batteries, and toners; 98% for glass & cans; and 75% for the street sweepings. The unsorted waste part is finally taken off to a landfill. The following pie chart (Figure 4) shows the types and the corresponding percentage of production of the waste produced inside the Savona Campus. In particular, it underlines that the street sweepings represent the biggest part of waste (48%), while the unsorted waste is only the 14%.

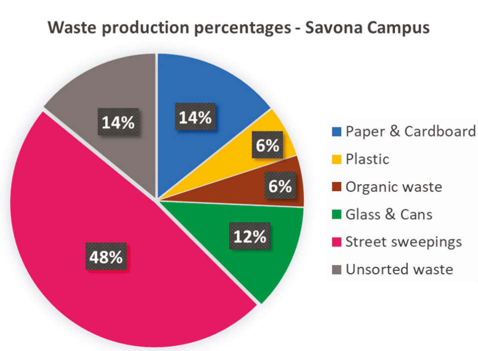


Figure 4. The pie chart shows the percentages of production relative to different types of waste: paper & cardboard, plastic, organic waste, glass & cans, street sweepings and unsorted waste.

4.3. Results about the Use of Sport Infrastructures

The outdoor sport infrastructures of Savona Campus, namely the U-Trail, the football field and the tennis court are generally used during the warmest months, namely from May to October. In the near future (second semester 2019), the football field will be roofed (U-Field project) allowing the training also during the colder months. It is important to highlight that such infrastructures are freely accessible from 8.00 a.m. to 8.00 p.m., not only for the University people, but also for the population, due to the public nature of the Savona Campus area.

Data are available since May 2018, when the U-Trail was completed and unveiled. On average about 50 persons per month practiced football and tennis, except in August since, due to summer holidays, the training is stopped. The U-Trail gained a growing importance during the summer because several students, and workers as well, started to learn the exercises and enjoyed the open-air training in their free time. Moreover, some local high schools in the nearby brought their students to practice open air sport during their sport sciences lessons. The following graph (Figure 5) highlights this growing trend.

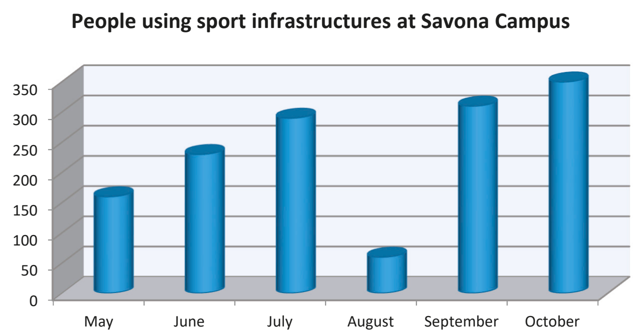


Figure 5. The graph shows the number of people (students, workers and local schools) per month, who used the sport facilities of Savona Campus from May to October 2018.

5. Discussion & Conclusions

The research activities carried out at the Savona Campus in the sustainability field have permitted to develop important R&D projects in collaboration with industrial companies and foreign universities and research centers. As regards the energy sector, valuable collaborations have been established with Enel SpA, Fiamm SpA, and Siemens SpA to study islanded microgrids, smart electric mobility systems, electrical storage devices, and energy management systems. The aforesaid companies have financed scholarships for PhD students and Assistant Professors in order to strengthen their collaboration with the Savona Campus. Moreover, the main results of the research activities have been published in renowned international journals and presented at international conferences. This has permitted to start joint research programs with notable universities such as ETH Zurich and MIT Boston. Furthermore, the SPM and SEB projects are currently used as examples of smart districts by municipalities that intend to refurbish urban areas with the aim of reducing primary energy consumptions and carbon dioxide emissions. The proposed Living Lab concept can be applied to provide such urban areas with the following facilities and practices: installation of renewable power plants, adoption of energy consumption management systems, and smart mobility, creation of public amenity areas for relaxation and sport activities, as well as social housing areas characterized by the presence of business incubators and innovative 4.0 craft workshops.

In particular, the research activities carried out in the sustainable energy field at the Savona Campus have allowed development of skills and practical expertise on how to develop a smart city project within an urban area [21]. The analysis of the interaction between a smart microgrid and a smart building and the optimal management of the whole infrastructure has permitted to highlight criticalities and potentialities of such innovative facilities. In particular, with regard to energy production technologies, renewable energy power plants, cogeneration units, and storage systems have been deeply investigated in order to evaluate their performance, capital and operating costs, reliability, and availability. It is important to highlight that the optimal design of a smart energy infrastructure based on the aforesaid technologies needs a very detailed energy audit of the end-users, in terms of thermal and electrical loads, in order to choose the best type and size of technologies. Furthermore, the daily management of such complex infrastructures needs the adoption of accurate forecasting tools used to predict thermal and electrical loads, as well as energy carrier prices and energy production from intermittent renewable sources. As described in the result section, the implementation of SPM and SEB projects has determined a huge number of advantages for the daily operation of the Savona Campus in terms of economic savings and emission reduction. Benefitting from the electricity production from the solar source and conveniently exploiting the cogeneration units, in periods characterized by a simultaneous need of electrical and thermal energy, and the storage systems, the energy bill of the Campus has been reduced since a lower amount of electricity has been withdrawn from the public grid and the use of natural gas for boilers has been limited. The resulting economic saving, coupled with the environmental one, has strengthened the sustainability concept within the Campus and has proved the real feasibility of this kind of projects, thus providing an example of a sustainable district for the smart cities of the future.

The activities developed at the Campus from 2014 till now on SPM and SEB infrastructures have also permitted to open new challenging research lines in the smart energy and sustainability field, that specifically refer to smart mobility and demand response. Indeed, in the next years the number of electric vehicles is envisaged to increase and their impact on power grids will be more and more impressive. The testing of V2G technology at the Savona Campus will permit evaluation of the role of electric vehicles within the ancillary service market and interesting analyses could be done in order to compare the performance of vehicle batteries to that of fixed storage batteries. As far as demand response is concerned, the possibility to manage controllable loads and other equipment will be tested and the application of demand response policies will give information on their feasible and profitable adoption in the urban environment.

Good results were obtained also by the implementation of the waste collection program, which allowed Savona Campus to become a public leading guide over Savona Municipality in terms of "smart" and empowered response of the involved community in following environmentally friendly rules.

Finally, health and wellbeing infrastructures contributed to creating a common awareness in Campus population about the benefits carried by the regular practice of sport and outdoor activities, creating as well a strong and positive link with neighboring citizens, who started to spend more and more time inside the Campus living a healthy life.

Author Contributions: Conceptualization ad project administration, F.D. and S.B.; methodology, writing—original draft preparation, P.L.; formal analysis, P.L. and A.M.; engineering modeling, A.M.; data curation, P.L. and S.B.; writing—review and editing, S.B., F.D. and A.M.; supervision and funding acquisition, F.D.

Funding: These researches were funded by the Italian Ministry of Education and Research, the Italian Ministry of the Environment and Protection of Land and Sea, Liguria Region authority and University of Genoa.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Jong, M.; Joss, S.; Schraven, D.; Zhan, C.; Weijnen, M. Sustainable-smart-resilient-low carbon-eco-knowledge cities; making sense of a multitude of concepts promoting sustainable urbanization. *J. Clean. Prod.* **2015**, *109*, 25–38. [CrossRef]
2. Trindade, E.P.; Hinnig, M.P.F.; da Costa, E.M.; Marques, J.S.; Bastos, R.C.; Yigitcanlar, T. Sustainable development of smart cities: A systematic review of the literature. *J. Open Innov. Technol. Mark. Complex.* **2017**. [CrossRef]

3. Angelidou, M.; Karachaliou, E.; Angelidou, T.; Stylianidis, E. Cultural heritage in smart city environments. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, *42*, 27–32. [CrossRef]
4. Bibri, S.E.; Krogstie, J. Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustain. Cities Soc.* **2017**, *31*, 183–212. [CrossRef]
5. Bibri, S.E. A foundational framework for smart sustainable city development: Theoretical, disciplinary, and discursive dimensions and their synergies. *Sustain. Cities Soc.* **2018**, *38*, 758–794. [CrossRef]
6. Caragliu, A.; Del Bo, C.; Nijkamp, P. Smart Cities in Europe. *J. Urban Technol.* **2011**, *18*, 65–82. [CrossRef]
7. Cocchia, A. Smart and Digital City: A Systematic Literature Review. In *Smart City: How to Create Public and Economic Value with High Technology in Urban Space*; Progress in IS; Dameri, R., Rosenthal-Sabroux, C., Eds.; Springer: Cham, Switzerland, 2014; pp. 13–43.
8. Yigitcanlar, T. Smart cities: An effective urban development and management model? *Aust. Plan.* **2015**, *52*, 27–34. [CrossRef]
9. Chini, C.; Canning, J.; Schreiber, K.; Peschel, J.; Stillwell, A. The Green Experiment: Cities, Green Stormwater Infrastructure, and Sustainability. *Sustainability* **2017**, *9*, 105. [CrossRef]
10. D'Auria, A.; Tregua, M.; Vallejo-Martos, M.C. Modern Conceptions of Cities as Smart and Sustainable and Their Commonalities. *Sustainability* **2018**, *10*, 2642. [CrossRef]
11. Talen, E. Sprawl retrofit: Sustainable urban form in unsustainable places. *Environ. Plan. B Plan. Des.* **2011**, *38*, 952–978. [CrossRef]
12. Hashem, I.A.T.; Chang, V.; Anuar, N.B.; Adewole, K.; Yaqoob, I.; Gani, A.; Ahmed, E.; Chiroma, H. The role of big data in smart city. *Int. J. Inf. Manag.* **2016**, *36*, 748–758. [CrossRef]
13. Zhang, N.; Chen, H.; Chen, X.; Chen, J. Semantic framework of internet of things for smart cities: Case studies. *Sensors* **2016**, *16*, 1501. [CrossRef] [PubMed]
14. Batty, M.; Axhausen, K.W.; Giannotti, F.; Pozdnoukhov, A.; Bazzani, A.; Wachowicz, M.; Ouzounis, G.; Portugali, Y. Smart cities of the future. *Eur. Phys. J. Spec. Top.* **2012**, *214*, 481–518. [CrossRef]
15. Albino, V.; Berardi, U.; Dangelico, R.M. Smart cities: Definitions, dimensions, performance, and initiatives. *J. Urban Technol.* **2015**, *22*, 3–21. [CrossRef]
16. Hunter, G.W.; Vettorato, D.; Sagoe, G. Creating Smart Energy Cities for Sustainability through Project Implementation: A Case Study of Bolzano, Italy. *Sustainability* **2018**, *10*, 2167. [CrossRef]
17. Angelidou, M. The Role of Smart City Characteristics in the Plans of Fifteen Cities. *J. Urban Technol.* **2017**, *24*, 3–28. [CrossRef]
18. Giffinger, R.; Fertner, C.; Kramar, H.; Kalasek, R.; Pichler-Milanovic, N.; Meijers, E. *Smart Cities: Ranking of European Medium-Sized Cities*; Centre of Regional Science (SRF), Vienna University of Technology: Vienna, Austria, 2007.
19. Hambleton, R. From the smart city to the wise city: The role of universities in place-based leadership. In Proceedings of the Smart City: New Media, Social Participation and Urban Governance, Shanghai, China, 5–7 June 2014; Shanghai University: Shanghai, China, 2014.
20. Dameri, R.P. The Conceptual Idea of Smart City: University, Industry, and Government Vision. In *Smart City Implementation: Creating Economic and Public Value in Innovative Urban Systems*; Progress in IS; Dameri, R.P., Ed.; Springer: Cham, Switzerland, 2016; pp. 22–43.
21. Delfino, F.; Procopio, R.; Rossi, M.; Bracco, S.; Brignone, M.; Robba, M. *Microgrid Design and Operation: Toward Smart Energy in Cities*; Artech House: Boston, MA, USA, 2018; ISBN 9781630811501.
22. Cosgrave, E.; Arbuthnot, K.; Tryfonas, T. Living Labs, Innovation Districts and Information Marketplaces: A Systems Approach for Smart Cities. *Procedia Comput. Sci.* **2013**, *16*, 668–677. [CrossRef]
23. Schaffers, H.; Komninos, N.; Pallot, M.; Trousse, B.; Nilsson, M.; Oliveira, A. Smart cities and the future internet: Towards cooperation frameworks for open innovation. In *The Future Internet Assembly*; Springer: Berlin/Heidelberg, Germany, 2011; pp. 431–446.
24. Bergvall-Kåreborn, B.; Ståhlbröst, A. Living Lab—An Open and Citizen-Centric Approach for Innovation. *Int. J. Innov. Reg. Dev.* **2009**, *1*, 356–370. [CrossRef]
25. Brenna, M.; Foiadelli, F.; Longo, M.; Bracco, S.; Delfino, F. Smart microgrids in smart campuses with electric vehicles and storage systems: Analysis of possible operating scenarios. In Proceedings of the ISC2 2016 IEEE 2nd International Smart Cities Conference: Improving the Citizens Quality of Life, Trento, Italy, 12–15 September 2016.

26. Bracco, S.; Delfino, F.; Pampararo, F.; Robba, M.; Rossi, M. A pilot facility for analysis and simulation of smart microgrids feeding smart buildings. *Renew. Sustain. Energy Rev.* **2016**, *58*, 1247–1255. [CrossRef]
27. Bracco, S.; Delfino, F.; Ferro, G.; Pagnini, L.; Robba, M.; Rossi, M. Energy planning of sustainable districts: Towards the exploitation of small size intermittent renewables in urban areas. *Appl. Energy* **2018**, *228*, 2288–2297. [CrossRef]
28. Energia 2020 Project. Available online: www.energia2020.unige.it (accessed on 30 October 2018).
29. Bracco, S.; Delfino, F.; Pampararo, F.; Robba, M.; Rossi, M. Economic and environmental performances quantification of the university of Genoa Smart Polygeneration Microgrid. In Proceedings of the IEEE International Energy Conference and Exhibition ENERGYCON 2012, Florence, Italy, 9–12 September 2012; pp. 593–598.
30. International Sustainable Campus Network. Available online: www.international-sustainable-campus-network.org (accessed on 30 October 2018).
31. UI Greenmetric. Available online: http://greenmetric.ui.ac.id/ (accessed on 30 October 2018).
32. Apostolopoulos, P.A.; Tsiropoulou, E.E.; Papavassiliou, S. Demand response management in smart grid networks: A two-stage game-theoretic learning-based approach. *Mob. Netw. Appl.* **2018**. [CrossRef]
33. Shi, W.; Li, N.; Xie, X.; Chu, C.; Gadh, R. Optimal Residential Demand Response in Distribution Networks. *IEEE J. Sel. Areas Commun.* **2014**, *32*, 1441–1450. [CrossRef]
34. Bracco, S.; Brignone, M.; Delfino, F.; Procopio, R. An energy management system for the savona campus smart polygeneration microgrid. *IEEE Syst. J.* **2017**, *11*, 1799–1809. [CrossRef]
35. Bryant, N.; Spencer, N.; King, A.; Crooks, P.; Deakin, J.; Young, S. IoT and smart city services to support independence and wellbeing of older people. In Proceedings of the 25th International Conference on Software, Telecommunications and Computer Networks (SoftCOM), Split, Croatia, 21–23 September 2017.

sustainability

MDPI

Article

Strategic Networking for Sustainability: Lessons Learned from Two Case Studies in Higher Education

Judith Kahle [1], Katrin Risch [2], Andreas Wanke [2] and Daniel J. Lang [1,*]

[1] Institute for Ethics and Transdisciplinary Sustainability Research, Leuphana University, Universitätsallee 1, 21335 Lüneburg, Germany; judith.kahle@leuphana.de

[2] Unit for Sustainability and Energy Management, Freie Universität Berlin, Schwendenerstraße 17, 14195 Berlin, Germany; katrin.risch@fu-berlin.de (K.R.); andreas.wanke@fu-berlin.de (A.W.)

* Correspondence: daniel.lang@leuphana.de; Tel.: +49-4131-677-1678

Received: 31 October 2018; Accepted: 4 December 2018; Published: 6 December 2018

Abstract: As places where future citizens are educated, knowledge is (co-)produced and societal developments are critically reflected, higher education institutions (HEIs) can play a key role in addressing sustainability challenges. In order to accelerate mutual learning, shared problem understanding, and joint development of sustainable solutions, interinstitutional exchange and collaboration between HEIs is crucial. However, little research to date has focused on institutional HEI networks in the field of sustainability. More specifically, we still understand little about the concrete development, implementation, and adaptation of such networks. This article explores early-stage HEI networks for sustainability from a conceptual and empirical stance in order to develop a framework that facilitates structured descriptions of these networks, as well as to foster cross-HEI learning on their effective performance. It therefore combines insights from an explorative literature review, two case studies and an interactive workshop at the ISCN Conference 2018. As results, we first suggest an analytical framework to facilitate a systematic characterization of HEI networks. Second, by applying the framework to the two case studies, we present and discuss lessons learned on how a single HEI can contribute to establishing a network and how it can utilize its network membership effectively to strengthen its efforts for sustainability.

Keywords: higher education institution; networks; sustainability; collaboration; interdisciplinarity; transdisciplinarity; learning; innovation; whole institution approach

1. Introduction

Global sustainability problems such as climate change, biodiversity loss, and poverty are leading to major socio-ecological change, prompting us to accelerate joint efforts to achieve a more sustainable and just future [1–4]. Higher education institutions (HEIs), as places where future citizens are educated, knowledge is (co-)produced, and developments are critically reflected, can play a key role in addressing sustainability challenges [5–12]. The term *higher education institution* (HEI) in Germany usually encompasses research universities, universities of applied sciences, as well as colleges of art and music. In this article, we focus on the first two types of HEIs. Within their different fields of operation such as governance, research, education, campus management, reporting, and transfer (meaning mutual exchange of knowledge, ideas, services, technologies, and experience between HEIs and other societal actors from politics, industry, public sector, and civil society) [6,10,13,14], HEIs provide structures and resources to bring together various kinds of actors and expertise. They allow working on approaches for creating, critically reflecting, testing, and further developing concrete sustainable solutions. As such, HEIs can serve as platforms for theoretical and practical learning for sustainability transformation [7,10,15].

Embedded in specific geographic, political, and cultural contexts, HEIs provide different approaches and expertise on how to address sustainability challenges. Therefore, interinstitutional exchange, collaboration, and even co-creation between HEIs are crucial, as they allow "for accelerating learning by sharing problem understandings, successful solutions, and important contextual considerations" ([4], p. 749). With regard to a general spectrum of formats of interaction, we consider exchange, collaboration including co-design, co-production, and outreach as relying on two-way-communication. While exchange generally requires little commitment, collaboration requires greater commitment, as well as more active engagement on an equal footing [16]. In this regard, local, national, and international networks allow for a multilateral type of exchange and collaboration between persons, teams, institutes or institutions (so-called "nodes") in the higher education sector [17]. Such HEI networks are often regarded as "vehicles for innovation and improvement in educational systems" ([18], p. 6); as well as a powerful impetus for organizational learning and the development of innovative solutions [19,20].

Networks proceed through consecutive developmental stages, in which they integrate different functions to reach specific benefits [20]. Based on the life-cycle model, Verburg and Andriessen [20] suggest three stages of networks: development, implementation, and adaptation. From a political stance, networks allow institutions such as HEIs and their actors to form new collaborative formats and interest groups [19]. As part of this *political function* declarations, as well as incentive structures, can be helpful to encourage inter- and transdisciplinary collaboration for sustainability within and across HEIs [8,12]. Furthermore, related to an *incentivizing or motivating function*, the reference to the network activities may also act as a leverage for a single HEI to move forward with new projects, e.g., in sustainable campus management [19]. This positive effect is closely connected to the *psychological function*, as institutional, team and individual network members find themselves amongst a group of like-minded HEI actors, working towards similar goals, values, and jointly developed products (e.g., publications in sustainability research, manuals, and best practice-collections as guidance for sustainability managers or policymakers), in or across their institutions—thus allowing individual learning and empowerment [19,20]. This is also facilitated by the *information function* that networks serve. An ever-growing range of face-to-face, as well as virtual exchange and collaboration formats, allows for an information flow across institutions and in many cases hierarchies. These settings also give individuals and groups, representing HEI members in a network, opportunities to acquire new skills from their peers that may not be offered by traditional training schemes [19]. The implicit *skills function* of networks is increased in international, trans- and interdisciplinary formats of exchange, fostering the intercultural sensitivity and competency of network members [1,19].

Exchange, collaboration, and even co-creation for sustainability is rooted in the comprehensive experience of well-established and large HEI networks, such as the International Association of Universities (IAU, founded in 1950) [21], the Association of African Universities (AAU, founded in 1967) [22], and the Global University Network for innovation (GUNi, founded in 1999) [23]. These networks span up to several hundreds of members from a great number of countries and include sustainability-related objectives in their strategic alignment. Other HEI networks, such the International Sustainable Campus Network (ISCN, founded in 2007) [24] and the Association for the Advancement of Sustainability in Higher Education (AASHE, founded in 2005) gained momentum and large numbers of members from different parts of the world in the past 10 to 15 years. They follow a clear agenda focusing on the contribution of HEIs to sustainable development on the local, regional, national, and international level. Both examples of large HEI networks have clear governance structures and a widely diversified portfolio of instruments available to contribute to sustainability, e.g., regular reports, annual conferences, joint projects, and a spectrum of options to share and spread information among their members and beyond. In addition, a number of smaller HEI networks have been established in the last years in order to work more intensively with a concentrated number of HEI members toward contributions for sustainability, such as the University Alliance for Sustainability (UAS, founded in 2014) [25] and Sustainability at Higher Education Institutions Network (HOCH-N, founded in 2016) [13]. In this article, we focus our research attention on hitherto barely investigated early-stage HEI networks for sustainability.

A growing body of literature investigates different formats of inter- and transdisciplinary HEI-collaboration [4], e.g., focusing on international, often bi-lateral research collaborations and co-authorships [26,27], joint education projects [4,28,29], as well as mutual knowledge and first-hand experiential exchange on efforts for sustainable campus management [24]. Other works address different forms of networks from a meta-perspective [17,20]. However, little research to date has focused specifically on early-stage networks of institutions in the field of sustainability, especially not from the perspective of single HEIs as members or nodes in such networks. Furthermore, we still understand little about the concrete contributions of single HEIs to the development, implementation, and adaptation, as well as concrete outcomes of such networks for sustainable development.

In this article, we pursue the following objectives: First, we suggest an analytical framework to spur a more structured description and reflection of HEI-networks. Secondly, we adopt this framework to investigate two contrasting cases of HEI-networks for sustainability in greater detail to test its applicability and learn more about structures and processes facilitating or inhibiting networks to meet specific functions. Besides a general comparison on the network level, we do so from the node perspective of a single HEI-network member to facilitate cross-HEI learning on the effective performance of these networks. For each of the two exemplary cases, we focus on a specific aspect of HEI networks for sustainability. On the one hand, we provide insights into how a single HEI-node in a network can contribute to establishing an HEI network. On the other hand, we focus on concrete outcomes for a single HEI as a member in a network for sustainability.

In Section 2, we describe the methodical proceeding we used for addressing the aims of this article. In Section 3, we first present a set of 15 characteristics to allow a structured and detailed description HEI-networks before we apply these characteristics to the two case studies. Section 4 integrates and discusses the results by focusing on lessons learned from the two case studies. These results are complemented by insights from a workshop held at the 12th International Sustainable Campus Network (ISCN) Conference. Section 5 concludes by reassessing the HEI-networks as a contribution to sustainability.

2. Methods

To address the two main objectives, this article employed a qualitative research approach combining insights from an explorative literature review, two contrasting case studies and a joint interactive workshop at the ISCN Conference 2018 in Stockholm [30]. We triangulated the insights to (i) identify and test key characteristics for describing HEI networks and (ii) to gain insights into the development, as well as into first impacts of two smaller networks focusing on sustainability.

2.1. Explorative Literature Review

An explorative review of the literature from different fields of study was conducted in Google scholar revolving around the terms “networks”, “sustainability”, and “higher education institutions”. In addition, similar terms derived from the literature, such as “collaboration”, “internationalization”, “partnerships” and “universities”, were applied in different search strings to identify further relevant literature. English and German references were considered for the review. Various scholars have already discussed the limitations of literature reviews relying on a single database in general, and relying on Google scholar in particular [31–33]. In fact, no single database provides full coverage of the relevant literature [31]. For the explorative literature review at hand, we did not strive for a full coverage of the literature. Instead we aimed for a selection of scientific literature from different academic disciplines to gain a broad view on networks as the overall basis for the analytical framework. Despite its flaws discussed in the literature, e.g., the lack of reliable advanced search functions [32], we still decided to rely on Google scholar because of its high coverage, especially in relevant fields for this article, such as business, economics and management, humanities, literature and arts, as well as the social sciences [33]. We analyzed the obtained literature qualitatively with the intention to inductively extract characteristic features that capture the specific traits of networks [34]. The collected text junks in form of short paragraphs, sentences, and parts thereof, as well as key words were clustered according to similar or related content. In a next step, appropriate terms were developed or gained from the literature itself for each of the clusters constituting the set of network characteristics. The set of characteristics developed in this way, was then put into a logical order and specified via short descriptions and/or illustrative examples (see Table 1). The characteristics represent an essential first result of this article which were subsequently applied to two case studies of HEI networks for sustainability in order to structure our empirical and experiential findings and to test the applicability of the characteristics.

2.2. Case Study

For the empirical part of our study, we applied a case study approach [35–37]. We focused on two HEI-networks that both employ a whole institution approach to facilitate and institutionalize HEI engagement for sustainable development: (a) Network of Higher Education Institutions for Sustainability (HOCH-N), a national consortium of German universities and universities of applied sciences; and (b) University Alliance for Sustainability (UAS), an international network of five partner universities from Germany, Israel, Canada, China, and Russia. Both cases imply a rich learning potential for whole HEIs to individual HEI-actors, as they follow similar aims and approaches but span different geographic scales and rely on different instruments and strategies for their implementation. As the authors play crucial roles as co-founders, network managers and members, conducting self-reflexive case studies and presenting them at the ISCN Conference 2018 was viewed as important steps to take stock and seek constructive feedback for potential adjustments.

For each of the case studies, a self-reflexive process was implemented from the perspective of the two German universities represented by the authors: Freie Universität Berlin and Leuphana University Lüneburg. For doing so, information on involved actors, selected and applied instruments, as well as strategies, established structures, and first outcomes including benefits and obstacles, were collected, respectively. Based on the conceptual framework developed from the literature, the information was structured and documented in order to allow the narration of a context- and case-specific story [35]. On the one hand, the tabular short descriptions of each network formed the point of departure for an internal systematic reflection of our own empirical research within the HOCH-N network. On the other hand, we relied on practical experiences, as well as personal observations of processes and dynamics within HOCH-N and UAS network. The collected information was internally discussed with regard to the strengths and weaknesses of each network's structures, processes and first outcomes as a contribution to sustainability.

2.3. Interactive Workshop at the ISCN Conference 2018 in Stockholm on 12th June

During the 12th ISCN Conference, the authors of this article jointly conducted an interactive workshop on strategic networking among HEIs for sustainability. Both the workshop organizers and participants represented different status groups of several HEIs. In total, 15 people from eight countries participated in the interactive session. The participants came from a wide range of professional backgrounds: five researchers; four (senior) sustainability managers; one PhD student, two students, and one participant represented a non-governmental organization. The professional backgrounds of two persons could not be specified. In total, nine men and six women participated. We are aware, that the participants most certainly did not reflect a representative sample of international HEI actors engaged in networking for sustainability. Nevertheless, the overall ISCN conference context can be viewed as a pre-selective filter of international HEI stakeholders who are aware of and also actively engaging in HEI networking for sustainability. Another filter is the individual motivation to engage, not in one of the parallel workshops, but in this specific workshop on HEI networks for sustainability pointing to the participants' personal commitment and expertise in the topic. Subsequently, the small sample encompassed an impressive variety of participants in terms of degree of academic qualification, field of action, and duration of professional experience, as well as geographic origin of their home HEI. This group has discussed lively and actively contributed its diverse expertise within the workshop. Although not representative, we decided to incorporate the valuable contributions into this article in order to enrich the discussion of HEI networks for sustainability based on two contrasting cases and the scientific literature in the field. The authors briefly introduced each case study in order to provide inspiration and a shared starting point for the subsequent interactive part. Workshop participants were engaged in two rounds of small group discussions, in order to share and collect their expectations and experiences with HEI-networks for sustainability, as well as to debate leverage points and practices to strategically advance such networks. Afterwards, the outcomes from the group discussions were recorded, supplemented, and restructured to increase intelligibility. Finally, they were used to complement the lessons learned from the two case studies on HEI-networks for sustainability, as discussed in Section 4.

3. Results

3.1. Characterizing HEI-Networks for Sustainability

Table 1 presents the analytical framework to characterize HEI-networks based on the explorative literature review, as well as insights from our personal experience as co-founders of two HEI-networks for sustainability.

The 15 characteristics represent an analytical framework to systematically differentiate between structure (characteristics #1–9), processes (characteristics #10–13), and context (characteristic #14) which are unique to each network and are already existing or aspired outcomes of the network activities (characteristic #15). They first specify which individual and/or groups of actors—from a specific region and supported by certain resources—are collaborating with each other for a specific topic in order to jointly strive for common goals. Secondly, they specify how this collaboration is organized and proceeding along the different developmental stages of a network. Thirdly, the societal context is covered in which a network is embedded. Finally, the results and impacts a network can unfold are covered. The set of characteristics is designed to make essential features of HEI-networks explicit for both members and external stakeholders alike. The characteristics were derived from the scientific network and collaboration literature of various academic disciplines. They therefore do not focus on networks for sustainability in particular but on HEI networks in general. By adopting the characteristics to two exemplary HEI networks for sustainability, we investigated their applicability to the context of sustainable development in the higher education sector. According to the literature used, all identified features were included in the analytical framework for structured descriptions of HEI networks. Our goal was to introduce a literature-based comprehensive set of characteristics that is, at the same time, as specific and general as possible. As to our knowledge, such a framework for HEI networks has not been introduced before. Due to the limited literature bases, we are aware that our synthesis may have overlooked single network features. However, the 15 characteristics can serve as a means to derive commonalities and differences between networks, thus informing potential future network members, but also allowing a network to be systematically located within the landscape of other networks.

To make the 15 characteristics more tangible, they are applied, slightly adapted, and discussed in the subsequent Sections 3.2 and 3.3 with regard to the two exemplary HEI-networks for sustainability in this article—HOCH-N and UAS.

Table 1. 15 characteristics of networks among organizations such as higher education institutions (HEIs) based on an exploratory scientific literature review.

	Characteristic	Specification	References
1.	Geographic scope	Dispersion of network members on a local, regional, national, international level.	[1,20]
2.	Subject	Overall topic a network focuses on.	[1]
3.	Objective	Overall objective or spectrum of objectives a network pursues, e.g., building institutional capacity, jointly developing educational programs, staff exchange, etc.	[4,20,26]
4.	Resources	Financial, institutional, and human resources a network has at hand to work with.	[1,10,26]
5.	Composition	Clarifies how many and which actors (individuals up to whole HEIs) are part of a network, as well as who is collaborating with whom.	[1,4,20,26]
6.	Organizational structure and role of leadership	Specifies how a network is internally structured and operating in terms of role distribution, decision-making power, and hierarchy.	[20,38]
7.	Open/closed	Networks either encompass a fixed number of members or are open to enroll new members.	[20]
8.	Heterogeneity/homogeneity	Diversity aspects such as ethnicity, gender, language, etc., relevant in a network, as well as different working cultures and norms relating to hierarchy and status within and between HEIs.	[1,7,26]
9.	Degree of formalization	Specifies how far structures and processes of a network are institutionalized, e.g., via defined memberships, formal rules of composition, interaction and communication.	[1,20,26]
10.	Type(s) of collaboration	Specifies the organizational type through which collaboration is implemented in a network, e.g., via joint teaching, collaborative research, visiting students and staff, joint institutes.	[1,4,26]
11.	Mode of interaction and communication	Face-to-face or virtual exchange and collaboration via application of information technology.	[1,20,26]
12.	Developmental stages	Networks develop over time by going through consecutive stages from birth to death (life-cycle perspective) or from low-to-high levels of maturity (evolutionary perspective).	[20,26]
13.	Ethos	Specifies the social frame in which a network is embedded, e.g., encompassing working atmosphere, joint identity, trust, commitment.	[1,17,20,26]
14.	Context	Political, cultural, and economic context, as well as societal structures and processes a network is embedded in.	[1,8,12,26]
15.	Outcome	Results and impacts a network has for all or some of its members, for actors, structures, and processes in- and outside the network.	[1,4,7]

3.2. Learning How to Effectively Contribute to the Development of an HEI-Network for Sustainability: The Case of the HOCH-N Network

In this section, we shed light on the practical, conceptual, and empirical contributions of a single university to help establish a national HEI network for sustainability. The case study at hand, focuses on the network "Sustainability at Higher Education Institutions (HOCH-N)" especially from the perspective of Leuphana University Lüneburg in Germany, as one institutional node in this network. We specify the characteristics of the network and summarize them in Table 2, present its main governance structures, as well as the strategies that Leuphana University concretely contributed to the development of the HOCH-N network. Contributions were made on three different levels, national, single HEI-level, and research group level, and were examined concerning encountered challenges and coping strategies that were developed. Even though the insights related to HOCH-N as a young network might partly seem to be obvious, we think they provide valuable points for reflection for researchers with little experience in networking but also to some extent for more experienced actors.

3.2.1. Fostering Sustainability in Higher Education via National Collaboration

In 2015, the Global Action Program on Education for Sustainable Development (ESD) resumed the Decade of ESD by the United Nations Educational, Scientific, and Cultural Organization (UNESCO). This program particularly addresses Sustainable Development Goal #4 of the United Nations on education as one essential leverage point to promote sustainable development [39]. It is this top-down driving factor which motivated the German Federal Ministry of Education and Research to intensify its funding for sustainability projects in the education and higher education sector via its funding program "Research for Sustainable Development (FONA)" which aims to implement the Global Action Program on ESD on a national level. Another driving factor was the sustainability codex resolved by the German Council for Sustainable Development in 2011. The HOCH-N project set out to adjust this codex, which was originally dedicated to foster sustainable development in the private sector to the context of higher education institutions. A more bottom-up driving factor for the HOCH-N project and network was the wish for a joint effort to conflate the multitude and diversity of approaches to sustainability by an increasing number of HEIs across Germany. As a consequence, the joint research project "Sustainability at Higher Education Institutions: develop - network - report (HOCH-N)" was launched in 2016; funded by the German Federal Ministry of Education and Research. In HOCH-N, researchers from 11 German HEIs are collaborating with each other to integrate already existing expertise and future developmental potential of HEIs to contribute to sustainability. German HEIs involved in the HOCH-N project are: Bremen University, Duisburg-Essen University, Eberswalde University for Sustainable Development, Freie Universität Berlin, Hamburg University, Leuphana University Lüneburg, Tübingen University, Ludwig-Maximilian-Universität Munich, Technische Universität Dresden, Vechta University, Hochschule Zittau-Görlitz. The overall lead in this project lies at Hamburg University. The management and coordination of the HOCH-N network, representing one specific objective of the underlying joint research project, is led by Hamburg and Bremen University. Within the HOCH-N project and its network, an interdisciplinary team of sustainability-oriented research experts from Leuphana University is actively involved.

With the launch of the project, also the design and planning phase, as well as first steps to establish the HOCH-N network were taken. Acknowledging already existing HEI-networks for sustainability (i) on the federal state and international level; (ii) between a small selection of HEIs and other research institutions; as well as (iii) spanning just one specific group of HEI-stakeholders (e.g., sustainability managers), the HOCH-N network embarked on a national scope, bringing together various groups of HEI stakeholders from deans to students, from researchers and lecturers to technicians and administrators. Therefore, researchers and practitioners from other German HEIs outside HOCH-N were specifically invited to become members of the open HOCH-N network in order to share their expertise and contribute to the overall goal of HOCH-N. That is to promote sustainable development across the different fields of action at German HEIs. For this, available expertise and established approaches how to consequently reflect upon and integrate sustainability into research, teaching, governance, transfer, campus management and reporting, were collected and visualized. In HOCH-N, making sustainability related scientific and practical knowledge explicit and accessible is considered a basic condition to increase awareness, facilitate and accelerate mutual exchange, learning and inter- and transdisciplinary collaboration for sustainability within and across German HEIs. In addition, via inviting new members to the network and implementing joint workshops on sustainability-oriented topics in all fields of action of an HEI, HOCH-N aims for strengthening the commitment among HEI-stakeholders to reflect, develop and implement sustainability measurements on campus, as well as bolstering existing bi- and multilateral bonds between German HEIs, and especially to establish new ones. Within the first two years, five HEIs and 163 individual actors from 101 German HEIs joined the HOCH-N network.

3.2.2. Governance: Organizational Structures and Role of Leadership

The HOCH-N network is still a young network, currently in a transition between its development stage on one hand and its active stage on the other. During the development stage, the collaborative ties among the eleven HEIs, were strongly formalized, e.g., via the formulation of a shared overall goal, a clear distribution of tasks and roles documented in the joint project proposal, the overall project lead assigned to Hamburg University, the central management of the HOCH-N network assigned to Hamburg University and Bremen University, regular face-to-face and virtual meetings for interdisciplinary exchange and collaboration, an online platform to share documents and reporting duties with regard to current research progress and intermediate results in order to seek internal feedback, as well as feedback from the advisory board and the Federal Ministry of Education and Research, etc.

Following a whole institution approach, the project encompassed six working packages dedicated to the different fields of action of HEIs: research, teaching, governance, transfer, reporting, and campus management [14]. In each of the working packages, two HEIs collaborated with each other respectively, thus enabling new bilateral research partnerships for sustainable development. In addition, regular joint workshops across the working packages allowed multilateral knowledge exchange, mutual trust building and learning, as well as collaboration on joint products, such as a shared understanding of "sustainability", joint scientific publications, and practical guides.

On behalf of the formalization of the wider HOCH-N network—beyond the 11 HEIs—basic structures were established, such as a project's website, an online map giving an overview of the number, distribution, and sustainability-related expertise of the network members, a set of admission criteria for potential future members, etc.

3.2.3. Instruments to Develop the HOCH-N Network

As outlined above, establishing the HOCH-N network was centrally managed by an interdisciplinary team of sustainability-oriented researchers at Hamburg and Bremen University. At the same time, each of the other nine HEIs involved in the HOCH-N project were asked to actively support this early stage of the network. In the following, we provide insights on how Leuphana University Lüneburg concretely contributed to setting up the HOCH-N network, which obstacles occurred, and which coping strategies were developed. Finally, we reflect upon expected outcomes for Leuphana University as soon as the HOCH-N network fully switches from the initial development to the active implementation stage.

3.2.4. National Level

In order to reach out to the wider community of sustainability-oriented stakeholders at German HEIs, the research group at Leuphana University decided to combine the invitation to the network with an inquiry to a nationwide online questionnaire on sustainability-oriented research. We contacted the vice presidents of the 399 HEIs in Germany via email, briefly informed them about the network, included a link to its online presence and cordially invited the vice presidents to become members, as well as to forward the invitation to sustainability-oriented researchers/stakeholders at their institution. Shortly after the invitations were sent to the vice presidents, inquiries to become network members increased. Although new members were not asked how they got to know about the open HOCH-N network, it is likely that there was a causal connection to the invitation via email.

We also collected a list of already existing sustainability-oriented networks among different status groups of German HEIs and invited the hosts to spread the word and to become a member of the HOCH-N network. With this, we intended to foster exchange and collaboration across already existent

HEI-networks for sustainability which focus on single HEI status groups, are located on a regional to federal state level, or are dedicated to just one or two fields of action.

3.2.5. Level of Single Higher Education Institution

Another approach to support the acquisition of members in the HOCH-N-network was to spread information on the network and gain new members at Leuphana University itself. Due to technical limitations a maximum of seven to eight individual stakeholders of one HEI could become members. Thus, we decided for a targeted selection of potential future members, up to three from each status group, HEI-management and administration, research and teaching, as well as the student body. Additionally, we considered the specific expertise and hitherto observable commitment to engage for sustainable development, as well as a person's continuance in office. We also minded a gender balance and spectrum of academic qualification among the potential members.

The selected stakeholders were contacted via email and/or personally in order to invite them to the network. Support was given to create and establish individual network profiles as the entrance ticket to the network. Here we faced organizational challenges as different stakeholders required different contact strategies. Often several emails and/or personal contacts were necessary in a time-consuming and prolonged process due to high workload of the contacted persons, the generally voluntary character of networking activities and insecurity about the relation of individual effort and advantages of a membership. At an interval of several weeks, friendly reminders were sent out and the opportunity given to discuss open questions and potential benefits via email or personally. The given information was finally forwarded to Hamburg University and incorporated into the online map of the network.

3.2.6. Level of Research Group

The main contribution to the development of the HOCH-N network was to work up a practical guide in collaboration with sustainability-oriented researchers from Ludwig–Maximilian University Munich. The guide focuses on research as one of the six fields of action addressed in the joint project HOCH-N and is based on conceptual and social empirical research. Its goal is not to provide an instant recipe on how to conduct ideal-typical sustainability-oriented research. With regard to the diversified landscape of such research, the guide provides a spectrum of hands-on information and examples to demonstrate different options of how research can be designed and implemented as a concrete contribution to sustainable development. The guide thus provides inspiration and orientation for future sustainability-oriented research at German HEIs [40].

More specifically and based on an online-questionnaire implemented at all 399 HEIs in Germany the guide provides insights into the current landscape of sustainability-oriented research at German HEIs. Three-hundred-and-fifty-eight HEI actors, mostly researchers but also technicians, administrators, and students from about 100 German HEIs participated in the survey.

We are aware that the data is not representative for sustainability-oriented research at German HEIs in total. One of the challenges was to develop an approach to identify researchers as sustainability-oriented or not. We decided to rely on self-identification. Thus, researchers who may conduct sustainability-related research without calling it that were not reached with this strategy. Another challenge was to develop a contact strategy to reach out to the sustainability-oriented research community at German HEIs effectively. As there is no database available which entails an overview of all researchers at German HEIs, we sent the questionnaire via e-mail to the vice presidents at all German HEIs via e-mail and kindly asked them to forward it to relevant stakeholders at their home institution. In addition, we sent the questionnaire to the contact persons of regional sustainability-oriented HEI or research networks and asked to spread it among the network members. On the one hand, both contact strategies had the potential to reach out quickly and with limited effort to a great number of sustainability-oriented researchers at German HEIs. On the other hand, both strategies depended on the collaborative willingness of a rather small number of key actors.

However, the collected data allows a first impression of the current landscape of sustainability-oriented research foci, trends, and gaps. The data thus contains valuable information for sustainability-oriented researchers and whole research institutions on how to locate their own work within the current landscape and strategically plan their future sustainability-oriented research including research collaborations.

In addition, the guide provides application-oriented information on how to concretely initiate, implement, and/or expand sustainability-oriented research at the home HEI. Based on a narrative literature review, three ranges of action were identified as practical leverages to facilitate sustainability-oriented research, i.e., research setting, research process, and academic qualification. This conceptual contribution was validated and completed via semi-structured telephone interviews with 27 stakeholders from research services, research and teaching, as well as sustainability offices from seven selected German HEIs. Subsequently, a fourth range of action on “networking” was added. Furthermore, exemplary instruments and strategies for each of the four ranges were developed from the interviews with researchers from HEI network members, as well as illustrated by tried and tested practical examples.

Parallel to the challenges in the survey, we adapted the self-identification strategy to select our interview partners by relying on explicitly sustainability-related information of potential interview partners presented on the website of their home institution. Another challenge was to develop a clearly structured and appealing form of presenting the spectrum of collected instruments and practical examples for an interested audience. For this, we searched for inspiration in practical guides such as the Green Guide for Universities [41], as well as collegial feedback from within the HOCH-N project.

As a side effect of the survey and interviews, a comprehensive number of stakeholders from German HEIs who were involved in the quantitative and qualitative data collection were informed about the underlying joint research project, as well as the HOCH-N network, thus increasing its visibility.

3.2.7. Expected Outcomes at Leuphana University Lüneburg

After contributing to the development of the HOCH-N network, Leuphana University is looking forward to continued active engagement in and concrete benefits from the network in the near future. One of the next steps is to test and, if necessary, refine the collected instruments and strategies at other HEIs in the HOCH-N network. This is planned as a multilateral collaboration between Leuphana University and additional HEIs. We, therefore, expect to further strengthen the ties between HEI-nodes in the HOCH-N network, as well as to stir inspiration and learning at Leuphana University itself to further develop solution-oriented sustainability research.

3.3. Learning How to Leverage Strategic Benefits from an HEI-Network for Sustainability: The Case of the UAS Network

In this section, we share insights on how a single HEI can leverage positive outcomes for its sustainability activities from networking internationally. The case study refers to the “University Alliance for Sustainability” network, of which Freie Universität Berlin was initiator and co-founder. The authors of this section contributed actively to building and consolidating the network as UAS program leader and network manager and provide a critical self-reflection of lessons learned. It will be shown how the step-by-step establishment of the network became the basis for the internal networking of sustainability-related stakeholders and the initiation of new teaching formats at Freie Universität Berlin. In the following, we specify the characteristics of our network including a concise overview in Table 2, introduce governance structures, instruments, and assess the effects on sustainability related structures and processes at Freie Universität Berlin. Insights gained are reflected against challenges and developed coping strategies.

3.3.1. Fostering Sustainability via International Collaboration

Considering the global scope of the topic of sustainability and the international research community universities are embedded in, there is tremendous potential for international collaboration. This mindset led to the foundation of the "University Alliance for Sustainability" (UAS) in 2015. The UAS network with Freie Universität Berlin as one of its nodes is based on the bilateral strategic university partnerships that have evolved from long-standing university partnerships, including the Peking University (partner since 1981, strategic partner since 2011), Hebrew University of Jerusalem (partner since 1986, strategic partner since 2011), St. Petersburg State University (partner since 1968, strategic partner since 2012), and the University of British Columbia (partner since 2012, strategic partner since 2014). Establishing strategic partnerships with leading research universities worldwide is part of the internationalization strategy of Freie Universität Berlin. The objective of these alliances is to allow for comprehensive networking and collaboration on all university levels, i.e., regarding the sustainable support of young researchers, the initiation and implementation of innovative research co-operation, the development and establishment of future-oriented teaching, and the exchange of researchers, students, and staff. When selecting strategic partners, Freie Universität Berlin takes into account the diversity and intensity of existing contacts, as well as the potential for future cooperation.

It is the objective of the UAS to foster an inter-university and transdisciplinary dialogue, connecting university stakeholders in the field of sustainability. Following a whole institution approach the partner universities leverage the relationships and collaborations they built in various disciplines to address sustainability challenges in research, teaching, campus management, and transfer. This implies the placement of sustainability issues in all structural and thematic entities of the universities, going beyond the usual segmentation of an HEI. The UAS partners developed a high degree of formalization with an institutionally rooted governance structure aimed to ensure effective management of the network and a successful transfer of best practice examples between institutions.

3.3.2. Governance: Organizational Structures and Role of Leadership

Looking back, the clear structure of the decision-making bodies and their anchoring within the leadership level, ensured the high visibility and institutional support given to the network from the outset. The *Network Board* is the highest decision-making body and comprises vice presidents or prominent academic representatives from all partner universities.

At Freie Universität Berlin a *Steering Committee* is responsible for the strategic development of the network. It consists of the vice president for international affairs and the former vice president for research and sustainability in teaching, the UAS program leader and network manager, as well as a representative of the Center for International Cooperation at Freie Universität Berlin. This composition ensures that decisions are reflected in the overall internationalization strategy of Freie Universität Berlin, in addition to the day-to-day needs of the UAS network development.

The network activities are coordinated by the Unit for Sustainability and Energy Management that is in charge of steering sustainability management at Freie Universität Berlin. The operational management aspects of the UAS are largely dealt with by the network manager at Freie Universität Berlin and the respective coordinators at the partner universities. As the crucial contact persons for incoming fellows, they ensure the smooth proceeding of the exchange program between the partner universities. In addition, they facilitate networking in research and campus management at their home university by keeping track of stakeholders involved, supporting joint project proposals, and research triggered in the network.

3.3.3. Instruments of Implementation

The UAS mobility program offers exchange options for faculty, staff, and students for research, study or internship stays at the partner universities. Since its initiation, more than 240 individuals have actively participated in the program and evaluated their stays in fellow reports, which are openly accessible on the UAS website. An evaluation of the UAS fellows showed that—despite the open application system and incremental network growth—there is a nearly even distribution of male and female participants (47% male, 53% female). In terms of stakeholder groups funded, the distribution is also relatively even: 36% senior researchers, 22% junior researchers, 20% students, and 22% administrators. The slightly higher number of senior researchers resulted from the numerous research workshops and strategy meetings in the UAS network. Freie Universität Berlin received most incomings from the partner universities (52%), which is due to funding requirements and the workshops, as well as Spring Campus Conferences held in Berlin. Freie Universität Berlin's outgoings went to University of British Columbia (18%), Peking University (14%), Hebrew University of Jerusalem (9%), and Saint Petersburg State University (7%). A total of 410 participants attended the three Spring Campus Conferences from 2016–2018. About half of them came from Freie Universität Berlin. Of these, more than a third were students and PhD students. This transparent monitoring of the fellow network helped to build on existing contacts and projects, as well as map the network's development. Reports are evaluated by the network manager, who also maintains a database of people involved in the bilateral collaborations. This overview, combined with proactive communication including a large number of personal conversations about the UAS, significantly contributed to the incremental development of the network, by allowing the linking of researchers at the partner universities and mutual trust building.

Networking in the fields of teaching and campus management is facilitated by incubator workshops aimed at exchanging best practices, developing joint projects, and offering peer-to-peer training opportunities. The joint research, exchange, and outreach activities are addressed by the annual Spring Campus Conferences held at Freie Universität Berlin. During these events, UAS partners showcase and discuss their research and projects in teaching and campus management with an international audience. From 2015 to 2018, the UAS network facilitated three Spring Campus Conferences, two Teaching and five Management Incubators, as well as numerous bilateral research workshops.

The participation of key stakeholders from each partner university in the workshops and conferences largely depended on three factors:

(1) Contacts established during research stays through the mobility program;
(2) Invitations by the coordinators at the respective partner university or the network manager in Berlin;
(3) Calls for contributions, triggering the participation of experts who have not been previously involved in the UAS.

Looking back, the first two approaches proved to be most effective in addressing high-level researchers and senior management staff, who contributed established research or best practice examples.

The UAS receives funding from the German Academic Exchange Service sponsored by the Federal Ministry of Education and Research from 2015 to 2020. This funding contributed significantly to the successful foundation of the network, as it covered the mobility program and the position of the UAS network manager. In order to set the course for the years to come, a Future Lab will be held in late 2019. This will bring together representatives of all UAS partners to carry out an evaluation and to discuss the prospective nature of the partnership for the subsequent years. To ensure continuity, the Executive Board of Freie Universität Berlin has decided to permanently assign the UAS network manager position.

3.3.4. Outcomes at Freie Universität Berlin

The UAS network works with a detailed milestone and measurement plan, which focuses on the aforementioned mobility program, conferences, and incubators. Regular reporting duties to the governance bodies of the UAS and the donor also ensure the continuous reflection and evaluation of measures taken and their respective outcomes. Already in the start-up phase, the partners have defined which goals they aim to achieve in the first four years of the network collaboration (2015–2018).

At the end of the first round of funding, it can be concluded that the network initiated the establishment and deepening of manifold research and teaching projects at UAS partner universities. Fostering these is an ongoing process. Planned results of UAS include:

(1) Building an international sustainability researchers' network;
(2) Fostering education for sustainable development including cross-HEI curricula development;
(3) Embedding sustainability in the overall management and campus of each partner institution.

In contrast to the intended network results, the UAS' whole institution approach, and moreover, the cross-sectional theme of sustainability, decisively contributed to radiating results in a wide variety of areas. This is also reflected by the network's claim to involve and address all stakeholders and entities of the university. Therefore, results in the field of sustainability did not only affect the work environments of researchers or lecturers but also clearly addressed the overall management and administration of the network member institutions. In addition, the international collaboration sparked a variety of opportunities for additional impacts and initiatives. They essentially resulted from the fact that the process of establishing the international network became increasingly important for internal networking at Freie Universität Berlin. The incremental development of the UAS allowed the network management to embrace and support these spin-offs. In the following, we will specifically reflect on the interdependent developments in the area of teaching at Freie Universität Berlin.

The collaboration in the UAS has been an important impetus for strategic sustainability projects at Freie Universität Berlin. The Unit for Sustainability and Energy Management that is in charge of steering the sustainability management at Freie Universität Berlin and coordinating the UAS, was able to leverage the attention sparked by the network activities and the best practices presented by the partners to advance internal sustainability activities at Freie Universität Berlin. While not being an explicit goal, this was paramount for the central UAS network management at Freie Universität Berlin. The overall aim of deepening the existing collaborations of the partner universities with the normative goal to foster sustainability, was also a trigger to push innovations in the field at Freie Universität Berlin. The UAS network proved to be a door opener for sustainability issues within the university. This was particularly evident in the areas of research and teaching. The interdisciplinary and international design of UAS allowed addressing researchers in all faculties of the university. Personal meetings to introduce the network and respective funding opportunities of the exchange program, conversations on leadership level, as well as networking opportunities during the UAS events, sparked follow-ups with professors and largely contributed to mapping the existing sustainability-related research at Freie Universität Berlin. It also facilitated the dialogue on sustainability and raised awareness for the topic on campus. In this respect, the governance decision to anchor the UAS project in the Unit for Sustainability and Energy Management at Freie Universität Berlin with direct contacts to the Executive Board and a wide range of university contacts has proven to be beneficial.

An evaluation of the milestone plan revealed that a significant number of planned results have been achieved by UAS. However, the network management and members were confronted with a range of challenges and obstacles which led to essential lessons learned. While the partners embraced the whole institution approach, it remained a challenge to address overarching sustainability projects in the segmented structure of Freie Universität Berlin. With regard to interdisciplinary sustainability research projects, it became clear that such a collaboration across academic disciplines is often proclaimed valuable; however, most researchers have not yet developed routines, accordingly. In the UAS-context, this needed to be practiced, especially in terms of creating mutual awareness of and integrating different disciplinary languages. In regards to the teaching collaboration in terms of joint courses and degree programs, the UAS university stakeholders learned that taking small, incremental steps was the most fruitful strategy. They also understood that setting up international teaching collaborations requires strong and continuous administrative support from the respective home HEIs, time intensive input from involved teaching personnel, as well as a clear foundation in the local study regulations. The last factor includes considerations of credit recognition and language of instruction. Here, the network management learned that these processes often need more time than expected. In the beginning activities should thus focus on the exchange of best practices, short-term lectureships, and individual joint courses to facilitate the development of joint programs and degrees in the long-run.

One area where the additional impacts of the international networking (in that scope) became particularly evident at Freie Universität Berlin is the area of teaching. The exchange on curricula, didactics, methods, and resources in the Teaching Incubator contributed to the development of an interdisciplinary curriculum "Sustainable Development" in the General Professional Skills courses at Freie Universität Berlin, which is mandatory for undergraduate students. The idea to establish such an inter- and transdisciplinary teaching format open to students from different faculties took further shape and was driven by the international UAS network. The exchange provided an overview of best practices at all partner universities, including projects, courses, methods, and virtual resources. It brought together key stakeholders from teaching and curriculum development at Freie Universität Berlin, who had the chance to connect with colleagues at partner universities.

Inspired by the international best practice examples, members of the working group "teaching" of the sustainability steering committee at Freie Universität Berlin integrated these insights and tailored a curriculum to the specific needs of students at Freie Universität Berlin. Actively integrating the leverage points provided by the international collaboration, contributed to the rapid realization of the project in only two semesters. The exchange in the UAS network, as well as working towards success with the network partners, strengthened their awareness for the sustainability discourse, as well as for the support provided by the FUB top management and created opportunities for sustainability-related innovation. Besides a strong commitment from the FUB leadership, the international network, as well as reporting obligations to the donor facilitated swift implementation of the new competence area "Sustainable Development". As already indicated, the double responsibility of the Unit for Sustainability and Energy Management for the UAS network, as well as for the sustainability management at Freie Universität Berlin, played a key role for the internal advancement of sustainability efforts at FUB from a governance perspective. As the Unit is also in charge of the coordination of the new teaching format it was able to optimally interconnect both processes.

Additionally, the idea to generate a "Sustainability Toolbox" was driven by the UAS network as a whole. The open source toolbox attempts to realize a joint digital teaching and learning platform for the UAS partners and provides sustainability-related expertise to an interested public. Additionally, it aims at facilitating a blended learning approach in on-site courses at the UAS partner universities. Embracing the potential of digitalization in on-site teaching, cross-HEI teaching cooperation and active involvement of the university community in building the toolbox, brought new momentum to the network collaboration. In terms of sustainability, this platform should help to foster the virtual mobility of students and teaching staff, as well as to increase the internationalization of the teaching curricula on sustainability, by including content provided by professors involved in the UAS network.

Based on the detailed case stories of the HOCH-N and UAS network outlined above, Table 2 summarizes and contrasts their main commonalities and differences in a structured overview.

Table 2. Structured overview of the two exemplary HEI-networks for sustainability based on the 15 characteristics derived from the literature (October 2018).

	Characteristic	HOCH-N	UAS
1.	Geographic scope	National	International
2.	Subject	Sustainable development in all areas of HEIs including governance, research, teaching, campus management, and outreach, as well as reporting activities	
3.	Objective	Foster contribution of network members and the network as such to sustainable development by:	
		Strengthening exchange, collaboration, joint learning, mutual inspiration across HEIs for sustainability	Strengthening existing strategic partnerships in the area of sustainability
		Contributing to the discourse of sustainability by inter- and transdisciplinary research	Contributing to the discourse of sustainability by developing joint research and teaching projects
		Disseminating research findings as scientific publications, practical guides and best practices within and beyond the network	Disseminating research findings and best practices at UAS Conferences, as scientific publications and in UAS working paper series
4.	Resources	Inter- and transdisciplinary sustainability-oriented research expertise	
		2016–2020: Funding by German Federal Ministry of Education and Research	2015–2020: Funding by German Academic Exchange Service sponsored by German Federal Ministry of Education and Research
			Financial contributions of partners to mobility program
5.	Composition	11 German HEIs incl. a team of ca. 40 researchers and practitioners (HOCH-N project) backed by additional 5 HEIs and 163 individuals from 101 German HEIs (HOCH-N network)	Ca. 30 Executive Board members, researchers and practitioners
6.	Organizational structure & role of leadership	Central management at Hamburg University and Bremen University, supplemented by 9 other HEIs from HOCH-N project	Central management at Freie Universität Berlin and project coordinators at partner universities; strong support of university leadership of all partners, anchored in Network Board
7.	Open/closed	Open to new members from German HEIs, politics, industry, and civil society; additional outreach to experts from international HEI-networks for sustainability	Closed; focused on the strategic partner universities of Freie Universität Berlin with strong outreach activities in international sustainability networks
8.	Heterogeneity/homogeneity	German (mother tongue)	English (working language, mother tongue for one member)
		Stakeholders from research, teaching, governance, campus management, transfer and reporting	Stakeholders from research, teaching, transfer, management and administration

Table 2. *Cont.*

	Characteristic	HOCH-N	UAS
9.	Degree of formalization	HOCH-N project encompasses 6 working groups, each with an interdisciplinary research team from two HEIs; supported by central management and advisory board	Clear governance structure consisting of Network Board, Steering Committee and central network management, as well as representatives and coordinators at each partner university
		Network management rooted at sustainability-oriented research teams of Hamburg and Bremen University involved in the HOCH-N project	Network management anchored in the Unit for Sustainability and Energy Management, which is directly assigned to the Executive Board of Freie Universität Berlin
		Research proposals for the HOCH-N project (phase I: 2016–2018 and phase II: 2018–2020) incl. detailed milestones	Mission statement; Detailed milestones and measurement plans
		HOCH-N network formalized by conditions of admission, joint website and network map, regular meetings, workshops, and newsletter	Network website and communication
10.	Form(s) of collaboration	Regular workshops among 11 HEIs from HOCH-N project, incl. researchers, students and management staff from other HEIs	Teaching and management incubators to trigger collaboration and best practice exchange
			Annual conference in Berlin including research and management related workshops, PhD conference
		Interdisciplinary, interinstitutional research, joint presentations at national and international conferences, as well as joint development of scientific publications and practical guides	Mobility program for researchers, PhD candidates, students, and management staff for research and study stays
			Additional bilateral workshops
		Regular teleconferencing among heads from 6 working groups and central management	Exchange opportunities for student volunteer initiatives
			Short-term lectureships; joint courses (virtual, blended or on-site)
		Shared data base among 11 HEIs	Website
		Website and newsletter	
11.	Mode of interaction and communication	Personally and virtually	
		Decentralized mode of interaction	Mixed mode of interaction, central impulses, interaction patterns of ripple effects
12.	Developmental stages	Transition between development stage and implementation stage	Implementation stage

Table 2. *Cont.*

	Characteristic	HOCH-N	UAS
13.	Ethos	Joint trust, identity and strong commitment within HOCH-N project gradually built via joint project goals, regular exchange and close collaboration on joint products, such as practical guides and scientific publications	Collaboration has grown incrementally, built on institutional and personal contacts and trust; Strong commitment and participation of leadership facilitates whole institution approach
		Up to now mostly loose ties in the greater HOCH-N network with more intensive collaborations planned for 2018–2020	
14.	Context	HOCH-N is linked to national efforts to implement the UNESCO world action program, to efforts to adjust the sustainability codex resolved by the German Council for Sustainable Development to the context of HEIs, as well as to intentions of German HEIs to strengthen exchange and collaboration toward sustainability.	The UAS network was established from a joint understanding that universities have a societal responsibility to contribute and shape the global sustainability discourse.
15.	Outcome	Project goals and milestones largely reached on network and node-level:	
		Initiation of bi- and multilateral research collaborations among 11 HEIs of HOCH-N project	Numerous joint projects in research and teaching have emerged at Freie Universität Berlin and at partner universities
		6 practical guides to implement sustainability in governance, research, teaching, transfer, campus management and reporting of German HEIs	Intensified sustainability activities at Freie Universität Berlin To date 240 participants
		Joint understanding of sustainability among 11 HEIs of HOCH-N project	Several additional impacts, e.g., the UAS has led to valuable contacts and collaboration with other universities
		Sustainability codex of German Council for Sustainable Development adapted to context of HEIs	
		Scientific publications	

4. Synthesis and Outlook

This article addresses two objectives. On the one hand, we suggest an analytical framework that allows a more structured description of HEI networks (Table 1) and apply it to two exemplary HEI networks for sustainability (Table 2). On the other hand, we provide insights on how a single node within a network, namely a single university, can concretely contribute to and benefit from its membership in an HEI network for sustainability. In the following, we first discuss the conceptual and practical contribution, as well as the limitations and future developmental potential of the analytical framework. Subsequently, we discuss the lessons learned from the two exemplary HEI networks for sustainability—HOCH-N and UAS—and complement them with the outcome of the interactive workshop at the ISCN Conference 2018.

4.1. An Analytical Framework to Facilitate Learning about Structures, Processes, and Outcomes of HEI Networks for Sustainability

Networks are complex organizational and social entities. The 15 characteristics presented in this article offer an analytical framework to systematically describe and differentiate the structures, processes, and outcomes of HEI networks in general. Their applicability was tested in the context of two concrete early-stage HEI networks for sustainability. The characteristics help to highlight the essential features of each of the two networks. Furthermore, this structured representation of networks facilitates learning between different networks and utilizing potential complementarities. Learning enables improvement of the own network. Looking at the two case studies, HOCH-N could for instance benefit from the experiences of UAS related to the different instruments to foster HEI collaboration. The UAS network can benefit from the insights of the HOCH-N project and network in the area of sustainability-oriented research, teaching, and transfer. Secondly, as universities are often members or nodes of different networks, they can more strategically profit from them and use their complementarities if the network profiles are more transparent. Besides HOCH-N, Leuphana and Freie Universität Berlin are for instance both members of ISCN, which is also following a whole institution approach but with a stronger focus on campus structures and activities. This focus links to several activities of UAS and HOCH-N, yet are rather complementary in nature. Finally, characterizing the landscape of networks in a specific area can also help to create a network of networks, in which the different networking activities strategically complement one another so that both the single nodes but also the landscape of networks unfold their optimal potential with regard to their overarching goal, i.e., fostering sustainability. The characteristics have been derived from relevant scientific literature but make no claim to be complete. To validate the characteristics, it is necessary to apply them to further networks and to adapt and expand the framework accordingly. In the following, we will use the 15 characteristics to discuss lessons learned from the two case studies and complement them with the results from the interactive workshop at ISCN 2018.

4.2. Lessons Learned from Both a Meta- and a Single-Node Perspective on Two Exemplary HEI Networks for Sustainability

The juxtaposition of the two exemplary networks has made it clear that, while they share fundamental similarities regarding the characteristics #2 subject, #3 objective, #5 composition (in terms of stakeholder groups involved) presented in Table 2, they also have different starting situations, reflected in the characteristics #1 geographic scope, #8 homogeneity versus heterogeneity, as well as #14 political and procedural context. In the following, we will introduce commonalities and differences in lessons learned in an attempt to shed light on the overall question of this article on how strategic networking for sustainability can be facilitated from the node perspective of a single HEI-network member.

4.3. Governance

Both networks work with a high degree of formalization (characteristic #9, Table 2), in that they build clear governance structures, as well as define strategic goals and areas of activity. In both cases, a clear decision-making structure proved decisive to goal-oriented and effective communication. The leadership role is assigned to representatives of the executive boards of the member universities in both networks. This highlights two network functions. On the one hand Leuphana University Lüneburg and Freie Universität Berlin as node members utilize the political function, by forming innovative collaborative groups with a clear commitment (characteristic #13 ethos, Table 2) to fostering sustainability not in one or two fields of action such as research or teaching but holistically [6,8,19]. At the same time, the network collaborations proved to be incentivizing for mapping and accelerating sustainability-oriented research (Leuphana) and teaching (Freie Universität) in their home institutions (#15 outcome, Table 2).

The clearly defined subject and objective contributed to establishing a shared vision for the network and aligned the activities of the network members (#2 and #3). The guiding principle of the whole institution approach that shaped these two characteristics was well accepted and supported by all network members. However, the commitment to this principle does not mean that it has already been fully implemented in every member HEI. Both HOCH-N and UAS are characterized by a great diversity of members, ranging from pioneering universities to members with well-established sustainability strategies to beginners (#5 composition). This asymmetry needs to be addressed transparently and balanced by a differentiated set of network instruments for mutual benefits.

4.4. Instruments

Common to both networks is a central network management (#6 organizational structure and role of leadership), which is placed at one of the partner universities. Besides management and communication tasks, the coordinators record network activities, build databases about existing and potential contacts, and facilitate networking in regard to the overall strategic purpose of the network. The UAS network works with a milestone and measure plan whereas defined work packages are allocated among the six different working groups in the HOCH-N network (#9 degree of formalization). In the initial phase, the focus was on taking stock. Workshops and bilateral exchange (personal and virtual) were the main forms of collaboration (#10). In case of the UAS the focus was on sustainability-related activities in all areas of the university, as well as on mapping existing bilateral contacts. The working group research in the HOCH-N network concentrated on mapping sustainability-oriented research activities across German HEIs. This process was essential for establishing a stable operational working structure and ensuring successful build-up and upkeep of the network. The information function of the network is evident in the close collaboration facilitated in different but constant modes of interaction (#11), which contributed to the rapid exchange of information among the network members, as well as at the node universities [19].

Most networks are constantly undergoing changes in composition. In case of HOCH-N, as an explicitly open network (#7), this is especially true and can best be addressed by a transparent communication of the central network management. The eleven founding HEIs, who spearhead the different working groups (#11 mode of interaction and communication), take on a special role here, as in the case of Leuphana University, new members were invited and introduced to the processes. These initial exchange and interaction opportunities formed a basis for incremental trust building, thus shaping the ethos of the network (#13). The UAS network on the other hand focuses on deepening the ties with the strategic partner universities of Freie Universität Berlin (#11). While the institutional composition remains (currently) constant, there was always a need for the renewal of relationships as a result of staff and organizational changes (#12 developmental stages). These changes are quite significant for universities, in particular concerning their governance structure. Identity building measures, like the UAS mission statement, annual topics, strategic meetings in the starting period, and constant communication helped to address these challenges. In the international framework of the

UAS, the communicative and intercultural competence of the network team is just as decisive for the success of the network.

4.5. Outcome

In order to keep-up and proceed effectively, e.g., to accelerate efforts for sustainability, HEI networks need to constantly provide attractive conditions for their members. Besides offering a professional and resilient network management, their members expect benefits for their own development. Participants from HOCH-N benefit from topic- and demand-specific networking with other university actors across Germany and receive early access to the contents of the research project. They gain visibility for their sustainability projects and can strengthen their sustainability-oriented reputation in the HOCH-N project and network. In the case of the UAS, the network offered members the opportunity to deepen the already existing partnerships in an important future field that has high integration potential due to its cross-cutting character. The joint efforts in research and teaching, as well as the exchange of best practices in campus management, makes the UAS an incubator for change at the respective home institutions. Additionally, UAS partners follow their transfer approach and strive to be a sustainability model for other universities. Both case studies provide exemplary insights in the political and psychological functions networks can unfold [19]. Network members find themselves amongst a group of like-minded HEI actors working towards similar goals and can form collaborative groups that are able to utilize leverage points at their home institution and beyond.

As pointed out in the results section, the network also contributed to the integration and networking of sustainability-oriented research and teaching at Freie Universität Berlin. The active engagement in the UAS network proved to be an innovative factor for the sustainability-oriented efforts at Freie Universität Berlin. This innovation function could be successful because it was based on a governance structure which ideally combined the UAS collaboration with the sustainability management at Freie Universität Berlin. Additionally, the numerous networking events facilitated peer-to peer learning and allowed participants to broaden their knowledge and acquire new skills [1,18,20]. This implicit skills function of the network has decisively contributed to the ability of stakeholders to implement innovative projects (#15 outcome) [19].

The question of concrete benefits derived from network memberships was also posed during the interactive session of the ISCN workshop when participants discussed their expectations towards HEI-networks for sustainability. For them the overall prospect of network membership was to create new contacts, as well as to get inspiration for sustainability-related innovations at their own HEI. More specifically participants were expecting to exchange best practice examples and lessons learned.

4.6. Outlook

This article has outlined the strategic outcomes a node university can have on the development of a network, as well as the outcome a network can have on the sustainability strategy of a node university. For the outlook and future development potential of both networks we need to iterate that third-party funding was a necessary condition for the foundation of both. Including the subsequent funding it allows the networks to develop for four (HOCH-N) to six (UAS) years (#4 resources). Once funding expires, both networks need to find sustainable modes of communication and interaction. The question of benefits for the participating HEI members will be of paramount importance. A roadmap needs to be jointly established as proposed in the UAS Future Lab format. Furthermore, the contributions of the stakeholder group of the ISCN workshop provide valuable recommendations. Participants identified leverage points to advance HEI-networks and to strategically use them to foster sustainability at their HEI. For the future advancement of existing HEI-networks, external feedback and internal peer-review procedures were suggested to allow self-reflection, as well as to secure quality standards and efficacy. Another recommendation was to strategically win HEIs with high international reputation as members for networks. On the individual HEI-level, participants suggested to particularly mind the multiplicity of exchange opportunities and to concentrate on active participation in selected networks.

Despite the successes achieved during the development period, it will be a challenge for both the HOCH-N and the UAS network to secure their existence after the funding phase. Ultimately, the future of both networks depends on whether they succeed in proving and expanding their attractiveness for the participating universities. Moreover, both networks must also prove their indispensability in their respective political contexts. This will require not only feasibility studies in close coordination with existing network members, but also close feedback to the respective political actors and potential funding institutions.

5. Conclusions

This article presented conceptual and empirical insights into how single HEIs can support and benefit from being a node in an HEI network for sustainability. The analytical framework of 15 characteristics introduced in this article has proven to contribute to the structured description and analysis of two exemplary HEI networks for sustainability. It enables the specification of a network's purpose, as well as its structures, processes, context, and outcomes. The framework also shows that social networks are complex entities that require a conscious and targeted design process, as well as regular reflections on optimization potentials.

Furthermore, we derived a set of practice-oriented lessons learned from two case studies, as well as from an interactive workshop at the ISCN Conference 2018. From a meta-perspective on HEI networks for sustainability, we found: (i) The composition of actual members, applied modes of interaction, available resources, and proposed outcomes are crucial aspects that influence the attractivity of an HEI network for new members. (ii) Different network governance structures, clearly assigned and distributed roles, consensus-based decision-making, as well as reliable, circumspect network management proved to be decisive factors for successful and continued network operation.

From an integrated perspective on an HEI network and its single HEI nodes, we found: (iii) (Co-)founders need to clearly highlight the benefits of membership and active participation in order to attract members from the institutional to the individual level. Higher education institutions can significantly increase the positive outcomes of a network membership at their institution by systematically facilitating interinstitutional exchange, collaboration, and mutual learning among its relevant HEI actors. In this context, a key finding from the UAS network, for instance, was that interinstitutional exchange sparked inspiration and learning at Freie Universität Berlin and subsequently the network itself was used as a means to accelerate sustainability-oriented teaching activities at this university. (iv) Ensured financial support is key in the sensitive phase of a network's foundation and first development, often initiated by one or few HEIs. We hope that our analyses help HEIs to be even more strategic in their networking activities, and existing and emerging networks learn from and complement each other. Non-strategic networking runs the risk of wasting precious resources on the individual and the institutional level, yet functional collaboration in networks has the potential to substantially leverage the contribution of HEI to sustainable development.

Author Contributions: Conceptualization, J.K., D.J.L., K.R., A.W.; Methodology, J.K., D.J.L., K.R., A.W.; Data collection, J.K., K.R., A.W., D.J.L.; Data analysis, K.R., J.K., A.W., D.J.L.; Writing—original draft preparation, J.K., K.R., A.W., D.J.L.; Writing—review and editing, J.K., K.R., A.W., D.J.L.; Funding acquisition: D.J.L.

Funding: This research was conducted within the joint research project "Sustainability at Higher Education Institutions: develop – network – report (HOCH-N)" funded by the German Federal Ministry of Education and Research, FKZ 13NKE007F, as well as within the network "University Alliance for Sustainability" funded by the German Academic Exchange Service.

Acknowledgments: The authors would like to thank the journal *Sustainability* and the guest editors Julie Newman, Göran Finnveden, and Leendert Verhoef for the invitation to contribute to this Special Issue. We would also like to thank the two reviewers, Annika Weiser and Guido Caniglia, for their critical and constructive comments on earlier versions of this paper. Another thanks goes to Cathel Hutchison and Amy Newsom for language assistance. Furthermore, we thank the participants of the interactive workshop on "Strategic Networking for Sustainability: Insights from Research and Practice" at the 12th International Sustainable Campus Network Conference at KTH Royal Institute of Technology in Stockholm, 11–13 June 2018, for their active engagement and input on HEI-networks for sustainability. Judith Kahle and Daniel J. Lang would like to thank the German

Federal Ministry of Education and Research (BMBF) for providing funding for the empirical research at Leuphana University, in the context of the joint research project "Sustainability at Higher Education Institutions: develop – network – report", as well as for the publication of this paper. On behalf of Freie Universität Berlin, Katrin Risch and Andreas Wanke would like to thank the German Academic Exchange Service (DAAD) for funding the "University Alliance for Sustainability" in the framework program "Strategic Partnerships and Thematic Networks" sponsored by the German Federal Ministry of Education and Research.

Conflicts of Interest: The authors declare no conflict of interests.

References

1. Caniglia, G.; Luederitz, C.; Groß, M.; Muhr, M.; John, B.; Withycombe Keeler, L.; von Wehrden, H.; Laubichler, M.; Wiek, A.; Lang, D. Transnational collaboration for sustainability in higher education: Lessons from a systematic review. *J. Clean. Prod.* **2017**, *168*, 764–779. [CrossRef]
2. O'Brien, K. Global environmental change II: From adaptation to deliberate transformation. *Prog. Hum. Geogr.* **2012**, *36*, 667–676. [CrossRef]
3. Van der Leeuw, S.; Wiek, A.; Harlow, J.; Buizer, J. How much time do we have? Urgency and rhetoric in sustainability science. *Sustain. Sci.* **2012**, *7*, 115–120. [CrossRef]
4. Withycombe Keeler, L.; Wiek, A.; Lang, D.J.; Yokohari, M.; van Breda, J.; Olsson, L.; Ness, B.; Morato, J.; Segalàs, J.; Martens, P.; et al. Utilizing international networks for accelerating research and learning in transformational sustainability science. *Sustain. Sci.* **2016**, *11*, 749–762. [CrossRef]
5. Crow, M.M. Organizing Teaching and Research to Address the Grand Challenges of Sustainable Development. *BioScience* **2010**, *60*, 488–489. [CrossRef]
6. Finnveden, G.; Egan, E.-D.; Sandberg, T.; Strömberg, E. A Holistic Approach for Integration of Sustainable Development in Education, Research, Collaboration and Operations. In *Handbook of Theory and Practice of Sustainable Development in Higher Education*; Leal Filho, W., Skanavis, C., do Paço, A., Rogers, J., Kuznetsova, O., Castro, P., Eds.; Springer International Publishing: Cham, Switzerland, 2017; pp. 287–303, ISBN 978-3-319-47888-3.
7. König, A.; Evans, J. Introduction: Experimenting for sustainable development? Living laboratories, social learning and the role of the university. In *Regenerative Sustainable Development of Universities and Cities*; König, A., Ed.; Edward Elgar Publishing: Cheltenham, UK, 2013; pp. 1–23, ISBN 978-1-78100-364-0.
8. Lozano, R.; Ceulemans, K.; Alonso-Almeida, M.; Huisingh, D.; Lozano, F.J.; Waas, T.; Lambrechts, W.; Lukman, R.; Hugé, J. A review of commitment and implementation of sustainable development in higher education: Results from a worldwide survey. *J. Clean. Prod.* **2015**, *108*, 1–18. [CrossRef]
9. Trencher, G.; Bai, X.; Evans, J.; McCormick, K.; Yarime, M. University partnerships for co-designing and co-producing urban sustainability. *Glob. Environ. Chang.* **2014**, *28*, 153–165. [CrossRef]
10. Verhoef, L.; Graamans, L.; Gioutsos, D.; van Wijk, A.; Geraedts, J.; Hellinga, C. ShowHow: A Flexible, Structured Approach to Commit University Stakeholders to Sustainable Development. In *Handbook of Theory and Practice of Sustainable Development in Higher Education*; Leal Filho, W., Azeiteiro, U.M., Alves, F., Molthan-Hill, P., Eds.; Springer International Publishing: Cham, Switzerland, 2017; pp. 491–508, ISBN 978-3-319-47876-0.
11. Wissenschaftlicher Beirat Globale Umweltveränderungen. *Welt im Wandel: Gesellschaftsvertrag für eine Große Transformation. Hauptgutachten*; 2., veränd. Aufl.; Wiss. Beirat der Bundesregierung Globale Umweltveränderungen (WBGU): Berlin, Germany, 2011; ISBN 978-3-936191-38-7.
12. Yarime, M.; Trencher, G.; Mino, T.; Scholz, R.W.; Olsson, L.; Ness, B.; Frantzeskaki, N.; Rotmans, J. Establishing sustainability science in higher education institutions: Towards an integration of academic development, institutionalization, and stakeholder collaborations. *Sustain. Sci.* **2012**, *7*, 101–113. [CrossRef]
13. Sustainability at Higher Education Institutions: Develop–Network-Report (HOCH-N). Available online: https://www.hochn.uni-hamburg.de/en.html (accessed on 25 November 2018).
14. Bassen, A.; Schmitt, C.T.; Stecker, C. Nachhaltigkeit an Hochschulen: Entwickeln–vernetzen–berichten (HOCHN). *uwf UmweltWirtschaftsForum* **2017**, *25*, 139–146. [CrossRef]
15. Lang, D.J.; Wiek, A. The role of universities in fostering urban and regional sustainability. In *Institutional and Social Innovation for Sustainable Urban Development*, 1st ed.; Mieg, H.A., Töpfer, K., Eds.; Earthscan: London, UK, 2013; pp. 393–411, ISBN 978-1138780552.

16. Stauffacher, M.; Flüeler, T.; Krütli, P.; Scholz, R.W. Analytic and Dynamic Approach to Collaboration: A Transdisciplinary Case Study on Sustainable Landscape Development in a Swiss Prealpine Region. *Syst. Pract. Action Res.* **2008**, *21*, 409–422. [CrossRef]
17. Borgatti, S.P.; Foster, P.C. The Network Paradigm in Organizational Research: A Review and Typology. *J. Manag.* **2003**, *29*, 991–1013. [CrossRef]
18. Rincón-Gallardo, S.; Fullan, M. Essential features of effective networks in education. *J. Prof. Capital Commun.* **2016**, *1*, 5–22. [CrossRef]
19. Sliwka, A. *Networks of Innovation: Towards New Models for Managing Schools and Systems*; Schooling for tomorrow (Project); Organisation for Economic Co-operation and Development, Centre for Educational Research and Innovation, Ed.; Organisation for Economic Co-operation and Development: Paris, France, 2003; pp. 49–63, ISBN 978-92-64-10034-3. Available online: https://www.oecd.org/site/schoolingfortomorrowknowledgebase/themes/innovation/41283632.pdf (accessed on 15 October 2018).
20. Verburg, R.M.; Andriessen, E.H. A typology of knowledge sharing networks in practice. *Knowl. Process Manag.* **2011**, *18*, 33–44. [CrossRef]
21. International Association of Universities. Vision, Mission, Governance Structure, Annual Reports. Available online: https://www.iau-aiu.net/# (accessed on 25 November 2018).
22. Association of African Universities. Vision, Mission, Our Strategic Goals, Our Strategy, Our Objectives. Available online: https://www.aau.org/about/ (accessed on 25 November 2018).
23. Global University Network for Innovation. Background, Mission and objectives, Executive Committee. Available online: http://www.guninetwork.org/presentation (accessed on 25 November 2018).
24. International Sustainable Campus Network. Organizational Structure, Purpose, Leadership. Available online: https://www.international-sustainable-campus-network.org/about/overview (accessed on 6 December 2018).
25. University Alliance for Sustainability. Available online: https//www.fu-berin.de/en/sites/uas/index.html (accessed on 25 November 2018).
26. Sabharwal, M.; Varma, R. Transnational Research Collaboration: Expatriate Indian Faculty in the United States Connecting with Peers in India. *East Asian Sci. Technol. Soc.* **2015**, *9*, 275–293. [CrossRef]
27. Coccia, M.; Wang, L. Evolution and convergence of the patterns of international scientific collaboration. *Proc. Natl Acad. Sci. USA* **2016**, *113*, 2057–2061. [CrossRef] [PubMed]
28. Caniglia, G.; John, B.; Bellina, L.; Lang, D.J.; Wiek, A.; Cohmer, S.; Laubichler, M.D. The glocal curriculum: A model for transnational collaboration in higher education for sustainable development. *J. Clean. Prod.* **2018**, *171*, 368–376. [CrossRef]
29. Sutrisno, A.; Hitendra, P. Knowledge transfer through a transnational program partnership between Indonesian and Australian universities. *Asia Pac. Educ. Rev.* **2015**, *16*, 379–388. [CrossRef]
30. Flick, U. *Triangulation. Eine Einführung*, 1st ed.; VS. Verlag für Sozialwissenschaften: Wiesbaden, Germany, 2004; pp. 27–48, ISBN 978-3531156668.
31. Boell, S.K.; Cecez-Kecmanovic, D. Are systematic reviews better, less biased and of higher quality? *European Conference on Information Systems*. 2011. (ECIS 2011), Paper 223. Available online: https://aisel.aisnet.org/ecis2011/223/ (accessed on 21 November 2018).
32. Gehanno, J.-F.; Rollin, L.; Darmoni, S. Is the coverage of google scholar enough tob e used alone for systematic reviews. *BMC Med. Inf. Decis. Mak.* **2013**, *13*, 7. [CrossRef]
33. Martín-Martín, A.; Orduna-Malea, E.; López-Cózar, E.D. Coverage of highly-cited documents in Google Scholar, Web of Science, and Scopus: A multidisciplinary comparison. *Scientometrics* **2018**, *116*, 2175–2188. [CrossRef]
34. Mayring, P. *Qualitative Inhaltsanalyse: Grundlagen und Techniken*, 11th ed.; Weinheim and Basel: Beltz Verlag, Germany, 2010; pp. 48–66, ISBN 978-3-407-25533-4.
35. Corcoran, P.B.; Walker, K.E.; Wals, A.E.J. Case studies, make your case studies, and case stories: A critique of case study methodology in sustainability in higher education. *Environ. Educ. Res.* **2004**, *10*, 7–21. [CrossRef]
36. Gerring, J. *Case Study Research: Principles and Practices*; Cambridge University Press: Cambridge, UK, 2007; pp. 15–37, ISBN 9780521859288.
37. Yin, R.K. *Case Study Research: Design and Methods*, 3rd ed.; SAGE: Newcastle Upon Tyne, UK, 2003; pp. 1–116, ISBN 9780761925521.

38. Getha-Taylor, H.; Silvia, C.; Simmerman, S. Individuality, Integrity: Leadership Styles in Team Collaboration. *Public Manag.* **2014**, *43*, 38–43.
39. Global Action Programme on Education for Sustainable Development. Available online: https://en.unesco.org/gap (accessed on 22 October 2018).
40. Kahle, J.; Jahn, S.; Lang, D.J.; Vogt, M.; Weber, C.F.; Lütke-Spatz, L.; Winkler, J. *Nachhaltigkeit in der Hochschulforschung (Beta-Version). BMBF-Projekt "Nachhaltigkeit an Hochschulen: Entwickeln-berichten-vernetzen (HOCH-N)"*. Lüneburg/Munich, Germany. 2018. Available online: https://www.hochn.uni-hamburg.de/-downloads/handlungsfelder/forschung/hoch-n-leitfaden-nachhaltigkeit-in-der-hochschulforschung.pdf (accessed on 06 December 2018).
41. International Alliance of Research Universities (IARU). *Green Guide for Universities*; SUSTAINIA: Copenhagen, Danmark, 2014; pp. 6–139, ISBN 978-87-93038-21-9. Available online: http://www.iaruni.org/images/stories/Sustainability/IARU_Green_Guide_for_Universities_2014.pdf (accessed on 06 December 2018).

sustainability

MDPI

Article

Transferring Sustainability Solutions across Contexts through City–University Partnerships

Lauren Withycombe Keeler [1,2,*], Fletcher D. Beaudoin [3], Amy M. Lerner [4], Beatrice John [2], Richard Beecroft [2,5], Kaidi Tamm [5], Arnim Wiek [2,6] and Daniel J. Lang [2]

1 School for the Future of Innovation in Society, Arizona State University, Tempe, AZ 85281, USA
2 Faculty of Sustainability, Leuphana University of Lüneburg, D-21335 Lüneburg, Germany; beatrice.john@leuphana.de (B.J.); richard.beecroft@kit.edu (R.B.); Arnim.Wiek@asu.edu (A.W.); Daniel.lang@leuphana.de (D.J.L.)
3 Institute for Sustainable Solutions, Portland State University, Portland, OR 97201, USA; beaudoin@pdx.edu
4 Laboratorio Nacional de Ciencias de la Sostenibilidad, Instituto de Ecología, Universidad Nacional Autónoma de México, Ciudad de México 04510, CDMX, México; amy.lerner@iecologia.unam.mx
5 Institute for Technology Assessment and Systems Analysis, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany; kaidi.tamm@kit.edu
6 School of Sustainability, Arizona State University, Tempe, AZ 85281, USA
* Correspondence: lauren.withycombe@asu.edu

Received: 15 June 2018; Accepted: 20 August 2018; Published: 21 August 2018

Abstract: The urgency of climate change and other sustainability challenges makes transferring and scaling solutions between cities a necessity. However, solutions are deeply contextual. To accelerate solution efforts, there is a need to understand how context shapes the development of solutions. Universities are well positioned to work with cities on transferring solutions from and to other cities. This paper analyses five case studies of city–university partnerships in three countries on transferring solutions. Our analysis suggests that understanding the interest, the action on sustainability, and the individual and collective sustainability competences on the part of the city administration and the university can help facilitate the transfer of sustainability solutions across contexts. We conclude that the nature of the city–university partnership is essential to solution transfer and that new and existing networks can be used to accelerate progress on the 2030 United Nations Sustainable Development Goals.

Keywords: sustainability; cities; universities; city–university partnerships; sustainability solutions; capacity-building

1. Introduction

While only one of the seventeen United Nations Sustainable Development Goals (SDGs) explicitly focuses on cities, the need for urban sustainability transformation underpins many of the other goals [1]. Municipal governments through their civic mandates and their long-term planning perspectives are the primary institutions capable of addressing climate change impacts, decarbonizing transit systems, transitioning to renewable energy, ensuring food access, and building more resilient and sustainable communities for their inhabitants and visitors [2]. While the focus of this paper and the case studies described is on cities, action by cities governments can have important implications for regions, the structure and function of which are central to SDGs. The complex and uncertain nature of current and future sustainability challenges and the transitions they require can be at odds with the organizational logic of municipal structures and often require novel funding and planning mechanisms to be effectively addressed [3]. To meet the SDGs by 2030, city administrations need to better utilize their existing assets and build their capacity for transformation, and part of that capacity building involves learning from other cities which have undergone similar transformations.

This paper explores the role of city–university partnerships (CUPs) in overcoming some of cities' challenges in addressing the problems of sustainability and resilience they experience. Universities with sustainability expertise can be strong partners for cities interested in and incumbent to implement sustainability measures [4,5]. CUPs are increasingly common in sustainability science and practice and represent a new functional paradigm for both partners [6,7]. Through CUPs, university actors and city administrations produce scientific and action-oriented knowledge that contribute to addressing local sustainability challenges. Networks of universities and CUPs can facilitate the transfer of novel solutions to other locales [8]. However, context does matter. Universities and cities alike are unique in their composition, competence, and enthusiasm relative to engaging in sustainability problem-solving. We hypothesize that key contextual factors exist across CUPs that, when understood, provide guidance for the transfer of sustainability solutions between CUPs with different cultures, geographies, and demographics. To test this hypothesis, this paper inductively analyzes five sustainability-oriented CUPs in three countries. However, in advance of the case study analysis, the paper expands on the new role of the university implicated by CUPs and how such partnerships can help universities deliver on promises to generate social good.

Universities have traditionally been seen as producers of knowledge that is taken up by civil society through formal and informal means of knowledge transfer. However, academia, and specifically the scientific community, have been charged with a "new social contract" that urges science to tend to the most urgent problems and generate knowledge to inform action [9]. Trencher and colleagues [10] describe a complimentary shift, the augmenting of the university function beyond societally relevant research to include knowledge co-production for sustainability with other societal actors that directly attempts to transform specific geographic areas or sectors. Crow and Dabars [11] write about the New American University which, similar to the global trend, recasts American, public research universities as fundamentally responsible for the thriving of the communities in which they are embedded and, as a result of this responsibility, to generating knowledge that can address societal challenges writ-large. In the 21st century, many universities are seeking to go beyond consultation and embed themselves in their communities and co-produce transformational knowledge for sustainability [12].

The paradigm of the embedded university developed alongside and helped support sustainability science as an academic discipline with constituent research, educational, and outreach mandates. Throughout the world there are university departments, centers, and degree-granting programs oriented towards sustainability, where students and faculties take on more active roles in applied research, capacity building, and communication of knowledge to the public [13,14]. Societal actors, too, are reframed from passive recipients of knowledge to knowledge creators and essential partners in an educational and research agenda capable of leveraging many forms of knowledge in service of better, more sustainable futures. Sustainability science is situated in this paradigm and under this new social contract between science and society in which societal values shape the scientific agenda and science provides knowledge of use to society, often through co-production [15], and in strong alignment with the 21st century university.

New institutional settings, such as (urban) transition labs, real-world labs, and science shops, are on the rise [16–19]. These partnerships, spaces, and methodologies facilitate transdisciplinary sustainability science while providing sustained support to solutions research and allowing for the integration of knowledge from diverse cases over longer periods of time. The smart city movement has also viewed cities as test beds for smart technologies [20,21]. New research seeks to integrate smart and sustainable cities concepts and urban labs have been developed that utilize smart technologies in the service of sustainability objectives [7,22]. To close the gap between knowledge generated in the lab and the knowledge necessary for action in the real-world, these "living labs", "transition labs" or "real-world labs" are developed at the university–city interface [2,17,23]. These collaborations between universities, cities, and sometimes corporate or non-profit partners allow researchers to study the features and functions of sustainability-relevant systems in real-world settings and monitor their impact. These types of transformative planning and research approaches have been identified as central to integrating and transforming both science and public policy to achieve the SDGs [24].

Partnerships between cities and universities challenge researchers to engage deeply with local context in order for their work to contribute to sustainability. For the SDGs, this means utilizing scientific methods to understand what moves cities and regions closer to achieving the goals, rather than detailing how sustainability problems manifest. However, a focus on local barriers and success factors can limit the generalizability of insights produced through these partnerships. Sustainability science has been prolific in generating theories of urban system functioning, transitions, and transformations but has struggled to achieve the vision of a transformational science that inspired its establishment [25]. Achieving this vision is central to delivering on the SDGs. As the university–city interface becomes crowded with labs and shops and partnerships, clarity is needed on what actually creates sustainability outcomes. Additionally, to accelerate progress on sustainability challenges, universities and cities need to learn from others, rather than unnecessarily repeat the mistakes of their peers.

In this research, we hypothesize that key contextual factors exist across CUPs that, when understood, provide guidance for the transfer of sustainability solutions between CUPs with different cultures, geographies, and demographics. This transfer of solutions can accelerate progress on sustainability and create the empirical link between the locally-embedded research university and its global impacts [8,26]. To test this hypothesis, this paper inductively analyzes five sustainability-oriented CUPs in three countries. The five case studies are part of the CapaCities project, a network of CUPs funded by the Global Consortium for Sustainability Outcomes (GCSO) (sustainabilityoutcomes.org) to (i) build capacity for transformational sustainability action in city administrations; and, (ii) transfer and scale insights across different cities and universities. In analyzing the partnerships and their distinct efforts at sustainability capacity building we derive a framework for understanding CUPs that transcends context. We demonstrate how the framework facilitated the transfer of insights across CUPs within the CapaCities network and provide recommendations for other universities and cities interested in establishing such partnerships for sustainability.

2. Materials and Methods

To analyze the city–university partnerships (CUPs), the CapaCities project team conducted two focus groups. These focus groups, held at the midpoint and endpoint of the year-long collaboration, included university researchers who presented their research along with relevant contextual information. Input from researchers followed the framework developed by Keeler and colleagues (2016) [8] and included a presentation and accompanying table to facilitate synthesis and comparability of insights. Tables 1 and 2 are an abbreviated version of that table.

Five case studies of CUPs for sustainability are described below. As a part of the focus group, each university partner was asked to give a summary of the actors involved in the project, the project goals, project process, their concept of sustainability capacity building, and the broader context for their work (e.g., cultural, political, and geographic factors). Each partnership was focused on its own sustainability problem and had developed a capacity building-focused solution, several of which included stakeholder engagement workshops and one that included a sustainability walk, in response to the problem at hand and the nature of the partnership. Tables 1 and 2 summarize each CUP involved in the GCSO collaboration and the embedded sustainability capacity-building research that was undertaken in year 1 of the CapaCities collaboration.

Table 1. Summary of city–university partnerships to build sustainability capacity: Arizona State University and Tempe, Karlsruhe Institute of Technology and Karlsruhe, and National Autonomous University of Mexico and Mexico City.

	Arizona State University—Tempe	**Karlsruhe Institute of Technology—Karlsruhe**	**National Autonomous University of Mexico—Mexico City**
Actor Summary	City of Tempe administration, senior department heads from all departments, sustainability manager	4 city bureaus of Karlsruhe, 1 Consortium for Sustainability Outcomes (CSO), KIT students and 3 units of KIT, 1 master student as accompanying research.	Resilience Agency (new official govt. office) in the Environment Secretariat of Mexico City; others at local (borough) scale and across other sectors of the city; NGOs
Goals	• Increase sustainability literacy among senior city officials. • Increase sustainability competence among senior city officials. • Identify goals for sustainability in Tempe among city administration. • Identify actions that support sustainability goals that have support among the administration. • Identify key partners in the administration for actions.	• Support inter-bureau discourse on sustainability and cooperation with external partners. • Foster a broader understanding of sustainability. • Make sustainability more visible in the KIT and the City of Karlsruhe. • Contribute to long-term cooperation city-KIT.	• Assisting in capacity-building in themes related to resilience for a greater implementation of the Resilience Strategy of Mexico City, with a focus in one case-study where there is a planning process occurring for better management of the area (Xochimilco). • Capacity-building includes system, futures, & collaborative thinking. • Assisting the creation & implementation of a Reconstruction Plan after the September 19 earthquake in the local case-study.
Project Process	1. Consult with sustainability manager, co-define objectives; 2. Design workshop; 3. Test workshop design; 4. Develop and deploy pre-work (discussing sustainability competencies); 5. Conduct workshop; 6. Analyze results; 7. Prepare and disseminate report; 8. Repeat.	1. Prepare in consultation with city bureaus; 2. Design and develop in a transdisciplinary project course; 3. Adjust and implement with CSO partner and in the real-world lab context; 4. Public disclosure and reflection.	1. Project facilitated three workshops to assist in the implementation of the Resilience Strategy for Mexico City (launched Sept 2016); 2. The National Laboratory for Sustainability Science (LANCIS-IE), UNAM, has a strong relationship with the Resilience Agency and is an associate of the Strategy but had not facilitated activities yet.

Table 2. Summary of City University Partnerships to build sustainability capacity: Leuphana University and Lüneburg and Portland State University and Portland.

	Leuphana—Lüneburg	**Portland State University—Portland**
Actor Summary	City Sustainability Manager; individuals from 4 city departments; a variety of local actors (businesses, community groups, associations), local press	4 different bureaus working on asset management within the city. ~6 other bureaus that support asset management activities and coordination.
Goals	• City-wide visioning exercise for the year 2030, facilitating conversations on the local interpretation of Sustainable Development Goals. • Cross-departmental conversation on feasibility and adaptability of good practices.	• Increasing inter-bureau conversations/understanding related to asset interdependencies under climate change and seismic scenarios. • Empowering and activating individuals within those bureaus to collaborate together on cross-bureau planning and investments.
Project Process	1. Project is city-led and funding by the German Federal Ministry of Education and Research secured by the city administration; 2. City drew on a long-standing collaboration of many research projects between university and city; 3. Conduct visioning exercise with ~200 citizens and 700 undergraduate students; 4. Analyze city activities, analyze best practices, actor analysis; 5. Five workshops for five core topics evaluating feasibility of best practices, challenges, conditions, and resources; 6. With results select actions and design urban lab and experiments within the city.	1. Project conceived out of cross-bureau asset managers group; 2. Group lacked time to engage, a point person to run it and resources to support engagement of other bureaus; 3. First meeting brought together 25 actors across 8 bureaus and helped frame the concept and rationale for future workshops; 4. Conduct 15+ interviews with bureaus to gather perspectives and values; 5. Conduct two workshops, on cross bureau dialogue and planning on climate resilience, and on seismic resilience; 6. Present information to all bureau directors, summary report with opportunities for building capacity; 7. Establish disaster resiliency advisory group.

2.1. Leuphana University of Lüneburg and Lüneburg, Germany

The city of Lüneburg and Leuphana University of Lüneburg (Faculty of Sustainability, Professorship for Transdisciplinary Sustainability Research, Lüneburg, Germany) are engaged in a project to realize the UN Sustainable Developing Goals on a local scale. Despite the long-standing partnership, this is so far the largest collective transdisciplinary backcasting approach undertaken within the city and includes a variety of actors at the science–society interface. The project addresses five core topics, namely (i) joint planning and decision making, (ii) facing climate change, (iii) joint economic collaboration, (iv) networking and provisioning, and (v) crafting city life. The layered organizational project structure leverages the specific resources and expertise from each partner and ensures ownership and commitment for the shared goal. The project steering committee consists of the sustainability manager of the city, the local newspaper, as well as representatives of the civil society and the research team. Topic specific field teams involve the research associates of the university, academic experts, selected city departments, and partners from civil society. Additionally, two field teams involve student research projects taking over the tasks of the research associates. The research team works in close proximity to the city departments from a shared office space. In the first phase the initial visioning process was dedicated to developing a shared vision for the city for the year 2030 and beyond, engaging in a dialogue about the Sustainable Development Goals and their meaning for the city of Lüneburg. During the second phase, intense preparation research by the university members included a series of interviews to evaluate the city's ongoing activities, and research to build a database of worldwide good practices. A series of workshops for each core topic aim to evaluate together with city departments, researchers, and members of local businesses and associations the feasibility and adaptability of best practice to Lüneburg. They also allow for cross-departmental conversations about challenges, institutional and legal conditions, as well as resources. The results inform directly the development of concrete actions to achieve the vision und are supposed to initiate urban labs to set up respective experiments.

2.2. Karlsruhe Institute of Technology and Karlsruhe, Germany

Karlsruhe is a city of about 300,000 inhabitants in the southwest of Germany, a wealthy region with different industries. The city government has developed—partly in a participatory process—priorities for its integrated city development plan which is structured mainly along the topics of the German national sustainability plan which specifies the sustainable development goals for Germany. Based on this, Karlsruhe was voted the most sustainable German city in 2015. Despite this deep rooting of sustainability in city planning, day-to-day city development lacks an integrated understanding of sustainability beyond ecological aspects, and the quality of cooperation between bureaus and with civil society organizations (CSOs) varies widely. Karlsruhe Institute of Technology (KIT) is a leading engineering university in Germany, known for energy research and data sciences. Sustainability studies, though well established, are not yet as visible.

This project was led by the Karlsruhe School of Sustainability, in cooperation with the Institute for Technology Assessment and Systems Analysis (ITAS) and embedded in the real-world lab "District Future–Urban Lab". It included partners from four city bureaus and one civil society partner. The aims were to (a) support inter-bureau discourse on sustainability and cooperation with external partners, (b) foster a broader understanding of sustainability beyond ecological standards, (c) make sustainability more visible in the profile of KIT both externally and internally, and (d) contribute to building a long-term cooperation between the city and KIT on sustainability issues.

The project has four phases: preparation, design and development, adjustment and implementation, and public disclosure and reflection. It established a sustainability walk in Karlsruhe, mainly through a transdisciplinary project course as phase 2. Teams of students co-developed the route, supported by researchers and external partners, to address abstract sustainability issues in a tangible, memorable way. Including city staff in this format is an unobtrusive capacity building process, nevertheless addressing different, interconnected urban sustainability challenges and offering recurring opportunities for engagement. The project has been successful in establishing a broad understanding of sustainability and in strengthening cooperation between KIT and the city, while supporting inter-bureau discourse has been a moderate success. Enhancing visibility of sustainability within and beyond KIT is part of a larger goal for the project, as faculty and students from KIT seek to establish long-term, sustainability-focused collaborations with the city government.

2.3. National Autonomous University of Mexico (UNAM) and Mexico City, Mexico

The goal of the National Laboratory of Sustainability Science in the Institute of Ecology of UNAM (LANCIS-IE) is to conduct transdisciplinary research and facilitate sustainability education to link science and decision-making which can lead to sustainability transitions in the country. This capacity-building project links LANCIS-IE UNAM to the Mexico City government, specifically the newly formed Resilience Agency which has emerged from Mexico City's participation in the Rockefeller Foundation's 100 Resilient Cities initiative. The purpose of the capacity-building is to train Mexico City government employees in implementation capacity, to execute the new Resilience Strategy for the city. Specifically, the Strategy calls for targeted resilience and sustainability planning for Xochimilco, one of the 16 boroughs (*delegaciones*) in the city which contains the last remaining wetland of the city (a current UNESCO World Heritage Site), and one of the epicenters of urban sprawl, often informal. The capacity-building focuses on government officials working at various scales and sectors in Xochimilco and, at the same time, assists in the planning process. The city actors most involved in the Resilience Strategy come from the Secretary of Urban Development and Planning, the Secretary of Environment, the Environmental and Regional Planning Attorney General's Office, the Commission of Water for Mexico City, and other local offices at the city and borough level. UNAM is the largest and one of the most well-respected universities in Mexico, which means that it has a high level of authority in providing information.

Competence-levels within the city government are generally quite low, reflecting the education system and party-politics of Mexico City (the party in government is more important than the capacities that they employ). City and borough governments rotate every 3–4 years which means that many of the employees are rehired with the change of governments, making long-term planning difficult. Despite these challenges, the current mayor positioned Mexico City in the 100 Resilience Cities consortium and signed his support of the Resilience Strategy, which was launched in September 2016. UNAM has a new graduate program in Sustainability Science, LANCIS-IE, and a research Institute in Ecosystems and Sustainability, reflecting an overall university interest in sustainability. However, there are many barriers to interdisciplinary, transdisciplinary, and applied work as well as initiatives that do not result in publications, such as capacity-building and the facilitation of sustainability planning in the public sector.

2.4. Portland State University and Portland, Oregon

The project focuses on capacity building for infrastructure management bureaus in the city of Portland to execute collective planning and implementation efforts related to seismic and climate resilience. The work is being driven by the Institute for Sustainable Solutions (ISS) at Portland State University—a cross-university hub for fostering effective collaborations between partners in the community, and students and faculty at the university. Currently there is significant activity and planning that takes place within the individual bureaus related to resiliency, however, these planning efforts tend to be siloed and not fully connected to the opportunities and constraints that the other asset management bureaus face. This first phase of the project looked broadly at the bureaus that are working on resiliency, which occurred through a series of in-person surveys. The second phase was to host two workshops with teams from each of the infrastructure bureaus. These workshops focused on facilitating conversations and joint work across the bureaus as it relates to opportunities and challenges for seismic and climate resiliency. The workshops raise a series of opportunities for cross-bureau investments and planning as well as specific guidance catalyzing and growing cross-bureau collaboration and planning on resiliency. ISS has provided convening expertise as well as time and expertise from students and faculty to help execute the interviews and preparatory work. When the effort began there was a small group of individuals from different bureaus interested in advancing cross-bureau collaboration on resiliency planning and implementation. Meaning that in this first phase the role of the university was closely focused on helping provide this group with support to crystalize a vision for the project and launch the idea. The workshops have created specific opportunities that can be acted on in future iterations of this project, which will provide opportunities to leverage other capacities and expertise at the university, such as faculty research, internships, and applied courses.

2.5. Arizona State University and Tempe, Arizona

The Arizona State University—the city of Tempe project focuses on building sustainability literacy among city staff, developing a common language with which to discuss sustainability problems and solutions, defining sustainability goals for the city and inventorying actions the city can and would like to take to achieve those goals. At Arizona State University, the primary partners were the School for the Future of Innovation in Society and the School of Sustainability The collaboration took the form of three workshops, which used games to help build capacity for sustainability ways of thinking. Participants were all department heads and project leaders with sustainability foci within the city administration. In the first workshop, participants played a collaborative game called Future Shocks and City Resilience [27] in which teams worked together to address chronic city issues and achieve strategic priorities while responding to an unexpected social or environmental shock. The game introduces sustainability ways of thinking and common sustainability vocabulary to participants and helps build a culture of sustainability. In the second workshop, participants played a collaborative role-playing game, AudaCITY, in which they reconstructed a strategy that was able to transform their city into a model of sustainability. The game teaches players about the impact of achieving sustainability goals on the urban environment and people's lives and introduces players to the kinds of actions available and necessary to make sustainability transformation a reality. In the third workshop, a group of students in a global sustainability research course at ASU adapted AudaCITY for use in developing a sustainable food economy for Tempe, a theme that emerged from the second workshop. The third workshop included city and non-city actors and workshopped transferring local food economy solutions from other parts of the world. The capacity building in the three workshops served as the internal educational foundation for the city's first Climate Action Plan, which is due to be completed in 2019.

3. Results: Transferring Sustainability Solutions across Contexts

Analysis of the focus groups centered on the question of how these partnerships can learn one from one another. The first focus group began with extensive sharing of demographic, historical. and geographic information on the cities. While interesting, these factors proved less relevant for understanding how solutions could be transferred between partners. Through dialogue followed by inductive analysis of the cities and the universities involved in each CUP and the rationale informing the structure of each partnership, the CapaCities team produced an inductive framework for specifying key contextual factors when attempting to transfer solutions between partners. Tables 3 and 4 demonstrate how the framework was applied to the CapaCities CUPs. Following the development of the framework and the application to the case studies, we demonstrate how conclusions about structuring sustainability solution interventions can be informed by the framework.

Table 3. Assessment of key contextual factors for Arizona State University and Tempe, Karlsruhe Institute of Technology and Karlsruhe and National Autonomous University of Mexico and Mexico City.

	Arizona State University—Tempe	**Karlsruhe Institute of Technology—Karlsruhe**	**National Autonomous University of Mexico—Mexico City**
City Interest	Strong interest among key staff, support from leadership.	Moderate interest in sustainability, interest in the CUP starting low, growing over the project.	Strong interest at the city level (Resilience Agency) and at the local level, also internationally because the local case, Xochimilco, is internationally recognized (UNESCO, RAMSAR).
City Individual Capacity	Key individuals with high sustainability competence. High domain-specific expertise related to sustainability (e.g., water, public works).	High to low, depending on bureaus.	Generally low across departments at the city and borough level.
City Collective Capacity	Low though the strategic management office is implementing a cross-department effort to build strategic competence.	Medium (established procedures covering minimum standards, low cooperation on further-reaching plans).	Low collaborative competence, little conversation across sectors and often between scales.
City Action	Low—the commitment to sustainability at the city is relatively new.	Concentrated in one department with strong ecological focus Integrated city development plan addresses several sustainability issues.	Little coordinated formal action, a lot of informal decentralized action (both in conservation and in informal urbanization and other threats).
University Interest	High, university has an explicit commitment to sustainability and to community-benefitting research.	Moderate, the university has a profile focusing on basic research in engineering and data sciences, sustainability is often reduced to eco-efficiency Institute for Technology Assessment and Systems Analysis is nevertheless a major research institute for sustainability science.	Moderate, university has supported the creation of a new graduate program in Sustainability Science and National Laboratory in Sustainability Science.
University Individual Competence	High, there are a number of individuals with high sustainability competence across a range of domains at the university.	High, but with low visibility for the city.	Low to high, new graduate program in Sustainability Science, a National Laboratory for Sustainability Science, and research institute for Ecosystems and Sustainability. University is extremely large, competence varies.
University Collective Competence	High, the university supports sustainability, has a school of sustainability, and considers it core to its mission.	High in ITAS and some other institutes, otherwise limited to technological aspects.	Moderate, there are generally high barriers for interdisciplinarity and traditional evaluation measures (articles and impact factor) that can deter inter and transdisciplinary work.

Table 3. *Cont.*

	Arizona State University—Tempe	Karlsruhe Institute of Technology—Karlsruhe	National Autonomous University of Mexico—Mexico City
University Action	High, the university is a testbed for sustainability and supports solution-oriented sustainability research.	Moderate, study programs on sustainability, campus transformation measures and research receive praise but insufficient funding. The real-world lab is being developed to a center for transformative science.	Moderate, there are individual or small-group initiatives that have not reached university-wide implementation.

Table 4. Assessment of key contextual factors for Leuphana University and Lüneburg, and Portland State University and Portland.

	Leuphana University—Lüneburg	Portland State University—Portland
City Interest	Moderate continuous interest, awareness and understanding	Strong interest in more inter-bureau conversations in this space, but lacking the resources and leadership to make it pervasive
City Individual Capacity	High to low competence of individuals within some departments in the city administration	High to low (high with some bureaus (water and environmental services) low with others (like parks)
City Collective Capacity	Moderate collaborative competence in form of networking, and shared understanding	Low (some conversations across bureaus, very little joint planning)
City Action	Little consistent, integrated, comprehensive actions across all departments Continuous actions in specific core topics High coordinated frequency of actions of partners in the community	Little action that effectively integrates across the bureaus; but significant action from individual bureaus on climate and seismic planning
University Interest	High, sustainable development and social responsibility is integrated into the university-wide strategy	High, the university has built up considerable expertise in sustainability research and education and also has the motto "let knowledge serve the city" which speaks to the university's strategic alliance with the city
University Individual Competence	High, sustainability manager at the administrative level, numerous individuals engage in sustainability topics in teaching and research across faculties	High, centered within the Institute for Sustainable Solutions, that connections to over 140 faculty fellows working on sustainability and 350+ student fellows
University Collective Competence	High, project placed within the Faculty of Sustainability; direct support of 2 sustainability science project seminar	High, the university has a coordinating unit for sustainability research and education, and 150 sustainability fellows and over 400 student fellows
University Action	High, the university fosters sustainability action and student associations and supports sustainability research and study programs	High, the university continues to invest significant resources into sustainability research and education efforts

3.1. Key Contextual Factors for Transferring Insights across CUPs

In exchanging knowledge as a part of the CapaCities project, the CUPs identified four key, contextual factors that once understood, facilitated the transfer of insights and solutions between very distinct universities in very different cities, these include: interest in sustainability, individual and collective sustainability competence, and action on sustainability. Interest refers to a university or city's expressed attention to and concern for issues related to sustainability. Individual competence is the sustainability knowledge, skills, and attitudes possessed by an individual in an organization [14]. For sustainability solutions, individual competence refers to the knowledge and skills to design, test, and implement sustainability solutions of researchers or city staff that are engaging in or could be engaged in the partnership [6]. This is differentiated from collective competence which is defined as the knowledge and skills possessed writ-large in an organization to implement sustainability. As sustainability efforts in cities often involve many different departments (e.g., parks, transportation) and many different focal areas (e.g., food, water, energy) understanding the collective sustainability competence of the organization is key to designing interventions that can be feasibly executed. Similarly, some universities have individual experts in aspects of sustainability who can partner with city governments while others have sustainability departments or degree programs that offer a breadth of sustainability expertise. It is critical to understand the relationship between individual and collective sustainability competence in both cities and universities to understand how a partnership can be developed and be effective at increasing the quantity and quality of sustainability actions in a city. Finally, it is critical to understand what kind of sustainability *action* cities and universities have already been engaged in. Previous actions can act as pathways for future action (e.g., a green bond worked for updating water infrastructure let us try it for a light rail extension) but can also create path dependence with which new solutions will need to contend. Table 5 expands on the framework above, including guiding questions to analyze the individual and collective sustainability competence, interest, and actions of universities and cities interested in partnering.

The framework presented above and exemplified through the case studies below provides foundational questions for assessing partnership opportunities and potential sustainability solutions. This assessment begins by looking at key contextual factors on both sides of the partnership, understanding their history of working on sustainability, their capability to support effective partnerships, and their interest in collaboration. Understanding the collaborative history of working on sustainability issues helps ensure that the solutions chosen, in these cases—how sustainability capacity is built—can be executed by the university and fit the needs of the city. The assessment of the contextual factors for each case study are summarized in Table 3.

Table 5. Framework for identifying contextual factors in CUPs for sustainability.

Key Factor	Definition	Guiding Questions for University	Guiding Questions for City Government
Interest	The attention and concern for sustainability exhibited by individuals or an organization.	Has the university or its researchers expressed a commitment to sustainability research, teaching and/or community engagement?	Does the city have dedicated personnel working on sustainability issues? What kinds of commitments toward sustainability has the city made (e.g., plans, policies, projects)?
Individual Competence *	The sustainability knowledge, skills, and attitudes exhibited by individuals.	Does the university have individuals with key sustainability competencies	Does the city have individuals with key sustainability competencies?
Collective Competence *	The sustainability knowledge, skills, and attitudes possessed by an organization.	Does the university have a sustainability department or other dedicated unit/institute? Does the university have individuals with a range of sustainability competencies?	Does the city government have staff with a range of sustainability competencies?
Action	The sustainability actions taken by an organization.	Does the university have individual researchers who are currently engaged in sustainability science research with local actors (e.g., city government)? Does the university support embedded, action-oriented sustainability research?	Has the city taken explicit action for sustainability? Does the city currently have sustainability plans, projects, and/or policies?

* Competence here references the key competencies framework identified by Wiek and colleagues (2011).

3.2. Assessment of Key Contextual Factors for Case Studies

In order to assess how universities and cities can function as partners in adopting and transferring sustainability solutions we describe the partnerships along each of the contextual factors and create CUP profiles based on combinations of factors. Profiles contain recommendations for transferring sustainability solutions developed by partnerships or cities with different profiles. These profiles are by no means comprehensive of the suite of CUPs that exist, but they are demonstrative of the way in which specifying the nature of the CUP can enable the transfer of sustainability solutions. The framework and profiles exemplified through the CapaCities CUPs demonstrate how contextual factors result in different design features for sustainability solutions research and different results in terms of sustainability plans, policies, and projects enacted. The discussion illustrates the framework aided transfer between CUPs and proposes how it can be utilized by other universities interested in establishing long-term sustainability partnerships with cities.

Arizona State University and City of Tempe have a strong partnership, particularly because of the mutually reinforcing interests and individual and collective competence. The city is interested in building capacity across the organization to implement sustainability and ASU has a faculty that is capable of designing and implementing such engagements and has an interest and institutional incentives to do so. While ASU has an established sustainability degree program, sustainability is a relatively new priority for the city government. In transferring solutions from other locales, this CUP should consider whether or not the solution requires collective capacity on behalf of the organization or a track record of sustainability action. If so, there may be need to have some intermediate steps, such as sustainability capacity building, and developing of pilot projects to boost sustainability action, to facilitate the transfer of solutions.

Portland State University and the City of Portland also have a strong partnership, with particular success in the reinforcing of sustainability actions. Portland State has the motto "Let Knowledge Serve the City" and has, over the last 10 years, established a robust partnership in the city that fulfills that call in the service of sustainability in the city. When transferring solutions to Portland, it is critical to consider whether the solution produces an outcome that has already been achieved within the city and whether or not there are, existing, in-city resources that could be leveraged to serve the goals. Complementarily, when adopting solutions from a city like Portland with an established, strong partnership it is critical to ask what activities preceded the solution and laid the foundation for its success.

Karlsruhe Institute of Technology and the City of Karlsruhe have a potential for partnership. Strengths including the high sustainability competence of the city and the university. However, the city does not recognize KIT as a strong partner for sustainability and Karlsruhe's track record of external recognition for their sustainability efforts may not incentivize engaging in collaborations with the university. When transferring solutions to this CUP it is essential to consider what kind of relationship building is necessary to establish a strong, long-term partnership and enable successful co-development of sustainability solutions—informed by efforts in other CUPs.

Leuphana University of Lüneburg and the City of Lüneburg have a strong partnership with complementary interests and competence. Continuously engaging the city in transdisciplinary student research projects over the last eight years and several externally funded research projects established a strong partnership. This engagement draws a lot on the collective competence of the university and individual competences in the City of Lüneburg. In order to move this CUP forward, several steps might be necessary, such as strengthening the collective capacity in the city by drawing on the availability of the faculty of sustainability or aligning collective action of the partnership in order to increase the number of coherent sustainability actions in the city.

UNAM (and especially LANCIS-IE) and Mexico City also have a strong partnership, in the sense that the university has a strong tradition and role in local and national issues and is generally highly respected. However, this role is not necessarily directed specifically towards sustainability and resilience efforts. There are also different priorities within the city from the local to the city level, which means that solutions must be co-produced and proposed with sensitivity given the different needs throughout the city. The university can assist in building alliances across sectors and actors with the Resilience Agency, and given its role, can even strengthen the agenda of the Resilience Agency. However, the Agency is only one office within a larger government, and there is still the challenge of engaging the broader city government at various scales.

Many of these partnerships begin with a catalytic activity that is important for building a working relationship and for both parties to better understand the culture of the other organization. In choosing a project, it is helpful to fit it into a larger framework of change. For example, Portland State has focused its partnership with the City's Bureau of Planning and Sustainability around the implementation of their Climate Action Plan—a 30-year vision for a low carbon and climate resilient city. This was chosen because it contains a wide and diverse set of projects that staff have the responsibility to implement, which helps ensure that projects have a strong and responsive partner (because the project is mission critical). The actions in the Climate Action Plan also line up well with expertise and interest of faculty and students at Portland State—ensuring that there is a supply of students and faculty to meet the demands coming from the city. Arizona State University and Tempe also have a partnership that includes students and is oriented toward generating a climate action plan. The partnership, though, is different and this informs how insights from Portland are transferred to ASU. ASU is a global leader in sustainability research and education and also has a strong desire to build meaningful and impactful partnerships. They have a partnership with the city of Tempe, which has limited experience with sustainability initiatives (when compared to other cities, such as Portland or Karlsruhe) and has some experience and interest in partnering with the University. In this case, ASU has the individual and collective competence and interest to take on more complex and advanced sustainability partnership activities, while the city may not yet be ready. Therefore, the focus is on capacity building to support the City of Tempe in understanding how climate action fits with the city's other strategic priorities, rather than on delivering the full breadth of expertise offered by ASU. In learning from PSU and the City of Portland, ASU–Tempe has been keen to adopt strategies from Portland that inform the process of creating a climate action plan rather than adopting the actions themselves. In contrast, Portland State University has high levels of capacity, interest, and expertise, and they are partnering with a city that also has high levels of interest, capacity and expertise. As a result, the partnership projects that are undertaken are more complex and oriented toward more ambitious sustainability goals than many other city–university pairs. For these two different cases, the framework helps clarify the context, constraints, and opportunities that face a partnership. This information can be used to quickly identify which approaches can be brought to or from another context, and which strategies would not be applicable. It is unlikely that a strategy can be directly transferred, meaning that some adaptations will need to be made to fit the unique context of the transfer site.

4. Discussion and Recommendations

The framework in this article can help support solution transfer from one city–university pair to another. We define transfer as a one-to-one relationship that enables an effective strategy from one place to be applied in another place/context. We find that the framework is a useful tool for continuous learning and improving efforts that occur between city–university cases and also within a specific case. Establishing a common language allows for different universities–city pairs to provide support to each other on sustainability solutions and approaches in a systematic way. In these projects, significant focus is placed on the capacity to be built within the city (such as supporting the development of a new plan or policy) and those outcomes are usually balanced by the outcomes on the university side (student experience, research, etc.). However, less focus has been placed on the capacity building at the university and the city for executing effective partnership work. From our specific analysis of these case studies we have several recommendations for other city university partnerships that wish to transfer insights from their peer institutions.

- First, if interest is high at the university but low at the city, focus on developing the key relationships with personnel in the city government while developing the university's own individual and collective competence. Focus on bridge building. Strategies include utilizing students as interns in the city who can perform essential functions and build relationships, demonstrating that the university can be a strong and consistent partner.
- Second, if interest is high but action is low (regardless of competence), the university can provide the city with a platform to discuss their work. The university may be able to help the city or people within the city elevate sustainability efforts, providing legitimacy.
- Third, if individual competence is high but collective competence is low at the university, there can be a focus on developing strong teams of students and conducting educational research activities, i.e., designing courses in which students conduct research on aspects of sustainability relevant for your city.
- Fourth, if competence is low at the university and low at the city but there is interest in sustainability action, university partnerships and networks can be leveraged to increase competence.
- Finally, if all features are high at both the university and the city and there is collaboration established, strike while the iron is hot. Seek to maintain stable collaboration, focus on building the resiliency of the partnership. Create redundancies in expertise and in relationships, overlap competencies and understandings about the partnerships, and establish a transparent flow of information where processes and results are documented in areas accessible to all partners. Provide expertise to other cities and universities to help them achieve their sustainability goals.

The importance of solution transfer between cities, as well as regions, is critical to accelerating progress on the SDGs because effective solution transfer can save time, financial resources, and political capital so that high impact, high value strategies can be pursued.

There are also a number of potential applications of the framework beyond solution transfer. First, the framework can be used to assist with partnership diagnosis and strategy development, continuous improvement and learning, strategy transfer, and strategy scaling. Second, it can be used to determine the solution-readiness the city, university, and the partnership by helping to identify where synergies and gaps exist in experience and competence. Third, it can serve as a guide for conversations about an overarching framework for a CUP to facilitate stable rather than episodic engagement [4,28]. Finally, the framework can serve as a common language that integrates across multiple cases of university–city partnerships for sustainability, amplifying the transfer of sustainability solutions.

The framework that was developed through our two focus groups and applied to the cases has a number of strengths as well as limitations that limit its generalizability. First, it was developed looking in depth at five case studies, but this analysis was primarily performed by the researchers, often with consultation from city partners. Research is ongoing to analyze the variance in partnership and project evaluation between city and university partners. Second, the framework did not examine the totality of relationships that each university has with each city nor did it focus on other important actors, such as those in civil society. For example, KIT has extensive partnerships ongoing with the City of Karlsruhe and civil society actors that are not directly related to sustainability, and this is true to varying degrees in each case. By focusing exclusively on sustainability-oriented CUPs, the framework may not account for some of the underlying political and partnership dynamics that shape how solutions are developed and partnerships are pursued. Third, each of the CUPs is focused on capacity building as a sustainability solution; so, there is a need to examine how the framework applies to other types of sustainability solutions. To this end, the recommendations in this paper have been fed back to the Global Consortium for Sustainability Outcomes to facilitate the transfer of insights across other CUPs working on different types of sustainability solutions. Monitoring the applicability of the framework in these cases is ongoing. Finally, these partnerships are explicitly focused on universities and city administrations and therefore do not address the critical relationships that both have with regions, which are a critical scale and point of intervention for making progress on the SDGs. The authors look forward to and invite opportunities to further test and refine this framework with other cases and in collaboration with city partners.

5. Conclusions

As cities and countries strive to meet the 2030 Sustainable Development Goals, there is a need to accelerate progress by sharing solutions. While geography, demographics, and politics are relevant for developing sustainability solutions, the CapaCities projects indicate that there are more important factors that, once understood, can facilitate the transfer of solutions between very different locales. City–university partnerships (CUPs) are increasing in their prevalence and intensifying their focus on sustainability transformation. Sustainability and partnership networks (e.g., National Adaptation Forum, the Urban Sustainability Directors Network, the Network of Programs in Sustainability, the Association for the Advancement of Sustainability in Higher Education, etc.) can help share sustainability solutions, accelerating progress by allowing cities and universities to learn from one another. To transfer solutions, it is critical to understand the interest, the previous action on sustainability, and the individual and collective competences that exist at both the university and the city level. While there are a number of important factors that have to be re-specified when solutions are transferred, how such an initiative is inspired, developed, and implemented, depends profoundly on the knowledge, skills, and attitudes of the people involved. Through the CapaCities project, we have found that understanding the partners and the partnership is key to this acceleration. It is through these relationships that we are able to learn from one another and make progress on sustainability.

Author Contributions: Conceptualization, L.W.K., F.D.B., A.M.L., B.J., R.B., K.T., D.J.L., and A.W.; Methodology, L.W.K., F.D.B., A.M.L., B.J., and R.B.; Formal Analysis, L.W.K., F.D.B., A.M.L., B.J., and R.B.; Writing-Original Draft Preparation, L.W.K., F.D.B., A.M.L., B.J., R.B.; Writing-Review & Editing, L.W.K., F.D.B., A.M.L., B.J., R.B., K.T., D.J.L., and A.W.

Funding: This research was funded by the Global Consortium for Sustainability Outcomes (sustainabilityoutcomes.org) in line with the research project "CapaCities".

Acknowledgments: The authors gratefully acknowledge funding from the Global Consortium for Sustainability Outcomes (sustainabilityoutcomes.org) for their support of solution-oriented sustainability science. The authors also acknowledge their city partners who are excellent collaborators and friends. The manuscript benefited from various discussions with Annika Weiser and Antje Seidel, particularly with regard to insights from the research project "City of the Future Lüneburg 2030+". Thank you to Lakshmi Charli-Joseph for assisting in the analysis for UNAM-Mexico.

Ethics Statement: The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Arizona State University (IRB ID: STUDY00007900) and adhered to the ethical guidelines established by Portland State University (pdx.edu/research/integrity/human-subjects/policy), Leuphana University Lüneburg (Ethics Committee Guidelines), the National Autonomous University of Mexico (https://consejo.unam.mx/static/documents/codigos/codigo-etica-unam.pdf), and Karlsruhe Institute of Technology (http://www.kit.edu/downloads/KIT_Ethische_Leitlinien.pdf).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Finnveden, G.; Gunnarsson-Östling, U. Sustainable development goals for cities. In *Connecting the Dots by Obstacles? Friction and Traction Ahead for the SRIA Urban Transitions Pathways*; Bylund, J., Ed.; JPI Urban Europe: Brussels, Belgium, 2017.
2. Nevens, F.; Frantzeskaki, N.; Gorissen, L.; Loorbach, D. Urban Transition Labs: Co-creating transformative action for sustainable cities. *J. Clean. Prod.* **2013**, *50*, 111–122. [CrossRef]
3. Saha, D.; Paterson, R.G. Local Government Efforts to Promote the "Three Es" of Sustainable Development. *J. Plan. Educ. Res.* **2008**, *28*, 21–37. [CrossRef]
4. Allen, J.H.; Beaudoin, F.; Gilden, B. Building Powerful Partnerships: Lessons from Portland's Climate Action Collaborative. *Sustain. J. Rec.* **2017**, *10*, 276–281. [CrossRef]
5. Whittaker, J.R.; Clark, J.K.; SanGiovannni, S.; Raja, S. Planning for Food Systems: Community-University Partnerships for Food-Systems Transformation. *Metrop. Univ.* **2017**, *28*, 7. [CrossRef]

6. Withycombe Keeler, L.; Beaudoin, F.; Wiek, A. *Building Transformative Capacity for Implementing Sustainability Solutions through City-University Partnerships*; Working Paper; Arizona State University: Tempe, AZ, USA, 2018.
7. Schäpke, N.; Bergmann, M.; Stelzer, F.; Lang, D.J. Guest Editors Labs in the Real World: Advancing Transdisciplinary Research and Sustainability Transformation: Mapping the Field and Emerging Lines of Inquiry. *GAIA-Ecol. Perspect. Sci. Soc.* **2018**, *27*, 8–11. [CrossRef]
8. Withycombe Keeler, L.; Wiek, A.; Lang, D.J.; Yokohari, M.; van Breda, J.; Olsson, L.; Ness, B.; Morato, J.; Segalàs, J.; Martens, P.; et al. Utilizing international networks for accelerating research and learning in transformational sustainability science. *Sustain. Sci.* **2016**, *11*, 749–762. [CrossRef]
9. Lubchenco, J. Entering the Century of the Environment: A New Social Contract for Science. *Science* **1998**, *279*, 491–497. [CrossRef]
10. Trencher, G.; Bai, X.; Evans, J.; McCormick, K.; Yarime, M. University partnerships for co-designing and co-producing urban sustainability. *Glob. Environ. Chang.* **2014**, *28*, 153–165. [CrossRef]
11. Crow, M.M.; Dabars, W.B. *Designing the New American University*; JHU: Baltimore, MD, USA, 2015.
12. Miller, T.R.; Wiek, A.; Sarewitz, D.; Robinson, J.; Olsson, L.; Kriebel, D.; Loorbach, D. The future of sustainability science: A solutions-oriented research agenda. *Sustain. Sci.* **2014**, *9*, 239–246. [CrossRef]
13. Trencher, G.; Yarime, M.; McCormick, K.B.; Doll, C.N.H.; Kraines, S.B. Beyond the third mission: Exploring the emerging university function of co-creation for sustainability. *Sci. Public Policy* **2014**, *41*, 151–179. [CrossRef]
14. Wiek, A.; Withycombe, L.; Redman, C.L. Key competencies in sustainability: A reference framework for academic program development. *Sustain. Sci.* **2011**, *6*, 203–218. [CrossRef]
15. Gibbons, M. Science's new social contract with society. *Nature* **1999**, *402*, 81–84. [CrossRef] [PubMed]
16. Schäpke, N.; Singer-Brodowski, M.; Stelzer, F.; Bergmann, M.; Lang, D.J. Creating Space for Change: Sustainability Transformations: The Case of Baden-Württemberg. *GAIA-Ecol. Perspect. Sci. Soc.* **2015**, *24*, 281–283. [CrossRef]
17. Voytenko, Y.; McCormick, K.; Evans, J.; Schliwa, G. Urban living labs for sustainability and low carbon cities in Europe: Towards a research agenda. *J. Clean. Prod.* **2016**, *123*, 45–54. [CrossRef]
18. Evans, J.; Karvonen, A. 'Give Me a Laboratory and I Will Lower Your Carbon Footprint!'—Urban Laboratories and the Governance of Low-Carbon Futures. *Int. J. Urban Reg. Res.* **2014**, *38*, 413–430. [CrossRef]
19. Savoia, A.; Lefebvre, B.; Millot, G.; Bocquet, B. The Science Shop Concept and its Implementation in a French University. *J. Innov. Econ.* **2017**, *22*, 97. [CrossRef]
20. Ahvenniemi, H.; Huovila, A.; Pinto-Seppä, I.; Airaksinen, M. What are the differences between sustainable and smart cities? *Cities* **2017**, *60*, 234–245. [CrossRef]
21. Cosgrave, E.; Arbuthnot, K.; Tryfonas, T. Living Labs, Innovation Districts and Information Marketplaces: A Systems Approach for Smart Cities. *Procedia Comput. Sci.* **2013**, *16*, 668–677. [CrossRef]
22. Ibrahim, M.; El-Zaart, A.; Adams, C. Smart sustainable cities roadmap: Readiness for transformation towards urban sustainability. *Sustain. Cities Soc.* **2018**, *37*, 530–540. [CrossRef]
23. Parodi, O.; Beecroft, R.; Albiez, M.; Quint, A.; Seebacher, A.; Tamm, K.; Waitz, C. The ABC of Real-world Lab Methodology: From "Action Research" to "Participation" and Beyond. *Trialog* **2016**, *126*, 74–82.
24. McCormick, K.; Neij, L.; Mont, O.; Ryan, C.; Rodhe, H.; Orsato, R. Advancing sustainable solutions: An interdisciplinary and collaborative research agenda. *J. Clean. Prod.* **2016**, *123*, 1–4. [CrossRef]
25. Wiek, A.; Farioli, F.; Fukushi, K.; Yarime, M. Sustainability science: Bridging the gap between science and society. *Sustain. Sci.* **2012**, *7*, 1–4. [CrossRef]
26. Lang, D.J.; Wiek, A.; von Wehrden, H. Bridging divides in sustainability science. *Sustain. Sci.* **2017**, *12*, 875–879. [CrossRef]
27. Withycombe Keeler, L.; Gabriele, A.; Kay, B.R.; Wiek, A. Future Shocks and City Resilience: Building Organizational Capacity for Resilience and Sustainability through Game Play and Ways of Thinking. *Sustain. J. Rec.* **2017**, *10*, 282–292. [CrossRef]
28. Munro, A.; Marcus, J.; Dolling, K.; Robinson, J.; Wahl, J. Combining forces. *Int. J. Sustain. High. Educ.* **2016**, *17*, 812–826. [CrossRef]

sustainability

MDPI

Article

A Research and Innovation Agenda for Zero-Emission European Cities

Francesco Fuso Nerini [1,2,*], Adriaan Slob [3], Rebecka Ericsdotter Engström [1] and Evelina Trutnevyte [4]

1 Unit of Energy Systems Analysis, KTH—Royal Institute of Technology, 114 28 Stockholm, Sweden; rebecka.engstrom@energy.kth.se
2 Payne Institute, Colorado School of Mines, Golden, CO 80401, USA
3 TNO Strategic Analysis and Policy, NL-2509 Den Haag, The Netherlands; adriaan.slob@tno.nl
4 Section of Earth and Environmental Sciences, Renewable Energy Systems group, Institute of Environmental Sciences, University of Geneva, CH-1211 Geneva, Switzerland; Evelina.Trutnevyte@unige.ch
* Correspondence: francesco.fusonerini@energy.kth.se

Received: 18 January 2019; Accepted: 19 March 2019; Published: 20 March 2019

Abstract: The Paris Agreement and SDG13 on Climate Action require a global drop in Green House Gases (GHG) emissions to stay within a "well below 2 degrees" climate change trajectory. Cities will play a key role in achieving this, being responsible for 60 to 80% of the global GHG emissions depending on the estimate. This paper describes how Research and Innovation (R&I) can play a key role in decarbonizing European cities, and the role that research and education institutions can play in that regard. The paper highlights critical R&I actions in cities based on three pillars: (1) innovative technology and integration, (2) governance innovation, and (3) social innovation. Further, the research needed to harmonize climate mitigation and adaptation in cities are investigated.

Keywords: cities´ decarbonization; European Union; zero carbon cities; smart cities; circular economy; governance; social innovation

1. Introduction

Cities account from 60 to 80% of global CO_2 emissions, depending on the estimates [1]. In the European Union, around three quarters of the population lives in cities, but this share continues to increase [1]. It is clear that the achievement of a "well below 2 degrees" climate change trajectory, as required by the Paris Agreement [2], will need cities as key actors.

Furthermore, cities are the "melting pots" where decarbonization strategies for energy, transport, buildings, and even industry and agriculture coexist and interact [3]—hence the potential for sectorial integration is especially high. Local expertise, density of infrastructure, and the possibility to leverage economies of scale are some of the many reasons to focus on cities in the European decarbonization challenge. In many cases, cities have also launched decarbonization plans that are more ambitious than the national plans. An example is the Covenant of Mayors programme, originally an EU initiative, which to date organizes 7755 cities in ambitious decarbonization commitments from cities around the world [4].

In this context—where city action is both needed and increasingly taken—it is crucial to examine and understand where and how research and innovation (R&I) is needed to support cities in accelerating decarbonization efforts, and then to plan an R&I agenda accordingly. From the academic community, research and development agendas have been proposed for several aspects of urban sustainability. These include suggestions on the future of urban ecology research [5], an agenda for cities as smart interconnected systems [6], as well as proposed efforts to enhance urban climate change adaptation [7] and resilience [8]. Further, methodology-specific research agendas to accelerate the transformation to low carbon cities have been proposed for "urban ecosystem modeling" [9], "urban living labs" [10], and future energy analysis of the built environment [11]. Most of these include some aspects on how urban societies can transition into sustainable cities with low or zero climate emissions. However, an overarching R&I agenda centered on how research and innovation institutions can support the decarbonization challenge in cities is missing. The New Urban Agenda [12] spans all spheres for urban sustainable development and stresses the importance of climate change mitigation (and adaptation) actions from several perspectives. However, its focus lies primarily on politics and governance. It emphasizes the importance of science and academia (in particular related to the need for social, technological, digital, and nature-based innovations) but does not guide city actors or the scientific community to specific R&I needs.

Many scientific studies on urban-centered climate change mitigation also analyses or review political, technical, or economic measures to curb urban emissions. One study [13] emphasizes that equitable access to low carbon solutions for all (including low-income) urban populations is important for cities to substantially reduce Green House Gases (GHG) emissions. Another study [14] provides analysis of per capita GHG emission of city dwellers in different parts of the world and stresses the importance of emission inventories as a starting point for effective urban climate mitigation. Another study [15] shows how the diversity of (22 studied) cities lead to diverse collections of solutions to effectively reduce emissions. They argue that acknowledging such specific city characteristics can provide additional policy options for nation states in their climate mitigation efforts. This is especially the case for measures that can be directed towards urban infrastructure development and that go beyond carbon pricing or other broader market instruments.

A decade-old study [16] called for future research to adopt an integrated system perspective, integrating all sources, sinks, and opportunities for infrastructure and technology for carbon management of cities. Such research should account for the potential multiple benefits of climate change mitigation in cities (such as combined mitigation and adaptation actions) and identify efficient urban carbon governance (by ascertaining who can influence the urban carbon mitigation, and by what extent). In recent years, initial assessments of such multiple benefits have been assessed related to selected urban sustainability measures [17].

Another complication is that cities in the European Union are very diverse (in terms of technical context, affordability of low carbon investment, governance, etc.). What works in one city does not necessarily work in another. Approaches to the decarbonization of cities are also diverse. To exemplify such differences, this paper compares three EU cities, one in the North of the European Union (Stockholm), one in the South (Barcelona), and one in the East (Warsaw).

However, to date there is a lack of a holistic view on how R&I actions could evolve in the future to support low- and zero-carbon efforts in very diverse European cities. To overcome this research gap, the aim of this paper is to provide an overview of key areas that will need research and innovation to support the decarbonization challenge in the European Union, and to select a number of actions that are perceived to be critical to achieve zero-carbon cities in the European Union. First, the methods for such assessment are presented. Then, selected R&I actions in cities are categorized into three areas: (1) innovative technology and integration, (2) governance innovation, and (3) social innovation. Finally, the paper explores the holistic challenge of climate action in cities, and the role of diverse actors in such a challenge, with a focus on higher research institutions.

Diverse Challenges and Low-carbon Solutions in Diverse Cities

Table 1 presents key decarbonization parameters for three European cities: Stockholm, Barcelona, and Warsaw. It shows how action on decarbonization is motivated and organized differently in the three cities. Two main differences appear: (1) how the city governance powers can influence decarbonization planning in cities. The cities' regulatory powers vary significantly across cities; (2) the approach taken on climate action. This point varies in terms of targeted sectors and focus.

Table 1. A comparison of three diverse European cities. Content adapted from a previous study [3].

Parameter	Stockholm	Barcelona	Warsaw
Population (within city boundaries)	950,000 (2017)	1,628,936 (2018)	1,758,143 (2017)
Jurisdiction	Strong mayoral powers regarding buildings, city roads, land use, and water. The city owns most of the land, and gets its financing from income taxes.	The city has strong powers and ownership over public buildings and urban land use. However, it has limited power over the city´s energy supply, and partial powers over the transport infrastructure.	Strong local government policy powers and ownership over public buildings, transport infrastructure, roads, and water systems.
Key plans acting on decarbonization	The actions for reducing emissions in Stockholm have been centered on heating, transport, waste, electricity, and gas. The city also has a focus on testing new low-carbon solutions in selected neighborhoods, and to then expand effective ones to the whole city.	Most of the policies that will decrease emissions in Barcelona are not specifically addressed at climate change mitigation, which features as a cross-cutting issue across policies, but rather at improving the local air quality and the livability of the city.	Focus on efficiency, transportation, and public awareness. Behavioral changes were promoted through targeted incentives, which were well received by the local population.

2. Materials and Methods

This paper aims to review the current need for research to support the decarbonization of European cities. The methods used can be summarized as an expert-driven, semi-structured literature search guided by experts in the field, developed in the context of the High-Level Panel of the European Decarbonization Pathways Initiative [3,18].

The steps to arrive at the results presented below are the following:

(1) The experts, composed by the authors of this paper, the members of the High-Level Panel of the European Decarbonization Pathways Initiative [3,18], and other members of the H2020 DialoguE on European Decarbonisation Strategies (DEEDS) project, decided on the categorization of the R&I actions in cities trough facilitated discussion over several meetings. Three pillars were selected to categorize future R&I actions in cities: (1) innovative technology and integration; (2) governance innovation; and (3) social innovation. For each of these pillars key R&I actions for cities to become zero carbon by 2050 are proposed. While there are clear connections in topics in these three pillars (e.g., governance needs social innovation and citizen participation), these pillars were deemed useful to categorize and divide R&I actions.

(2) The authors of this paper did a structured literature search for each of these pillars targeted at (a) capturing the current state of the art in R&I for European cities' decarbonization and (b) identifying key R&I gaps for the decarbonization challenge in the European Union´s cities. The authors of this study did not do a comprehensive literature review of all aspects of decarbonization in cities, but a targeted literature review aiming at capturing points (a) and (b) above. For instance, studies looking at which are the most promising technologies for decarbonizing a sector in cities (e.g., heat) were included, but studies going into detail for a single promising technology (e.g., geothermal heat pumps) were not comprehensively reviewed to limit the scope of the study.

(3) The state-of-the-art and R&I gaps discussed above were presented and refined during several meetings, including all the "experts" defined in point 1, during regular meetings for approximately one year. At each meeting, research priorities were discussed and iteratively refined through additional targeted literature reviews and facilitated discussions.

(4) Consensus was reached on the R&I priorities discussed below.

The resulting R&I actions presented below have neither the scope nor the ambition to provide an exhaustive assessment of all the sectoral and cross-sectoral decarbonization challenges in cities.

They represent a deliberate selection of topics that the experts involved in this paper consider of primary relevance for the design of a successful R&I strategy for decarbonizing EU cities. The R&I actions look at how GHG emissions can be decreased in cities with various actions ("decarbonisation achievements"), with the aim of achieving zero carbon cities by 2050; "zero carbon cities" mean cities that are carbon neutral, encompassing all direct and indirect emissions within their boundaries.

3. Research and Innovation Actions for Decarbonizing EU Cities

3.1. Key R&I Elements within Innovative Technology and Integration in Cities

As seen in Table 1, cities are heterogeneous across regions. Even within cities, building stocks in different areas differ in energy efficiency and level of digitalization. However, this Section identifies some common aspects on the role that innovative technology and integration can have in the decarbonization challenge. Those are categorized under the broad umbrella of smart cities, circular economy, and innovative technology development. While these three concepts are closely interconnected, they are divided here as they represent three interconnected but independent streams of research in literature.

3.1.1. Smart Cities

The first recurring key concept for the integration of low-carbon technologies in cities is the concept of "Smart Cities". A smart city is a city that is technologically interconnected through a network of sensors, IT platforms, open data, and programs that serve to make life within the city more efficient [3]. Smart city projects are diverse, and range from apps for reporting road defects, to the integration of electric vehicles into the city grid balancing [19]. While smart city concepts are being developed every day, there is a need to continue integrating innovative technologies and Innovation and Communication Technologies (ICTs) in the urban system, and to test those solutions in diverse cities. This could include both different designs and technology options, including from smart thermal grids, multi commodity grids, and mobility-as-a-service measures, but also smart lamp posts or smart bins that reduce consumption of energy. It is especially challenging to develop smart cities with new and innovative infrastructure within existing urban systems. There is a need to connect with the existing, sometimes decades- or even centuries-old infrastructure and building stock. Strategies are needed to overcome the trade-off between replacing existing infrastructure with completely new, and potentially expensive, infrastructure; or integrating less-revolutionary solutions that do not significantly challenge the existing interests and system.

3.1.2. Circular Economy

Circular economy (CE) is another key concept often mentioned to decarbonized cities. CE is related to the concept of smart cities, as the former can help enable the circular economy. While the term is used often, there is yet no consensus on the definition of circular economy [20]. By comparing 114 definitions, one study [21] defines circular economy as: "an economic system that is based on business models which replace the "end-of-life" concept with reducing, alternatively reusing, recycling, and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks), and macro level (city, region, nation, and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity, and social equity, to the benefit of current and future generations." Depending on the implementation of CE, it is estimated that it could have different impacts on EU energy usage and emissions. One study [22] estimates that CE could reduce the global primary energy demand by 5% to 9%. Another study [23] estimates that CE could reduce global and EU primary material consumption by 32% and 52%, respectively, by 2050. CE tends to use different technologies, both mature and innovative. Given the wide array of possible solutions, further research will be needed on the technologies that enable CE and how they interact. Waste management, digitalization, district heating, and transportation optimization are some of the topics that best relate circular economy with technology [3]. Further, knowledge-sharing on how CE is developed in different cities and countries will be essential to understand differences and capture best practices. This should include not only technical aspects, but also financing, governance, and social engagement practices.

3.1.3. Heat, Electricity, and Energy Efficiency Technologies

Finally, more research, innovation, and testing will be needed to understand which (and how) technologies can be used in cities to decrease emissions. The innovation in technologies could be in the technology itself, but also an innovative way of using a mature technology. Furthermore, all of these technologies can be used in conjunction as pieces of smart city and circular economy concepts.

Here, there will be a need to share best practices in building efficiency. In fact, while across the European Union, building efficiency has been rising in time, and the European Union has set the target of having all new buildings nearly zero energy by 2020 [24], most of Europe's existing building stock has yet to be affected by energy performance requirements [25]. Continuous research and innovation will be needed to promote both the refurbishment of existing non-efficient buildings and the design of innovative strategies for near zero-energy buildings [3]. That will also include the design of new smart urban spatial strategies when new cities and quarters are expanded.

Furthermore, with cities being hotspots of energy demand, R&I is needed to understand cities' roles in the local production of electricity and heat. For local electricity production, solar, bioenergy, waste, and wind sources can be harnessed. As for heat, several renewable heat sources can be integrated. Biomass-based CHP, solar thermal units, and waste-to-energy technologies are some of the most mature technologies currently used. In addition, geothermal energy is currently being investigated for its integration in urban areas [26].

3.1.4. Suggested Medium-Term R&I Actions for Innovative Technology and Integration

In Figure 1, some key actions are selected for the R&I on innovative technology and integration for decarbonization of cities in the European Union. The first need is to map and disseminate best practices in technologies and strategies for decarbonization in cities. Many cities are developing new innovative approaches, for example to circular economy, and transmitting the lessons learned is key to upscaling such innovative decarbonization solutions. There is a need to understand how renewable energy, electric mobility, and efficient and smart buildings can be integrated in a single city "organism". Smart city concepts and digitalization can provide the tools for integrating such systems in cities. R&I should also explain how this integration could differ in cities that vary by location, size, existing building stock, and transportation infrastructure. Finally, the European Union should engage in a race to the top in cities by developing a series of zero-carbon living labs, where new zero-carbon urban solutions can be tested and replicated.

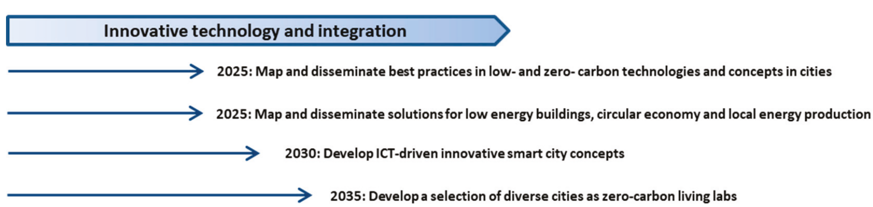


Figure 1. Key identified actions for innovative technology and integration for decarbonization in EU cities [3].

3.2. Key R&I Elements within Governance Innovation in Cities

The process of shaping the low-carbon transition in cities needs a paradigm shift from formal authority or governmental planning to governance [27,28]. Governance is here defined as "the totality of actors, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analyzed, and communicated, and how management decisions are taken" [29]. Using the concept of governance thus enables a holistic view to low-carbon transition in cities that cuts across micro-, meso-, and macro-scales, and across all kinds of institutions, responsibilities, rules, and norms in the broadest sense.

A holistic view of governance of low-carbon transition in cities also implies that action is required across multiple sectors and across technical and societal domains. As cities are "melting pots" for various types of infrastructures, integrated urban planning and cross-sector governance are key in order to go beyond sectoral silos and identify the opportunities and benefit from the synergy of coupling various sectors. Fundamental and systemic transition to low- and zero-carbon cities also requires multiple sectors innovating together and involving social innovation (see the next Section). For example, as mentioned above, a circular economy requires reducing, reusing, and recycling waste or recovering materials, whereas some of the waste streams can be used to produce heat, electricity, gas, or fertilizers. A radical transition from personal vehicles with internal combustion engines to new transportation concepts with public transport, car sharing, bicycles, walking, and electric vehicles also cut across the areas of transportation, energy, land-use planning, privacy, safety, and so on. The end-use technologies and social innovations tend to be marginalized so far as compared to technical solutions, especially in the energy supply or transportation domains [30,31]. Citizens are the main users of city infrastructure and the main drivers of consumption of energy, goods, and services. Transition to carbon-neutral cities, thus, should also include citizen-centric innovations, such as diet changes [32], sharing economy [33], device convergence [34], more sustainable forms of consumption [35], and many others (citizen social innovation is discussed in detail in Section 3.3).

Local government still has a pivotal role to play in this multi-actor governance process [36]. They can create a shared, ambitious long-term vision of the low-carbon transition as a way to align the actions of multiple actors towards the same goal [37,38]. When in line with global climate targets but still adapted to the specific local context, visionary concepts are powerful tools because they are endorsed by multiple actors, and hence help mobilize these actors and resources [39]. Examples of such visions are the concepts of a smart city, a circular economy, and a zero-carbon or 100% renewable energy city. Local government can also take a variety of other actions, such as implementing regulatory standards, providing financial incentives, joining public–private partnerships, organizing information and networking events, and so on. In fact, local governments are arguably the right actor to also reach out to the citizens at large, due to their stronger connection to the citizens than national governments, industrial actors, or NGOs [40]. Local governments could, for example, organize processes to find their citizens' low-carbon vision that is broadly legitimized and realistically implementable through public participation processes [39,41]. Furthermore, the analysis of climate activities in global cities showed that new governance schemes are emerging and often involve closer cooperation between public government and private bodies [30]. As illustrated in Table 1, European cities are very diverse. Not only are the challenges or low-carbon solutions different across Europe, but also the regulatory power of cities and the available means to finance or enable financing of low-carbon action. In all cases, the regulatory power of cities is limited and city governments have to interplay with regional, national, and European-level authorities.

Suggested Medium-Term R&I Actions for Governance Innovation

Given this state-of-play in European cities in the context of low-carbon transition, three R&I areas for governance innovation are needed (Figure 2). First, as European cities are diverse in their challenges, solutions, and governance situations, it is important to map the current approaches and best practices to low- and zero-carbon urban governance mechanisms that are used by local governments and other actors. For example, innovations on urban planning strategies are needed for revitalizing or extending existing city neighborhoods and to integrate low-carbon solutions across various sectors from the start, such as renewable energy, low consumption, green areas, and other carbon sinks.

Successful examples of developing broadly appealing low-carbon visions with quantified targets and then new innovations for systemic monitoring of implementation should provide information on what works when and where. It is key that any successful examples and monitoring outcomes are documented in a holistic way that allows for transferability and comparison across many cities in Europe. In this way, lessons learnt and best practices can be transferred from one city to multiple others with similar situations, despite the European diversity. Strategic partnerships between universities, local governments, as well as other stakeholders with the relevant data and tools, could be created to ensure a thorough, data-driven documentation of available governance strategies and their assessment.

Low-carbon transformation in European cities also needs R&I on new tools for financing, incentivizing, initiating new business models, and maximizing information to scale the successful solutions. Many of the current tools are not optimal for holistic, low-carbon measures, because they do not yet cut across sectoral silos, supply and consumption, or technology and society. In terms of multi-actor governance, the current tools also often target one type of actor with their specific powers and responsibilities. R&I could be used to create and assess new types of procurement procedures, public-private partnerships, or public entrepreneurship activities. Citizens can also be further involved as agents of change through measures like participatory budgeting or citizen-run community projects. It is key to understand how the various types of measures interact, from regulation to incentives or information. Universities could contribute here with a collection of independent evaluative evidence for the assessment of these measures.

A far-reaching and fast low-carbon transition in European cities also requires optimization of the role of local governments that are in a network with a multitude of other actors. R&I is, therefore, needed to craft processes of the vertical, multi-level governance that allows the governments to bridge the European Union directives and national policies with local interests, ranging from citizen engagement to the stakes of local companies. The coordination and integration of policy actions and instruments across local, national, and European scales in order to steer their interplay towards low-emission outcomes is key. As citizens of European cities are instrumental to city decarbonization, vertical, multi-level governance processes shall necessarily account for the European citizens' vision of a low-carbon future, low-carbon lifestyles, and social innovations. Through such long-term vision exercises, governments could pilot new ways to leverage resources across various types of public and private actors for productive zero-carbon innovation.

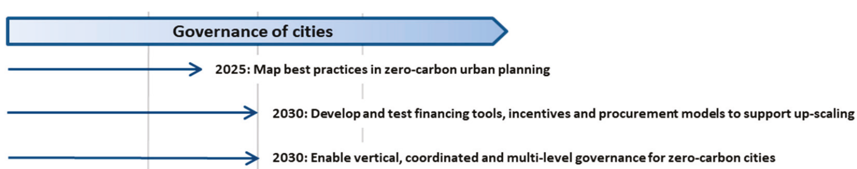


Figure 2. Key identified actions on governance innovation for decarbonization in EU cities [3].

3.3. Key R&I Elements within Social Innovation

Social innovation can boost bottom-up decarbonization in cities through local initiatives from citizens or citizen collectives. Social innovations are the result of the action of creative individuals or groups who are able to find innovative solutions to social problems in the community that are not adequately met by the local system. Those, in turn, can also result in governance change and innovation (discussed above). Local initiators act on the social needs and are skilled in finding novel ways (business models, ways of collaboration, funding mechanisms, etc.) to solve the issue. The social process that is initiated in this way, at the same time fosters the local capacity to solve the issue. In this way, social innovation creates new ideas for zero-carbon products, services, new social relationships, or innovative ways of organizing and collaborating that fit in the specific local context. It includes the empowerment of bottom-up initiatives, the embedding of (new) technologies in the socio-cultural sphere, achieving behavioral and social change, and improving social systems on a local or urban level. With this diversity of topics, social innovation is a rather broad field of research and innovation, and "has become characterized by conceptual ambiguity and a diversity of definitions and research settings" [42]. There seems to be an implicit agreement that an overarching definition of social innovation should contain two "core conceptual elements": (1) a change in social relationships, systems, or structures, and (2) that such change serves a shared human need or goal, or solve a socially relevant problem [42].

Two types of social innovation are of particular interest for the decarbonization challenge of cities: grassroots innovation and social entrepreneurship.

Grassroots innovation is "a network of activists and organizations generating novel bottom-up solutions for sustainable development and sustainable consumption that respond to the local situation and the interests and values of the communities involved" [43]. Grassroots innovations differ from mainstream innovation, as they possess different types of sustainable development and forms, such as cooperatives, informal community groups, social enterprises, and voluntary associations [44].

Social entrepreneurship contains several sub-concepts, which are identified as (a) social value creation, (b) the social entrepreneur, (c) the social entrepreneurship organization, (d) market orientation, and (e) social innovation [45]. The individual, the social entrepreneur, plays a key role in developing innovation that creates (local) social wealth.

Apart from solving local pressing issues, social innovation can also create local jobs. The emphasis on market orientation can differ among social innovation, but in general it is part of social entrepreneurship and grassroots innovations [43,46]. As the social innovations develop further, and the organization becomes more mature, professionalized, or commercialized, it can develop into a business-like organization. Many social innovations shift from a marginal to a commercial organization over time [43,47]. The distinction between "social innovation" and "business innovation" then becomes blurred. Businesses themselves can also develop social innovation [46], which is sometimes seen as a further development of Corporate Social Responsibility [48].

Two key challenges of social innovations in cities are (apart from the many challenges that social innovations are confronted with) the neglect of social innovation in terms of policy making, and the replication and upscaling of social innovations.

Suggested Medium-Term R&I Actions for Social Innovation in Cities

Figure 3 provides some Key identified actions on social innovation for decarbonization in EU cities.

The first one relates to the testing of social innovation strategies in diverse contexts. Many social innovations start on as small scale and are very locally situated, which causes them to generally have a problem in getting attention and recognition from policy makers [44]. On the other hand, social innovation can easily create tension with policy silos and related policies, as they do not keep themselves within the boundaries of defined policy domains while developing solutions for societal problems. Many social innovations operate with this tension between traditional "top-down" policies and "bottom-up" initiatives. In this respect, awareness campaigns for policy makers are needed regarding what social innovation can contribute to decarbonization policies and how social innovation can help to reach decarbonization goals. Research can help to highlight successful examples of the interplay between decarbonization and social innovation and can assist in developing suitable governance models for this interplay.

The second one relates to the scaling up of social innovations. Social innovations are developed in a specific local context for a specific local societal problem. Upscaling within the city or replication in other cities is, therefore, a challenge, and probably not possible for many social innovations in their complete form. Development of business models, cooperation with businesses and public authorities, and targeted replication and upscaling strategies for the (core elements of the) social innovation can help to solve this issue. Research can support these solutions through development of tailored strategies and adequate business models for upscaling and replication, and development of appropriate forms of cooperation with local governments or businesses. Research can further give insight in how to deal with the question of whether the complete social innovation could be upscaled or only some parts of it, and how and when this should be done.

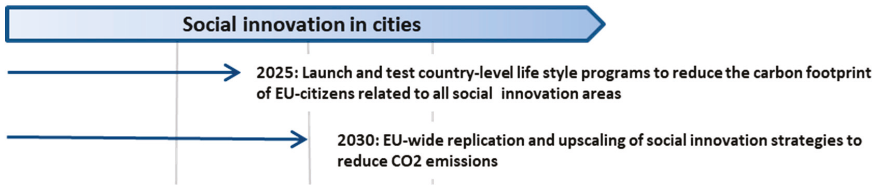


Figure 3. Key identified actions on social innovation for decarbonization in EU cities [3].

4. Conclusions: From Low Carbon Achievements to Zero-Carbon Cities in 2050

While the recommendations presented above are categorized into three pillars, they are highly interconnected and will all be needed to achieve zero-carbon cities. A system level approach, combining all areas of innovation listed above, will be needed to move from localized low carbon achievements to zero-carbon cities. This will involve many actors and diverse actions. First, strong city governance and vision will be needed. Clear targets and strategies will be needed to achieve the vision. For the transition to happen, citizens' buy-in and engagement will be crucial. All zero-carbon technology solutions will have to be tailored to the local context—and combined in "smart city" concepts. Electricity consumed in cities will need to be zero-carbon, therefore this challenge will also depend on the decarbonization happening in national power systems. Cities will also have to influence the power mix by locally producing renewable electricity. Transport and heating will need to become fully decarbonized as well—with a mix of renewable solutions and maximized internal flows. Waste will need to be minimized—and a circular economy realized. In summary, for zero-carbon cities, there will be no single "silver bullet" solution, but all solutions listed above will need to be used in conjunction and tailored to the local context [3].

Furthermore, a climate action in cities embeds a number of challenges that span across sectors. Climate policies can interact and have synergies (or trade-offs) with many development goals [49,50]. As examples, policies to improve livability and health outcomes in cities can also result in decarbonization, and vice versa. A clear example for this is the city of Barcelona case (Table 1), in which policies targeted at diminishing local air pollution also affected decarbonization outcomes. Furthermore, climate action in EU cities needs to be harmonized with other priorities, such as fighting energy poverty in cities [51]. A holistic approach to climate action in cities will, thus, be needed to capture the co-benefits of climate actions with other sustainability aspects. This includes planning climate mitigation and adaptation efforts in conjunction, and embedding nexus approaches that encompass several systems [49,52].

The R&I efforts listed above should also not treat cities in isolation. A large share of the connection between urban activities and both climate adaptation and mitigation run through city supply chains beyond city borders. "Embedded" emissions of imported goods are argued to be important to consider in city GHG inventories, along with subsequent mitigation efforts [53]. At the same time, these material/resource flows are increasingly vulnerable to the impacts of climate change, and need to be considered in climate adaptation planning [54]. Only scattered policies and research programs address the issue of "carbon leakage" of cities, even if it estimated that 12% to 35% of the European Union's consumption-based GHG emissions occur abroad [55]. That is particularly important in cities, as they are centers for the demand of products and materials.

This paper calls for selected R&I actions where higher education institutions can make a difference to the challenge of decarbonizing cities. The decarbonization challenge will require interdisciplinary and transdisciplinary science through broad cooperation between technical, economic, and social sciences, which poses a big challenge for scientists [56]. In interdisciplinary science there is integration of knowledge and interaction between disciplinary scientists by which a better or new understanding of the issue is developed. Transdisciplinary science goes beyond interdisciplinarity, and includes other forms of knowledge derived from a wide range of stakeholders. Both forms of cross-disciplinary science require sound processes for knowledge sharing, interaction, and knowledge production and an adequate, highly knowledgeable mediation of the inter- or transdisciplinary process, as the interaction can sometimes become heated. Research should uncover the process requirements. "Living labs" engaging every actor, from citizens to academia, local businesses and the municipality, could be created in cities to test innovation in practice.

Universities, other higher education institutions (HEI), and educational and research systems in general will need to step up to the challenge. There is a need to train broadly educated or well-experienced researchers in the facilitation of the inter- and transdisciplinary processes. HEI can educate the new generation of professionals that are familiar with low-carbon transition challenges and solutions, and in particular, are able to envision and implement solutions across several sectors in the context of multi-actor governance. Universities can also build capacity in governments, and engage in outreach at schools or public events. In addition, universities can themselves lead by example and demonstrate low- and zero-carbon solutions by initiating high-visibility flagship projects that are also used for research.

Finally, multi-actor partnerships and networks, such as the Viable Cities project in Sweden [57], joining local authorities, HEI, companies, and others, can gather and expand the knowledge base for the zero-carbon transition in cities. Such partnerships can find and demonstrate innovative solutions, inform adaptive decision-making processes, or help collect data to monitor the implementation of zero-carbon projects in cities.

Author Contributions: F.F.N. coordinated inputs from the other authors, designed the study and wrote the paper. A.S. supported the design of the paper, led the writing of the social innovation (Section 3.3) and reviewed the paper. R.E.E. supported the design of the paper, wrote parts of the introductory and conclusion sections, and reviewed the paper. E.T. supported the design of the paper, led the writing of the governance (Section 3.2), and reviewed the paper.

Funding: The work presented in this paper was funded by the European Commission under contract number no. 642242 (https://deeds.eu/).

Acknowledgments: The authors acknowledge the High Level Panel for their collaboration on the Final Report of the High-Level Panel of the European Decarbonization Pathways Initiative, to which this study contributed. The research in this paper benefited from collaboration with the members of the DEEDS consortium. The authors also thank the collaborators in the city of Stockholm, and in particular former mayor of Stockholm Karin Wanngård, Björn Hugosson, and Malin Parmander.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. European Commission Cities. Available online: https://ec.europa.eu/clima/policies/international/paris_protocol/cities_en (accessed on 19 September 2018).
2. United Nations Paris Agreement on Climate Change. 2015. Available online: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (accessed on 20 March 2019).
3. European Commission Final Report of the High-Level Panel of the European Decarbonisation Pathways Initiative. 2018. Available online: https://ec.europa.eu/info/publications/final-report-high-level-panel-european-decarbonisation-pathways-initiative_en (accessed on 20 March 2019).
4. Covenant of Mayors Covenant of Mayors Initiative. Available online: https://www.covenantofmayors.eu/about/covenant-initiative/origins-and-development.html (accessed on 6 December 2018).
5. McDonnell, M.J.; MacGregor-Fors, I. The ecological future of cities. *Science* **2016**, *352*, 936–938. [CrossRef]
6. Ramaswami, A.; Russell, A.G.; Culligan, P.J.; Sharma, K.R.; Kumar, E. Meta-principles for developing smart, sustainable, and healthy cities. *Science* **2016**, *352*, 940–943. [CrossRef]
7. Carter, G.; Cavan, G.; Connelly, A.; Guy, S.; Handley, J.; Kazmierczak, A. Climate change and the city: Building capacity for urban adaptation. *Prog. Plan.* **2015**, *95*, 1–66. [CrossRef]

8. Ernstson, H.; van der Leeuw, S.E.; Redman, C.L.; Meffert, D.J.; Davis, G.; Alfsen, C.; Elmqvist, T. Urban Transitions: On Urban Resilience and Human-Dominated Ecosystems. *Ambio* **2010**, *39*, 531–545. [CrossRef] [PubMed]
9. Chen, S.; Chen, B.; Fath, B.D. Urban ecosystem modeling and global change: Potential for rational urban management and emissions mitigation. *Environ. Pollut.* **2014**, *190*, 139–149. [CrossRef] [PubMed]
10. Voytenko, Y.; Evans, J.; Schliwa, G. Urban living labs for sustainability and low carbon cities in Europe: Towards a research agenda. *J. Clean. Prod.* **2016**, *123*, 45–54. [CrossRef]
11. Anderson, J.E.; Wulfhorst, G.; Lang, W. Energy analysis of the built environment—A review and outlook. *Renew. Sustain. Energy Rev.* **2015**, *44*, 149–158. [CrossRef]
12. UN New Urban Agenda. 2017. Available online: https://www.un.org/sustainabledevelopment/blog/2016/10/newurbanagenda/ (accessed on 20 March 2019).
13. Kammen, D.M.; Sunter, D.A. City-integrated renewable energy for urban sustainability. *Science* **2016**, *352*, 922–928. [CrossRef]
14. Hoornweg, D.; Sugar, L.; Trejos Gómez, C.L. Cities and greenhouse gas emissions: Moving forward. *Environ. Urban.* **2011**, *23*, 207–227. [CrossRef]
15. Kennedy, C.A.; Ibrahim, N.; Hoornweg, D. Low-carbon infrastructure strategies for cities. *Nat. Clim. Chang.* **2014**, *4*, 343–346. [CrossRef]
16. Bai, X.; Dawson, R.J.; Ürge-Vorsatz, D.; Delgado, G.C.; Barau, A.S.; Dhakal, S.; Dodman, D.; Leonardsen, L.; Masson-Delmotte, V.; Roberts, D.C.; et al. Six research priorities for cities and climate change. *Nature* **2018**, *555*, 23. [CrossRef] [PubMed]
17. Engström, R.E.; Howells, M.; Destouni, G. Water impacts and water-climate goal conflicts of local energy choices—Notes from a Swedish perspective. *Proc. IAHS* **2018**, *376*, 25–33. [CrossRef]
18. European Commission High-Level Panel of the European Decarbonisation Pathways Initiative. Available online: http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=3459 (accessed on 16 January 2019).
19. Latvakoski, J.; Mäki, K.; Ronkainen, J.; Julku, J.; Koivusaari, J.; Latvakoski, J.; Mäki, K.; Ronkainen, J.; Julku, J.; Koivusaari, J. Simulation-Based Approach for Studying the Balancing of Local Smart Grids with Electric Vehicle Batteries. *Systems* **2015**, *3*, 81–108. [CrossRef]
20. De Ferreira, A.C.; Fuso-nerini, F. A Framework for Implementing and Tracking Circular Economy in Cities: The Case of Porto. *Sustainability* **2019**. Accepted for publication.
21. Kirchherr, J.; Reike, D.; Hekkert, M. Conceptualizing the circular economy: An analysis of 114 definitions. *Resour. Conserv. Recycl.* **2017**, *127*, 221–232. [CrossRef]
22. Kalmykova, Y.; Sadagopan, M.; Rosado, L. Circular economy—From review of theories and practices to development of implementation tools. *Resour. Conserv. Recycl.* **2018**, *135*, 190–201. [CrossRef]
23. Ellen, M.; Company, M. Towards the Circular Economy: Accelerating the scale-up across global supply chains. *World Econ. Forum* **2014**, 1–64.
24. EUR-LEX Energy Performance of Buildings Directive. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/;ELX_SESSIONID=FZMjThLLzfxmmMCQGp2Y1s2d3TjwtD8QS3pqdkhXZbwqGwlgY9KN!2064651424?uri=CELEX:32010L0031 (accessed on 19 September 2018).
25. European Commission EU Buildings Factsheets. Available online: https://ec.europa.eu/energy/en/eu-buildings-factsheets (accessed on 19 September 2018).
26. Hirschberg, S.; Wiemer, S.; Burgherr, P. *Energy from the Earth: Deep Geothermal as a Resource for the Future?* Vdf Hochschulverlag AG (An der ETH Zurich): Zurich, Switzerland, 2014.
27. Rhodes, R.A.W. *Understanding Governance: Policy Networks, Governance, Reflexivity and Accountability*; Open University Press: Buckingham, UK, 1997.
28. Walker, G.; Tweed, F.; Whittle, R. A framework for profiling the characteristics of risk governance in natural hazard contexts. *Nat. Hazards Earth Syst. Sci.* **2014**, *14*, 155–164. [CrossRef]
29. IRGC. *Risk Governance: Towards an Integrative Apprach*; International Risk Governance Council: Geneva, Switzerland, 2005.
30. Castán Broto, V.; Bulkeley, H. A survey of urban climate change experiments in 100 cities. *Glob. Environ. Chang.* **2013**, *23*, 92–102. [CrossRef]
31. Wilson, C.; Grubler, A.; Gallagher, K.S.; Nemet, G.F. Marginalization of end-use technologies in energy innovation for climate protection. *Nat. Clim. Chang.* **2012**, *2*, 780. [CrossRef]

32. Ivanova, D.; Vita, G.; Steen-Olsen, K.; Stadler, K.; Melo, P.C.; Wood, R.; Hertwich, E.G. Mapping the carbon footprint of EU regions. *Environ. Res. Lett.* **2017**, *12*, 54013. [CrossRef]
33. Frenken, K.; Schor, J. Putting the sharing economy into perspective. *Environ. Innov. Soc. Trans.* **2017**, *23*, 3–10. [CrossRef]
34. Grubler, A.; Wilson, C.; Bento, N.; Boza-Kiss, B.; Krey, V.; McCollum, D.L.; Rao, N.D.; Riahi, K.; Rogelj, J.; De Stercke, S.; et al. A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. *Nat. Energy* **2018**, *3*, 515–527. [CrossRef]
35. Sahakian, M.; Wilhite, H. Making practice theory practicable: Towards more sustainable forms of consumption. *J. Consum. Cult.* **2013**, *14*, 25–44. [CrossRef]
36. Melica, G.; Bertoldi, P.; Kona, A.; Iancu, A.; Rivas, S.; Zancanella, P. Multilevel governance of sustainable energy policies: The role of regions and provinces to support the participation of small local authorities in the Covenant of Mayors. *Sustain. Cities Soc.* **2018**, *39*, 729–739. [CrossRef]
37. Berkhout, F. Normative expectations in systems innovation. *Technol. Anal. Strateg. Manag.* **2006**, *18*, 299–311. [CrossRef]
38. Spath, P.; Rohracher, H. "Energy regions": The transformative power of regional discourses on socio-technical futures. *Res. Policy* **2010**, *39*, 449–458. [CrossRef]
39. Rowe, G.; Frewer, L.J. A Typology of Public Engagement Mechanisms. *Sci. Technol. Hum. Values* **2005**, *30*, 251–290. [CrossRef]
40. Fudge, S.; Peters, M.; Woodman, B. Local authorities as niche actors: The case of energy governance in the UK. *Environ. Innov. Soc. Trans.* **2016**, *18*, 1–17. [CrossRef]
41. Volken, S.; Xexakis, G.; Trutnevyte, E. Perspectives of informed citizen panel on low-carbon electricity portfolios in Switzerland and the empirical evaluation of informational material. *Environ. Sci. Technol.* **2018**. Article AS. [CrossRef]
42. van der Have, R.P.; Rubalcaba, L. Social innovation research: An emerging area of innovation studies? *Res. Policy* **2016**, *45*, 1923–1935. [CrossRef]
43. Seyfang, G.; Smith, A. Grassroots innovations for sustainable development: Towards a new research and policy agenda. *Environ. Politics* **2007**, *16*, 584–603. [CrossRef]
44. Martin, C.J.; Upham, P.; Budd, L. Commercial orientation in grassroots social innovation: Insights from the sharing economy. *Ecol. Econ.* **2015**, *118*, 240–251. [CrossRef]
45. Choi, N.; Majumdar, S. Social entrepreneurship as an essentially contested concept: Opening a new avenue for systematic future research. *J. Bus. Ventur.* **2014**, *29*, 363–376. [CrossRef]
46. Martinez, F.; O'Sullivan, P.; Smith, M.; Esposito, M. Perspectives on the role of business in social innovation. *J. Manag. Dev.* **2017**, *36*, 681–695. [CrossRef]
47. Hockerts, K.; Wüstenhagen, R. When David meets Goliath: Sustainable entrepreneurship and the evolution of markets. In *Social Innovation: Blurring Boundaries to Reconfigure Markets*; Palgrave Macmillan: London, UK, 2011.
48. Mirvis, P.; Herrera, M.E.B.; Googins, B.; Albareda, L. Corporate social innovation: How firms learn to innovate for the greater good. *J. Bus. Res.* **2016**, *69*, 5014–5021. [CrossRef]
49. Fuso Nerini, F.; Hughes, N.; Cozzi, L.; Cosgrave, E.; Howells, M.; Sovacool, B.; Tavoni, M.; Tomei, J.; Zerriffi, H.; Milligan, B. Use SDGs to guide climate action. *Nature* **2018**, *557*, 31. [CrossRef]
50. Fuso Nerini, F.; Tomei, J.; To, L.S.; Bisaga, I.; Parikh, P.; Black, M.; Borrion, A.; Spataru, C.; Broto, V.C.; Anandarajah, G.; et al. Mapping synergies and trade-offs between energy and the Sustainable Development Goals. *Nat. Energy* **2017**, *3*, 10–15. [CrossRef]
51. Dobbins, A.; Fuso Nerini, F.; Deane, P.; Pye, S. Strengthening the EU response to energy poverty. *Nat. Energy* **2019**, *4*, 2–5. [CrossRef]
52. Howells, M.; Hermann, S.; Welsch, M.; Bazilian, M.; Segerström, R.; Alfstad, T.; Gielen, D.; Rogner, H.; Fischer, G.; van Velthuizen, H.; et al. Integrated analysis of climate change, land-use, energy and water strategies. *Nat. Clim. Chang.* **2013**, *3*, 621–626. [CrossRef]
53. Wachsmuth, D.; Cohen, D.A.; Angelo, H. Expand the frontiers of urban sustainability. *Nat. News* **2016**, *536*, 391. [CrossRef] [PubMed]
54. Hunt, A.; Watkiss, P. Climate change impacts and adaptation in cities: A review of the literature. *Clim. Chang.* **2011**, *104*, 13–49. [CrossRef]

55. Fuso Nerini, F.; Broad, O.; Volkart, K. Is Domestic Action Enough? Policies and Programs for the EU to Reduce Greenhouse Gas Emissions Outside of Its Borders. 2016. Available online: http://www.insightenergy.org/system/publication_files/files/000/000/054/original/HET18_GHG_outside_EU_borders_Final.pdf?1481106791 (accessed on 20 March 2019).
56. Huutoniemi, K.; Klein, J.T.; Bruun, H.; Hukkinen, J. Analyzing interdisciplinarity: Typology and indicators. *Res. Policy* **2010**, *39*, 79–88. [CrossRef]
57. Viable Cities Connecting the Future to Our Cities. Available online: http://viablecities.com/en/home/ (accessed on 16 January 2019).

sustainability

MDPI

Article

Sustainability Education and Organizational Change: A Critical Case Study of Barriers and Change Drivers at a Higher Education Institution

Edwin E. Akins II [1], Elizabeth Giddens [2], David Glassmeyer [3], Amy Gruss [4], Maria Kalamas Hedden [5,*], Vanessa Slinger-Friedman [6] and Matthew Weand [7]

1. Department of Architecture, Kennesaw State University, Kennesaw, GA 30144, USA; eakins1@kennesaw.edu
2. Department of English, Kennesaw State University, Kennesaw, GA 30144, USA; egiddens@kennesaw.edu
3. Department of Secondary and Middle Grades Education, Kennesaw State University, Kennesaw, GA 30144, USA; dglassme@kennesaw.edu
4. Department of Civil and Construction Engineering, Kennesaw State University, Kennesaw, GA 30144, USA; agruss@kennesaw.edu
5. Department of Marketing and Professional Sales, Kennesaw State University, Kennesaw, GA 30144, USA
6. Department of Geography and Anthropology, Kennesaw State University, Kennesaw, GA 30144, USA; vslinger@kennesaw.edu
7. Department of Evolution, Ecology and Organismal Biology, Kennesaw State University, Kennesaw, GA 30144, USA; mweand@kennesaw.edu

* Correspondence: mkalamas@kennesaw.edu

Received: 1 November 2018; Accepted: 1 January 2019; Published: 18 January 2019

Abstract: Integrating sustainability within institutions of higher education can have a tremendous impact on students, faculty, and the larger community. Sustainability efforts also experience many barriers to implementation within higher education contexts. A change management perspective can help characterize these barriers and ways to overcome them. In this critical case study, we use a process model to examine the kinds of barriers Kennesaw State University (KSU) has faced regarding implementation of academic sustainability and to evaluate change drivers that can advance sustainability during a time of leadership change. The process model evaluates barriers and change drivers according to published frameworks, and provides a way for higher education institutions to identify the most difficult barriers, easily surmountable barriers, and areas where change drivers can have the most impact. At KSU, the process model identified the self-determination of middle-tier change drivers as the most important way to advance sustainable development in higher education institutions (SD in HEI) until new leadership emerges. The process model is iterative and modifiable, because the specific frameworks used in the process model may vary depending upon the needs of each HEI and stage of progression toward SD.

Keywords: barriers to change; change drivers; critical case study; education for sustainability (EfS); faculty empowerment; higher education institutions; organizational change; sustainable development in higher education institutions (SD in HEI)

1. Introduction

Sustainable development in higher education institutions (SD in HEI, a synonym of education for sustainability, EfS) presents distinct challenges, which require an understanding of the inherent, multi-faceted complexity of sustainability and the interdisciplinary nature of the subject matter. "The analogy that 'being a leader of EfS is like trying [to] make a quilt' captures" the difficult role sustainability leaders must play [1] (p. 7). HEIs, like other organizations, rely on effective leadership to promote a sustainability culture. Scott et al. state that the crucial factor for advancing sustainability in

HE is to build viable leadership capabilities, competencies, support systems, and pathways [1]. Instead, HEIs often face barriers and obstacles when it comes to SD such as being perceived as an abstract idea espoused by environmental and social activists, seeming disconnected from the institution's strategic objectives, and lacking resources and/or administrative support for implementation. One of these stumbling blocks, the absence of forward-looking transformative leadership, is especially detrimental to SD. According to recent work [2–4], environmentally specific transformational leadership directly and indirectly affects employees' pro-sustainability behaviors in the workplace. As such, leaders in HEIs can encourage or stifle employees' sustainability efforts through their leadership practices.

Beyond the important role of traditional leaders in instituting organizational change, "any employee who is able to successfully engage with others regarding sustainability issues can become a sustainability leader, environmental champion, or change agent" [5] (p. 250). To be viable and authentic, SD in university academics and campus operations must be coordinated, integrated, and mutually supported and implemented [6,7]. That is, achieving a reasonable level of orchestrated program functioning at a large public university requires the effort and good will of all members of the university community (operations managers, permanent and part-time staff, full- and part-time faculty, deans, academic directors, and students at all levels and in all fields of study). There should be "'a whole-of-university' approach to sustainability" [8] (p. 55). Because sustainability is such a broad concept, it is no surprise that many factors, and potentially many levels of leaders, are needed to implement SD [9,10].

Currently, discourse in SD in HEI literature exists that considers whether leadership must be the traditional "top-down" variety or if it can follow a distributed leadership approach. Change agents at the faculty and staff levels can enact "'middle-out' change" [11] (p. 340). This concept refers to change that relies on collaboration, institutional know-how, political savvy, and patience but is not high profile. According to Brinkhurst et al., these middle-ground change agents are "social intrapreneur[s]" [11] (p. 344), whose entrepreneurial spirit can bring positive change to a university and make headway where progress is stalled. Although engagement and involvement of rank and file members matters in organizations [5], bringing about change through empowerment is the focus of this research. Specifically, the research team considered empowerment as a change driver and the role it plays in helping faculty overcome the barriers they face in the integration of SD. Taking an organizational change management perspective, the authors focused solely on faculty at Kennesaw State University as change agents.

In the conceptual framework, we summarized the organizational change literature as it pertains to the barriers and drivers related to implementing SD in HEIs. We also developed a holistic framework for overcoming barriers to change using employee empowerment. Following a five-phase assessment of the current status of SD at Kennesaw State University (KSU), we identified the barriers and drivers to change. Using a structured approach to analyzing and prioritizing the barriers to change and the related effects of empowerment, we developed a generalizable process model of change in HEIs looking to implement sustainability.

2. Conceptual Framework: A Change Management Perspective

2.1. Organizational Change in HEIs: Barriers and Change Drivers

The organizational change literature reports both barriers and drivers that affect the implementation of SD in HEIs. Among the most important barriers to change, Aleixo et al. [12] list issues with the concept of sustainability and the rigid structure of HEIs, a lack of commitment among faculty and other university stakeholders coupled with resistance to change, and a lack of resources and know-how. Verhulst and Lambrechts [13] (p. 191) also summarize the barriers to change found in the extant literature by dividing them into three broad clusters, namely, (1) those "related to lack of awareness," (2) those "related to the structure of higher education," and (3) those "related to the lack of resources." Since these three groupings encompass the ones mentioned by Aleixo et al. [12], we applied them to our institution of higher learning.

Prominent among the barriers to change are the human factors, or as some call people, the "soft side" of the HEI. As obstacles to change, people play a special role, one that has long been established in the organizational change literature (for a review pertaining to sustainability, see Verhulst, 2012 [14]). While these human factors may serve as deterrents to change, people can also be effective change agents. In fact, several researchers argue for the need to study the human factors as a means of effective organizational change in HEIs (e.g., [13,15]). Going a step further, Verhulst and Boks [16] focus on employee empowerment as a change driver or success factor. Drawing from the management literature, they describe employee empowerment using three dimensions: "authority[,]" "resources and specialization[,]" and "self-determination" [16] (p. 75). For HEIs looking to integrate SD, empowerment is one of the main motivators for effective organizational change [15]. Employee empowerment is a motivational tool whereby administrators, faculty, staff, and others become sustainability proponents. In practical terms, organizational change through empowerment means addressing all three dimensions (i.e., authority, resources and specialization, and self-determination) [15], essentially, the success factors. As critical success factors leading to organizational change in HEIs, the dimensions of employee empowerment thus deserve further study.

To understand the process of organizational change, both the barriers and the change drivers deserve attention. We therefore combined two theoretical frameworks: (1) the categorization of the barriers to change [13] and (2) empowerment as a change driver [15,16] into one holistic framework. The approach in this work used empowerment to overcome the barriers to sustainability implementation in HEIs and, ultimately, drive change (for a depiction, see Figure 1). In building upon these theoretical frameworks, this work contributes to the literature.

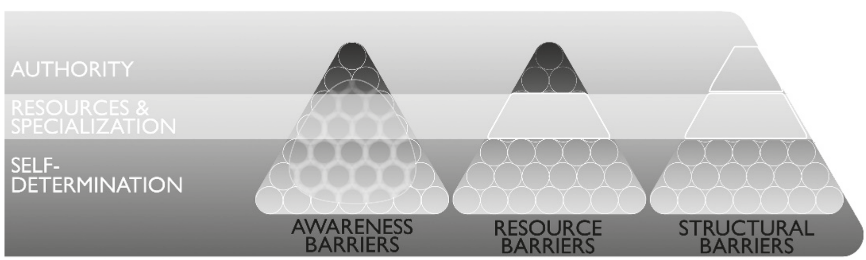


Figure 1. Overcoming barriers to change through faculty empowerment. Source: Research Team.

2.2. *Organizational Change in HEIs: A Process Model*

Referring to SD in HEIs, Brinkhurst et al. state that "changes have been achieved, but the processes underlying them are rarely examined. Consequently, it is difficult to ascertain which type of approach facilitates effective change in these complex organizations" [11] (p. 338). Barth [17] echoes this gap in the literature and calls for more generalizable process models that indicate how barriers to change and change drivers affect each other. By identifying the barriers to change, analyzing their type and difficulty, identifying change drivers and their degree of challenge, assessing which barriers should be addressed with which change drivers soonest for largest impact, and creating a plan for working on all barriers over time, our process model addressed this important gap in the literature. In treating the barriers and the drivers as dynamic variables, our process model captured the complexity of the change process in HEIs.

To develop a generalizable process model, we employed a critical case study. The goal was to learn from the shortcomings and virtues of the authors' institution in order to help other HEIs in their quest for SD change. In this light, we include a brief history of academic sustainability at KSU before moving to the methodology.

3. Context: KSU Academic Sustainability Efforts Before 2017

KSU is situated in north Metro Atlanta, Georgia (USA). It was created from a 2014 consolidation of two smaller universities, each with over a decade of previous commitments to sustainability initiatives and research. With two campuses and a larger suite of degree offerings, the consolidated KSU committed itself to sustainability initiatives both in its facilities and their operation and in the university's educational mission. KSU has a history of sustainability programs and efforts, and is a signatory to multiple nation- and state-wide higher education sustainability agreements. Within the university, KSU established a Climate Commitment Council in 2008, reconceived in 2013 as the Presidential Commission on Sustainability, to advance and coordinate all aspects of sustainability. The university also created the position of director of sustainability in 2008, specifically to promote sustainability across the curriculum, preserve natural areas, promote energy efficiency, and improve recycling programs [18]. In January 2016, KSU added a full-time sustainability program support coordinator to manage and monitor the work of the university staff in making the two campuses and their operations as sustainable as feasible.

During its first decade, the Commission made advances in operational sustainability. It collected data about campus facilities and operations to set baselines, benchmarks, and goals for energy and water use, recycling, waste reduction, and transportation improvements as well as considering sustainable policies in other areas of concern such as purchasing, landscaping, and natural areas. These data were used to plan improvements and to draft multiple yearly reports documenting progress toward sustainability benchmarks like KSU Greenhouse Gas Inventories and Climate Action Plans in 2014, 2015, and 2016. It also became an outlet through which sustainability-focused faculty, staff, and facilities personnel could network, share information about their sustainability-related projects and events, and garner support from one another.

Until the director's retirement in 2017, the trajectory of academic sustainability at KSU was ascending in parallel with operational sustainability, achieving successful initiatives in the faculty and student body. The director established a faculty workshop in 2009 to encourage an integrative sustainability pedagogy across the university's curriculum. Over eight years, it enrolled 77 faculty in 10 colleges and guided them in creating examples, lessons, assignments, and projects related to the intertwined environmental, economic, and social dimensions of sustainability. In addition, the director established a sustainability faculty fellow program in 2016. The fellows designed and executed academically focused year-long projects that strengthened faculty engagement in sustainability teaching and research. The fellows' projects often involved students as assistants or participating class members, consequently deepening student awareness and engagement university-wide.

To target the student body, the director created "Sustainability at KSU" as a cross-listed biology and environmental studies course, which was well enrolled and very popular with students. For example, one undergraduate who took this course became so passionate about promoting sustainability on campus that she created the Green Ambassadors student club, and it has become an important locus of student involvement in spreading student awareness of sustainability and supporting sustainable practices such as recycling, water conservation, reducing carbon emissions, and addressing food insecurity.

Across the board, from 2008 to 2017, the university supported what AASHE has identified as "an opportunity and a responsibility" to help transform society into a sustainable one in Beyond the Right Thing to Do: The Value of Sustainability in Higher Education [19] (p. 3). Reflection on the first decade of KSU efforts in academic sustainability would find that these sustainability efforts strengthened community and faculty relations, attracted students and prepared them for responsible citizenship, and advanced unification of "the campus around a shared sense of purpose" [19] (p. 4). This reflection is important because it provides an opportunity for assessing the human factors and obstacles that are influential in the integration of SD in this HEI. Furthermore, the insights garnered from the reflection process provide the foundation for our analysis.

4. Methods

In applied disciplines like engineering and business, case studies are popular educational and research tools. The same holds true in the social sciences in general and in the study of SD in HE in particular (for the advantages of case-study methodology in the social sciences, see George and Bennett [20]). According to Hoover and Harder, "case[-]study methodology has become one of the most common qualitative approaches in research on sustainability in HE" for it captures the complex nature and fluid boundaries of sustainability in academia [21] (p. 176). Case studies are a powerful method to convey the "sustainability story" of a university in ways that help define problems and help effect change [21]. These features make the case study an ideal research tool for examining sustainability within higher education [22]. Following suit, the research team applied the case-study methodology to a major southeastern university's sustainability quest. The approach, however, differed from the traditional case-study methodology in two ways: (1) it brought together two major theoretical frameworks and then applied them to KSU (see Section 2), and (2) it developed an overarching process model of organizational change for sustainability. Both of these contributions are in line with calls for case studies not only to make recommendations and provide strategic direction but also "to develop models or frameworks" that address the context-specific nature of sustainability in HEIs and the ensuing organizational change [21] (p. 177).

The team undertook a qualitative case study because of this design's "particularistic, descriptive, and heuristic" features [23] (p. 29). Specifically, this study focused on a specific situation of sustainability at a single institution of higher education (particularistic), included analysis of several variables, and their interplay, over time (descriptive), and aimed to enhance and extend a reader's understanding of the barriers to sustainability at an institution of higher education (heuristic) [23]. Corcoran et al.'s work [22] was integrated to ensure that the work met the criteria for a critical case study. Specifically, the team examined Corcoran et al.'s set of critical considerations for conducting case-study research in sustainability in higher education.

Focusing on SD at an HEI, KSU, the critical case study analyzed both the barriers and the change drivers to organizational change. To characterize the types of barriers based on Verhulst and Lambrechts' change-management theory [13], the team used the descriptions of each of the three elements of barriers to code the institutional information compiled. As outlined by Corcoran et al. [22] (p. 17), this task involved gathering information related to "the ecological, social[,] and economic dimensions of sustainability." Following Yin's definition of a case study, the team used "multiple sources of evidence" [24] (p. 23). This information included (1) KSU's mission and purpose of the institution, (2) curriculum and academic disciplines, (3) KSU faculty research, (4) KSU operations, (5) student opportunities, (6) faculty and staff development and awards/incentives, and (7) outreach and local community.

Additionally, a survey was administered to all KSU faculty to gather specific information on faculty perspectives on sustainability efforts at KSU and to identify barriers caused by a lack of awareness. An online survey was created to answer basic questions about faculty views of sustainability. The survey, "Sustainability-Related Attitudes and Behaviors among Faculty (Study 18–487)," was administered in late April and early May 2018 and completed by 467 individuals out of 1277 full-time faculty, a participation rate of almost 37 percent. The results of the survey participation were completely anonymous and no identifiers were collected from respondents. Survey questions were vetted through the Institutional Review Board to ensure unbiased examination.

As expected, not all descriptions within each barrier were pertinent to KSU. Therefore, specific barriers observed at KSU were delineated with a check mark in Table 1. For each SD barrier, corresponding empowerment-based actions taken by the KSU faculty were identified. Although identification of barriers and change drivers described the current climate at an HEI, it did not provide a plan or indicate an action that needed to be taken in order to break through the current barriers. Therefore, additional assessment was needed in order to initiate SD at HEI. This research characterized the barrier and empowerment findings in order to identify the impact of each change driver and, thus, determine the potential to overcome a barrier and implement SD.

Table 1. Change Barriers at KSU. Source: Comprehensive list of barriers adopted from Verhulst and Lambrechts [13].

Barriers to Change	Present at KSU
Related to Lack of Awareness	
1. Lack of interest and involvement of the majority of the students and staff members	
2. Lack of support by management and policy makers	✓
3. Lack of professionalization and training of teachers	
4. Lack of policy making in order to promote sustainability	✓
5. Lack of standard definitions and concepts of sustainable development (SD) in higher education (HE)	✓
6. Lack of recognition, change agents for SD are often not taken seriously	✓
7. SD seen as a threat to academic freedom and credibility	
8. SD is not seen as relevant to a certain course or discipline	✓
Related to the Structure of Higher Education	
9. Conservative disciplinary structure of HE institutions (HEIs), barely open to new paradigms	✓
10. Inefficient communication and shared information both top-down and bottom-up	✓
11. Resistance to change by education and research	
12. Focus on short-term profit as a result of managerial thinking and policy making in HE	
13. Lack of interdisciplinary research as a result of insufficient coordination and cooperation	✓
14. Overcrowded curriculum	
15. Focus on content-based learning	✓
Related to the Lack of Resources	
16. Lack of money, SD is not seen as a priority for funding	✓
17. High work pressure and lack of time; SD is often combined with other tasks	✓
18. Lack of access to information, due to absence of measuring instruments or by unwillingness of staff	
19. Lack of consistent legislation (phrased in this work as policy support from governing bodies)	✓
20. Lack of qualitative and quantitative performance indicators	
21. Technical problems	
22. Lack of physical place	

5. Results

The five-phase assessment of the current status of SD at KSU led to a list of barriers and associated change drivers, displayed in Table 2. The assessment phases were (1) identification of relevant barriers from Verhulst and Lambrechts [13], (2) identification of specific KSU barriers, (3) identification of change drivers at KSU, (4) designation of when the barrier emerged, and (5) the degree of significance or impact of each item (for a depiction of the process model, see Figure 2).

Once the research team observed that barriers specific to KSU often included all three elements from Verhulst and Lambrechts (i.e., awareness, structure, and resources), it organized the list so that the multiple dimensions of each barrier at KSU would be captured. KSU-specific barriers appeared in the far-left column, and the relevant elements from Verhulst and Lambrechts (V & L) were noted in the next three left-hand columns. (V & L cells without any text indicate that they were not relevant to KSU barriers; these were marked with an X.) In response to the barriers, current actions by the KSU sustainability community were included in the three right-hand columns. They were organized according to their origin: whether they arose from authority, on-hand resources and specialization, and/or self-determination. Barriers in existence before 2017 were listed at the top of the table, and those arising between 2017 and 2018 were placed at the bottom of the table.

Although this display of barriers and change drivers was useful, it suggested that all of the barriers were of equal significance and that all of the change drivers were of equal impact, which was not the case. Importantly, most barriers had no change driver in the "authority" category. Consequently, a subsequent step was added to characterize the degree of significance of the barriers and the significance or impact of each change driver in overcoming the barrier. This characterization was indicated by shading the cells of the table in order to provide an immediate visual of the difficulty of overcoming a barrier and the corresponding impact that identified change drivers had in response to the barrier. Cells with darker shading show a high degree of significance or impact, those with light shading indicate a moderate degree of significance or impact, and those with no shading indicate a low degree of significance or impact. When no change driver was listed in a cell, no action was occurring to address the related barrier, and these cells appeared with darker shading because the absence of any impact was highly significant. This design allowed the team to see at a glance the cells where change drivers were underway and those where barriers were unaddressed. In the barrier columns, the lighter the area, the less significant the current challenge. In the change-driver columns, the lighter the area, the more was being done to address the barrier though the impact of these efforts was low. Light shading indicated moderate impact, which was possible when administrators funded events or recognized SD. Dark shaded change-driver cells indicated areas that were of great significance but had *no* empowerment efforts underway. This step revealed the following about KSU barriers:

1. Five of 10 barriers were of high significance; 5/10 barriers were of moderate significance. There were no low-significance barriers.
2. Six of 10 barriers had three dimensions; 3/10 had two dimensions, 1/10 had one dimension. KSU barriers were complex.

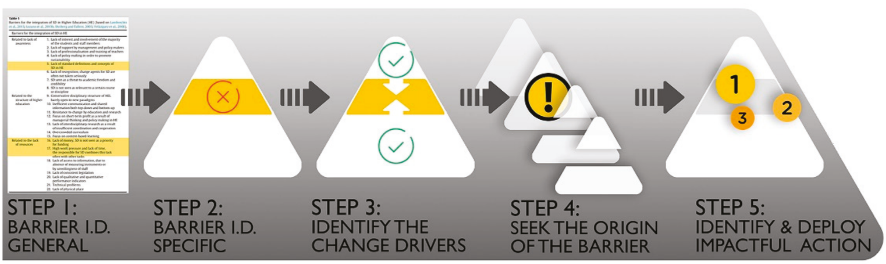


Figure 2. Process model of change in higher education institutions (HEIs) looking to implement sustainable development (SD). Source: Research Team.

This step revealed the following about KSU change drivers:

1. Only one moderate-level change driver existed in the authority dimension; this dimension was missing in nine change-driver cells. The absence of authority change drivers showed how current SD change agents were limited in their power.
2. No existing change drivers were of high impact. Sixteen of 17 existing change drivers were of moderate impact; 1/17 was of low impact.
3. Only 2/10 self-determination cells had no change driver; if actions existed in these cells, one (about university-wide funding) would be significant, but the other (about the state emphasis on student retention, degree progression, and timely graduation) would likely have only low impact because SD advocates were unlikely to influence state-level oversight at the Board of Regents.

Table 2. Current Assessment of Barriers and Change Drivers Using the Conceptual Model (2017–2018). Source: Research Team.

	Verhulst & Lambrechts' Barriers to Integration of SD in HEI			Dimensions of Empowerment as a Change Driver		
Barriers at KSU	**Awareness**	**Structure**	**Resources**	**Authority**	**Resources & Specialization**	**Self-Determination**
			Barriers Existing Before 2017			
Narrowly disciplinary & unintegrated SD concept	(5) Lack of standard definitions & concepts of SD in HE (8) SD is not seen as relevant to a certain course or discipline	(9) Conservative disciplinary structure of HEI, barely open to new paradigms	(16) Lack of money; SD is not seen as a priority for funding (17) High work pressure & lack of time; the responsibility for SD tasks is combined with other tasks (19) Lack of consistent [policy support from governing bodies]	• No change driver	• Use of broad & interdisciplinary UN Sustainability Goals to frame funded campus events such as Equinox Week. • Demonstrate how SD curriculum meets university strategic goals of transformational learning & action step of high-impact teaching.	• Active participation of SD change agents in SD campus events.
SD not part of general education or career development for all students; Faculty & administrators view SD as relevant only to a few disciplines (e.g., biological sciences, engineering, & architecture) The relevance to arts, humanities, social sciences, business, & education is not broadly accepted.	(2) Lack of support by management & policy makers (4) Lack of policy making to support SD (8) SD is not seen as relevant to a certain course or discipline	(9) Conservative disciplinary structure of HEI, barely open to new paradigms (10) Inefficient communication & shared information both top-down & bottom-up (15) Focus on content-based learning	(19) Lack of consistent [policy support from governing bodies]	• No change driver	• Demonstrate how SD curriculum meets university strategic goals of transformational learning & action step of high-impact teaching. • Events such as Equinox Week that highlight the interdisciplinarity of SD. • Use of commission meetings as a forum to inform university leaders.	• Collaboration of faculty to demonstrate interdisciplinarity (e.g., team-taught courses & projects). • External publication by an interdisciplinary team of faculty. Risky move for junior faculty with conservative department chairs & deans. • Curriculum planning by Faculty Learning Community (FLC).
SD has no university-wide academic funding	(2) Lack of support by management & policy makers (4) Lack of policy making to support SD		(16) Lack of money; SD is not seen as a priority for funding	• No change driver	• Use of commission meetings as a forum to inform university leaders.	• No change driver

Table 2. *Cont.*

	Verhulst & Lambrechts' Barriers to Integration of SD in HEI			Dimensions of Empowerment as a Change Driver		
Barriers at KSU	**Awareness**	**Structure**	**Resources**	**Authority**	**Resources & Specialization**	**Self-Determination**
			Barriers Existing Before 2017			
No state-level policy support for SD from the Board of Regents that oversees the university	(2) Lack of support by management & policy makers (4) Lack of policy making to support SD		(19) Lack of consistent [policy support from governing bodies]	• No change driver	• Use of commission meetings as a forum to inform university leaders.	• Faculty advocacy for a return of university support for SD because of its new status as an R2 institution, aligning the institution more fully with others in its class.
No clearinghouse for faculty with SD research interests to meet & collaborate	(2) Lack of support by management & policy makers (4) Lack of policy making to support SD	(10) Inefficient communication & shared information both top-down & bottom-up	(17) High work pressure & lack of time; the responsibility for SD tasks is combined with other tasks.	• No change driver	• Demonstrate that SD research is what strategic plan describes as "purposeful and relevant research" worthy of university support.	• A survey of faculty, which has drawn attention to the range of disciplines engaged in SD issues, teaching content, & research.
Low awareness of SD award winners & their achievements	(6) Lack of recognition; change agents for SD are often not taken seriously	(10) Inefficient communication & shared information both top-down & bottom-up		• No change driver	• Use of commission meetings as a forum to inform university leaders. • Gratitude for faculty awards & participation in existing programs.	• Commission members' & others' diplomatic but specific advocacy for renewed university support for SD.

Table 2. *Cont.*

Barriers at KSU	Verhulst & Lambrechts' Barriers to Integration of SD in HEI: Awareness	Structure	Resources	Dimensions of Empowerment as a Change Driver: Authority	Resources & Specialization	Self-Determination
Barriers Emerging in 2017–2018						
Elimination of Sustainability Director position	(2) Lack of support by management & policy makers. (6) Lack of recognition; change agents for SD are often not taken seriously	(10) Inefficient communication & shared information both top-down & bottom-up (13) Lack of interdisciplinary research as a result of insufficient coordination & cooperation	(16) Lack of money; SD is not seen as a priority for funding	• No change driver	• Use of commission meetings as a forum to inform university leaders. • Link director job to university goal of transformational learning & action step of high-impact teaching practices in strategic plan.	• Commission members' & others' diplomatic but specific advocacy for renewed university support for SD. • Opportunistic modification of existing FLC to advance SD.
No authority present to promote or implement SD curriculum or reporting to academic organizations	(2) Lack of support by management & policy makers (4) Lack of policy making to support SD (6) Lack of recognition; change agents for SD are often not taken seriously (8) SD is not seen as relevant to a certain course or discipline	(9) Conservative disciplinary structure of HEI, barely open to new paradigms	(16) Lack of money; SD is not seen as a priority for funding	• Future visit of university president to Sustainability Commission m	• Use of CETL program to create a FLC to support curricular innovation. • Use of commission meetings as a forum to inform university leaders.	• FLC work to identify arguments for renewed support & advocate for it via traditional activities such as publications & presentations.
A state emphasis on student retention, degree progression, & timely graduation limits the abilities of faculty to design new programs.	(2) Lack of support by management & policy makers (4) Lack of policy making to support SD	(15) Focus on content-based learning	17) High work pressure & lack of time; the responsibility for SD tasks is combined with other tasks.	• No change driver	• Demonstrate how SD curriculum meets university strategic goals of transformational learning & action step of high-impact teaching.	• No change driver
New R2 designation places faculty under new pressure to publish & creates disincentives for curriculum development (as service work) as opposed to research.	X	X	(17) High work pressure & lack of time; the responsibility for SD tasks is combined with other tasks.	• No change driver	• Demonstrate that SD research is what strategic plan describes as "purposeful and relevant research" worthy of university support.	• External publication by an interdisciplinary team of faculty (risky move for junior faculty with conservative department chairs & deans). • Faculty advocacy for the value of interdisciplinary SD research & for policy changes that protect faculty who engage in it.

Key to shading: High degree of significance or impact: [grey] Moderate degree of significance or impact: [light grey] Low degree of significance or impact: [white] X in a cell means that the V & L barrier is not relevant to the situation at KSU.

6. Discussion

In developing a process model for SD in HEIs (Figure 2), we addressed "the need for more theory-building and generalization" [17] (p. 162). From a theoretical perspective, our process model built on existing work by combining a comprehensive list of barriers with three dimensions of empowerment into a holistic framework. From a generalizability standpoint, our process model provided a useful tool for driving change at other HEIs. Although the interpretation of both the size of barriers and the adequacy of the change drivers was specific to KSU, the process was valuable for the research team in determining its strategy for moving forward. The same holds true for other HEIs that can use the same process for their own strategic purposes. The process model developed here also presents several benefits for addressing transformative organizational change at HEIs. Principally, it provides a structured method to analyze and prioritize barriers to change, and the related impact of empowered efforts on the pathway toward integration of SD. The benefits of the process model in relation to each of the three dimensions of empowerment are discussed below.

By placing barriers within an empowerment framework, the process model helps identify those barriers that are the most significant and difficult to overcome. The framework allowed the team to identify ways in which some KSU barriers presented difficulty in multiple dimensions because they were related to a lack of awareness, structure in HE, lack of resources, or a combination of those factors. We found that 50 percent of the barriers were of high significance and 60 percent involved three dimensions (Table 2), pointing to the complexity of KSU's barriers in general.

Among them, it was obvious that the most significant barrier to integrating SD at KSU was the retirement of and failure to replace the director of sustainability. This barrier was highly significant because it affected virtually all aspects of empowerment through authority. The long-established director position was eliminated in the spring of 2018. It had created a point person for university-wide SD, but after the person who had held the job retired, support from the Academic Affairs Office declined in awareness (understanding the value of the position), structural support (an authority and a locus of SD activity), and resources (the time and focus to advance SD). With no one assigned to report to the university president about sustainability or lead university-wide efforts, the academic branch of KSU's sustainability effort met with significant setbacks that jeopardized its upward trajectory in gaining participation of both faculty and students on its campuses. The vital role that the KSU faculty had played, and needed to continue playing, to seek academic sustainability benefits was placed at risk. KSU was once a state leader in sustainability, but it no longer is, having been surpassed by both nearby private institutions and by sister public institutions such as the University of Georgia, Georgia Southern University, and University of West Georgia. These institutions have reliable financial support, academic sustainability directors, and either certificates or concentrations available to all undergraduates.

Research in SD routinely concludes that the support of a university's leadership is important to establishing academic sustainability instruction and campus-wide resources for students and faculty [25,26]. Barth goes so far as to state that "active top-down support is essential" [25] (p. 142). To create a thriving environment for sustainability, university leadership needs to establish a vision of campus sustainability and support it consistently for it to take root and flourish. Leadership's role includes building a team with a collective vision, taking action from that vision, and using the vision to empower the campus. A vision of sustainability has the potential to stall or fail at any of these junctures [27]. In KSU's case, sustainability efforts stalled when the former director of sustainability retired and the university experienced successive changes in upper administration. Lacking leaders who share a "sustainability ethos" [27] (p. 80), the state of SD at KSU is in question. To commit to SD, the university needs future-oriented, transformative, and silo-busting leaders who make sustainability a priority [1]. Like other HEIs, KSU needs leaders who empower employees to forge ahead in their sustainability quest and change agents who see the worth in educating future generations about sustainability. Rather than seeing a lack of authority as insurmountable, empowered faculty can effect change through other dimensions of empowerment.

Another benefit of the process model is that it allowed us to identify barriers that are more easily surmountable (i.e., the "low-hanging fruit") and where change drivers can address multiple barriers and therefore have the greatest impact. Below we describe a few examples of these barriers and how they can be addressed through resources and specialization and through self-determination.

For KSU the most important resources include university policies, and venues that provide opportunities for networking among different organizational units. As an example of a relatively easily surmountable barrier, KSU faculty had no mechanism to become aware of each other's sustainability research efforts and therefore develop SD collaborations (see Table 2; row "No clearinghouse"), despite widespread interest in sustainability as indicated by our survey. Therefore, the creation of this clearinghouse is an obvious next step and it should be supported by the KSU strategic plan, which includes support for purposeful and relevant research (suitably broad). In this regard, any existing organizational policy that contains missions or goals supporting the advancement of SD is a valuable resource. Creating the clearinghouse could include something as simple as publishing the sustainability-related research activity of faculty on the KSU Sustainability website (the website already exists and requires minimal investment of additional resources). While this act has a relatively low impact, it could be used to start a coordinated SD network for research and teaching at KSU.

As an example of where resources and specializations can address multiple barriers, KSU's narrowly disciplinary and unintegrated concept for SD comprised six separate V&L barriers, so it is a major impediment to an integrated curriculum program (such as an academic sustainability certificate available to all students across all majors). SD advocates who are full-time faculty, can respond meaningfully to this multi-faceted barrier by highlighting the interdisciplinarity inherent in current university-wide events. For example, KSU already holds an annual "Equinox Week" celebration and symposium organized according to the UN Sustainability Goals, and this allows disparate departments to network. Here again, policy is an important resource. Faculty can demonstrate that SD in general and a certificate in particular would aid the university in pursuing its Strategic Plan. This plan includes the goal of transformational learning and an action step of high-impact teaching; in turn, these are linked in university documents to student research projects, internships, and project- and service-learning [28]. By using the university-approved terminology and by emphasizing the relevance of SD to its new plans, advocates can demonstrate that SD is a broad content-based mechanism toward "transformational learning" because students value education that they readily identify as relevant to their personal life choices, their career options, and the quality of life in their globally connected communities.

Meetings of the KSU Presidential Commission on Sustainability were also identified as a networking resource that could address multiple barriers. The meetings are vital to the success of SD because they are the primary venue for sharing pertinent information among disparate branches of the university. Members of the Commission include students, faculty, administration, and staff representing a wide array of different disciplines and operational divisions. Importantly, anyone can attend and present at these meetings. The meetings are also a key venue for interaction with authorities including the university president. While the new KSU president has not yet attended a meeting, the research team expects that a planned upcoming visit will help the Commission address the lack of awareness, policies, resources, and support.

At KSU, the lack of authority and paucity of resources with potential for high impact means that self-determination becomes the dimension of empowerment with chief importance. Indeed only 2 out of 10 barriers in Table 2 have no change driver identified for self-determination (lack of campus-wide funding, and state-level educational priorities that prevent new SD programming). Among the rest, self-determination at KSU is often unsurprising in form; change drivers have been maintaining participation in SD-related events or continuing to advocate for administrative support. However, in 2017 a group of faculty opportunistically gained support (for books and travel) from the KSU's Center for Excellence in Teaching and Learning (CETL) to form a Faculty Learning Community (FLC), which has since modified its plan of work to advance SD and address multiple barriers. Initial work focused on addressing the lack of SD in general education curricula, and later the development and implementation of the faculty survey. These efforts are still in process and could have lasting impact over the long term. For instance, if the director position is re-established, the FLC is well poised to suggest a certificate program, and the survey results can be used as the starting point for a research clearinghouse or networking directory. The FLC also identified ways that the broader KSU faculty can enhance the resiliency of SD in the absence of authority (see Table 3). These are actions of self-determination whose impact is directly proportional to the number of individuals who carry them out.

Table 3. Approaches for faculty to enhance campus sustainability efforts in HEIs. Source: Research Team.

	Faculty Resilience **Approaches for Individuals and Small Groups of Faculty**
Resources	• Observe energy, water, and materials conservation practices on campus and explain them to colleagues and students • Pursue autonomous efforts in teaching and publication • Participate in university-sanctioned committee activities in departments, colleges, and campus-wide situations • Seek funding from external sources (e.g., sustainability-related grants and fellowships) • Apply for sustainability-related awards
Academics	• Inform oneself of disciplinary connections to sustainability • Draw attention to sustainability topics in classes with examples • Demonstrate relevance of discipline-specific topics and issues to sustainability in classes • Develop research and scholarship projects that are linked to sustainability • Disseminate sustainability-related research findings through conferences, symposia, and publications
Innovation	• Highlight sustainability in department- and college-level concerns • Seek ways to shift the focus of existing campus programs toward sustainability topics and issues • Advance sustainability through innovative research topics and teaching techniques
Community	• Champion sustainability on and off campus • Contact like-minded faculty colleagues and share interests • Identify community partners such as businesses and nonprofit groups (e.g., clubs, civic groups, and churches) • Promote local service-learning assignments, internship, and co-op opportunities that connect to sustainability for students • Describe connections between sustainability and local groups, particularly as they affect future careers for graduates
Collaboration	• Undertake team teaching on sustainability topics • Undertake collaborative writing and research projects • Develop and offer interdepartmental sustainability-related workshops • Create ecocentric clubs for faculty • Participate in faculty learning communities on sustainability

Verhulst and Boks include "initiative, creativity and autonomy" under self-determination [16] (p. 93). These factors tie into Brinkhurst et al.'s idea of achieving change in HEIs by empowering faculty and staff, the middle part of the organization. In fact, "the greatest potential for long-term change comes from active intrapreneurship by faculty and staff" [11] (p. 351). Understanding the complexities of HEIs, faculty and staff can act as change agents who effect change within organizational boundaries. Change at the faculty/staff level is "'middle-out' change" or transformative change from within [11] (p. 340). Faculty, however, differ from staff in terms of expertise and specialization. As specialists who can understand and relay technical information, faculty are "'transmitters' of implementation processes" [17] (p. 172). They can effect change by serving to bridge the gap between administrators and other campus agents such as staff and students [17]. As the research team discovered, faculty can also act as self-sufficient innovators—change agents who take it upon themselves to introduce micro-change and push for macro-change.

7. Limitations and Future Research

At KSU, the process model suggested that, given the lack of authority and resources, self-determination is the most promising dimension of empowerment; therefore, expectations for advancing change should be tempered for the time being. However, there are several caveats to this outcome. While the process model captured some of the complexity of the change process in HEIs, it does not consider all university stakeholders (e.g., academic staff, plant operations staff, students, etc.). The selected framework focused on change driven by the middle rungs–only faculty. The role of staff still needs to be considered [17]. For example, feedback from academic and plant operations staff as well as from students will provide a more comprehensive look at barriers and change drivers from the perspective of all stakeholders at the institution. The reinstatement of authority figures such as the director of sustainability, or increased advancement of SD from senior administrators, could rapidly eliminate barriers and shift the expectations for change. KSU's leadership has changed rapidly in the last few years, and there is no indication that it has stabilized. Indeed, the model's outcomes were dependent upon the choice of framework used for identifying barriers and change drivers. Frameworks focusing on other aspects of organizational change may lead to different conclusions. A Socio-Technical Systems Thinking framework, for example, may be particularly suited for SD in HEIs, given the complexity of both sustainability *and* institutions of higher learning (for an overview, see Davis and Coan [5]). Ideally, HEIs should evaluate their progress toward SD through multiple frameworks. Though the discovery process is essentially the same, other HEIs may find alternative frameworks more suitable. Additionally, the organizational culture [29] and the types of change (e.g., planned versus emergent versus contingency) [5] sought may influence an HEI's chosen approach.

Finally, once the discovery process is complete, the next phase is discipline-based planning where faculty are rapidly brought up to speed regarding SD, including the results of discovery and the contributions of SD early adopters (for a discussion of the steps following the discovery phase, see Chambers, 2013) [30]. Although the discovery process may receive re-evaluation and re-iteration if its outcomes somehow do not lend themselves toward discipline-based planning, in the case of KSU, the process model has yielded useful information for advancing SD (Table 2).

8. Conclusions

The intellectual project of this work began with an effort to strategically advance SD in one HEI in order to overcome perennial and new barriers to establish an integrated program encompassing operations, administration, and academics. Though the research team initially thought that KSU's SD experience of setbacks and challenges was unique, it discovered that, though the details were individualized to the institution, the arch of the project was not atypical. Consequently, the search for an approach to respond to current circumstances revealed how much the team could learn from others' similar struggles and, further, the change-management literature they had generated. This work is intended to provide others with a way to analyze an HEI's distinctive situation thoroughly and dispassionately, producing new insights into the available change drivers and specific behaviors and actions that SD change agents should adopt to enable success. As Neil B. Weissman explains in the Association for American Colleges and Universities' journal Liberal Education,

> Experts in careers related to sustainability particularly require the ability to constantly remake their technical training in an arena in which successful strategies must be flexible and adaptive. Moreover, the integrative nature of sustainability challenges gives rise to a demand for "translators," professionals with the understanding and communication skills to carry knowledge across the boundaries that divide communities of experts, policy makers, and the public. [31] (p. 8)

Though its proponents see SD as an obvious priority in a twenty-first-century university, others may not. Proponents must translate the value and relevance of SD for others. To do so, they must adopt proactive resilience as an approach. Just as an individual person makes changes in behaviors and routines incrementally to support the sustainability of the planet and all its species, shifts toward academic sustainability should be expected to occur gradually as well. If an institution truly wants to meet the needs of its time, essential re-imaginings of traditional approaches to fulfilling its mission will follow. Vijaya Deshmukh lists the breadth of the goals that pertain to SD and must be pursued through collaboration and sharing; these include

> [i]ntegrating actions of conservation and human development, satisfying basic human needs, achieving equality and social justice for all, facilitating social self-determination and cultural diversity, managing legacy for future generations, maintaining ecological integrity, [and] developing new technologies and product manufacturing processes. [32] (p. 3)

These are obviously goals in keeping with the mission of most HEIs, so proponents need to make the case and make it as desirable as possible for those with authority to invest in SD.

Author Contributions: E.E.A.II., E.G., D.G., A.G., M.K.H., V.S.-F., and M.W. contributed equally to the paper.

Funding: Funding for this research was provided by the Kennesaw State University Center for Excellence in Teaching and Learning (CETL), the College of Humanities and Social Sciences, the College of Science and Mathematics, and the College of Architecture and Construction Management.

Acknowledgments: We gratefully acknowledge Kennesaw State University's Center for Excellence in Teaching and Learning (CETL) for its support of the Sustainability Faculty Learning Community (FLC) during AY 2017 and AY 2018. CETL supplied research materials and travel funding to the members of the FLC. In addition, we acknowledge the support and encouragement of the members of KSU's Presidential Commission on Sustainability as well as the Office of Diversity and Inclusion, longstanding proponents of campus sustainability initiatives.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Scott, G.; Tilbury, D.; Sharp, L.; Deane, E. *Turnaround Leadership for Sustainability in Higher Education: Executive Summary 2012*; Department of Industry, Innovation, Science, Research and Tertiary Education, Australian Government Office for Learning and Teaching: Sydney, NSW, Australia, 2012; pp. 1–21; ISBN 978-1-922218-01-8.
2. Robertson, J.L.; Barling, J. Greening Organizations through Leaders' Influence on Employees' Pro-environmental Behaviors. *J. Organ. Behav.* **2013**, *34*, 176–194. [CrossRef]
3. Robertson, J.L.; Barling, J. The Role of Leadership in Promoting Workplace Pro-environmental Behaviors. In *The Psychology of Green Organizations*, 1st ed.; Robertson, J.L., Barling, J., Eds.; Oxford University Press: New York, NY, USA, 2015; pp. 164–186; ISBN 978-0-19-999748-0.
4. Robertson, J.L.; Carleton, E. Uncovering How and When Environmental Leadership Affects Employees' Voluntary Pro-environmental Behavior. *J. Leadersh. Organ. Stud.* **2018**, *25*, 197–210. [CrossRef]
5. Davis, M.; Coan, P. Organizational Change. In *The Psychology of Green Organizations*, 1st ed.; Robertson, J.L., Barling, J., Eds.; Oxford University Press: New York, NY, USA, 2015; pp. 244–274; ISBN 978-0-19-999748-0.

6. Cortese, A.D. The Critical Role of Higher Education in Creating a Sustainable Future. *Plan. High. Educ.* **2003**, *31*, 15–22. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.607.6556&rep=rep1&type=pdf (accessed on 18 December 2018).
7. Avissar, I.; Alkaher, I.; Gan, D. The Role of Distributed Leadership in Mainstreaming Environmental Sustainability into Campus Life in an Israeli Teaching College: A Case Study. *Int. J. Sustain. High. Educ.* **2018**, *19*, 518–546. [CrossRef]
8. McMillin, J.; Dyball, R. Developing a Whole-of-University Approach to Educating for Sustainability: Linking Curriculum, Research and Sustainable Campus Operations. *J. Educ. Sustain. Dev.* **2009**, *3*, 55–64. [CrossRef]
9. Fien, J. Advancing Sustainability in Higher Education: Issues and Opportunities for Research. *Int. J. Sustain. High. Educ.* **2002**, *3*, 243–253. [CrossRef]
10. Lozano, R.; Lukman, R.; Lozano, F.J.; Huisingh, D.; Lambrechts, W. Declarations for Sustainability in Higher Education: Becoming Better Leaders, through Addressing the University System. *J. Clean. Prod.* **2013**, *48*, 10–19. [CrossRef]
11. Brinkhurst, M.; Rose, P.; Maurice, G.; Ackerman, J.D. Achieving Campus Sustainability: Top-down, Bottom-up, or Neither? *Int. J. Sustain. High. Educ.* **2011**, *12*, 338–354. [CrossRef]
12. Aleixo, A.M.; Leal, S.; Azeiteiro, U.M. Conceptualization of Sustainable Higher Education Institutions, Roles, Barriers, and Challenges for Sustainability: An Exploratory Study in Portugal. *J. Clean. Prod.* **2018**, *172*, 1664–1673. [CrossRef]
13. Verhulst, E.; Lambrechts, W. Fostering the Incorporation of Sustainable Development in Higher Education. Lessons Learned from a Change Management Perspective. *J. Clean. Prod.* **2015**, *106*, 189–204. [CrossRef]
14. Verhulst, E. The Human Side of Sustainable Design Implementation from the Perspective of Change Management. Doctoral Thesis, University of Antwerp, Antwerp, Belgium, 2012.
15. Lambrechts, W.; Verhulst, E.; Rymenams, S. Professional Development of Sustainability Competences in Higher Education: The Role of Empowerment. *Int. J. Sustain. High. Educ.* **2017**, *18*, 697–714. [CrossRef]
16. Verhulst, E.; Boks, C. Employee Empowerment for Sustainable Design. *J. Corp. Citizen.* **2014**, *55*, 73–101. Available online: https://www.jstor.org/stable/jcorpciti.55.73 (accessed on 18 December 2018). [CrossRef]
17. Barth, M. Many Roads Lead to Sustainability: A Process-Oriented Analysis of Change in Higher Education. *Int. J. Sustain. High. Educ.* **2013**, *14*, 160–175. [CrossRef]
18. Rodriguez, Y.R.C. Paul: "Father of Sustainability". 2013. Available online: http://news.kennesaw.edu/stories/2013/RC-Paul-Father-of-Sustainability.php (accessed on 18 December 2018).
19. AASHE (The Association for the Advancement of Sustainability in Higher Education). *Beyond the Right Thing to Do: The Value of Sustainability in Higher Education*. 2017, pp. 1–5. Available online: http://www.aashe.org/wp-content/uploads/2017/10/AASHE_2017_BeyondRightThingToDo_Brochure.pdf (accessed on 18 December 2018).
20. George, A.L.; Bennett, A. *Case Studies and Theory Development in the Social Sciences*, 1st ed.; MIT Press: Cambridge, MA, USA, 2005; ISBN 0-262-57222-2.
21. Hoover, E.; Harder, M.K. What Lies Beneath the Surface? The Hidden Complexities of Organizational Change for Sustainability in Higher Education. *J. Clean. Prod.* **2015**, *106*, 175–188. [CrossRef]
22. Corcoran, P.B.; Walker, K.E.; Wals, A.E.J. Case Studies, Make-your-case Studies, and Case Stories: A Critique of Case-study Methodology in Sustainability in Higher Education. *Environ. Educ. Res.* **2004**, *10*, 7–21. [CrossRef]
23. Merriam, S.B. *Qualitative Research and Case Study Applications in Education, Revised and Expanded from Case Study Research in Education*, 2nd ed.; Jossey-Bass Publishers: San Francisco, CA, USA, 1998; ISBN 0-7879-1009-0.
24. Yin, R.K. *Case Study Research Design and Methods*, 2nd ed.; Sage Publications: Newbury Park, CA, USA, 1989; ISBN 0-8039-3471-8.
25. Barth, M. *Implementing Sustainability in Higher Education*, 1st ed.; Routledge: New York, NY, USA, 2015; ISBN 978-0-415-83374-5.
26. Barlett, P.F.; Chase, G.W. *Sustainability in Higher Education: Stories and Strategies for Transformation*, 1st ed.; MIT Press: Cambridge, MA, USA, 2013; ISBN 978-0-262-51965-6.
27. Thomashow, M. *The Nine Elements of a Sustainable Campus*, 1st ed.; MIT Press: Cambridge, MA, USA, 2014; ISBN 978-0-262-02711-3.
28. Kennesaw State University. *We Prepare Students for Better Lives*. 2018–2023 Strategic Plan. Available online: https://planning.kennesaw.edu/docs/KSU_StratplanLettersize_p2A.pdf (accessed on 18 December 2018).

29. Weick, K.E.; Quinn, R.E. Organizational Change and Development. *Ann. Rev. Psych.* **1999**, *50*, 361–386. [CrossRef] [PubMed]
30. Chambers, D.P. A Discipline-Based Model for Embedding Sustainability in University Curricula. In *Sustainability Assessment Tools in Higher Education Institutions: Mapping Trends and Good Practices around the world*, 1st ed.; Caeiro, S., Filho, W.L., Jabbour, C., Azeiteiro, U.M., Eds.; Springer International Publishing: Cham, Switzerland, 2013; pp. 309–321; ISBN 978-3-319-02374-8.
31. Weissman, N.B. Sustainability and Liberal Education: Partners by Nature. *Lib. Educ.* **2012**, *98*, 6–13. Available online: https://www.aacu.org/publications-research/periodicals/sustainability-liberal-education-partners-nature (accessed on 18 December 2018).
32. Deshmukh, V. Achieving Resiliency through Sustainable Literacy. In *Handbook of Theory and Practice of Sustainable Development in Higher Education*, 1st ed.; Filho, W.L., Azeiteiro, U.M., Alves, F., Molthan-Hill, P., Eds.; Springer International Publishing: Cham, Switzerland, 2017; Volume 4, pp. 3–13; ISBN 978-3-319-47876-0.

sustainability

Article

Transition to Sustainability in Macro-Universities: The Experience of the National Autonomous University of Mexico (UNAM)

Ken Oyama [1], Ayari G. Pasquier [2,*] and Edgar Mojica [2]

1 Escuela Nacional de Estudios Superiores (ENES)-Morelia, UNAM, Morelia 58190, Mexico; kenoyama@unam.mx
2 Secretaría de Desarrollo Institucional, UNAM, Mexico City 04510, Mexico; emojica@unam.mx
* Correspondence: ayari.pasquier@unam.mx; Tel.: +52-55-5622-1187

Received: 25 October 2018; Accepted: 15 December 2018; Published: 18 December 2018

Abstract: In this paper, we assess the challenges of macro-universities to incorporate sustainability as an integral dimension of their activities and institutional development, and as a public higher education institutions that have an important role in sustainable development in the Global South. To this end, we analyzed the efforts oriented towards incorporating sustainability into research and teaching agendas, as well as the campus management activities of the Universidad Nacional Autónoma de México (UNAM), a university with national presence and a community of more than 420,000 people comprising students, academics and administrative staff. UNAM has historically been one of the most important research and teaching institutions in Latin America. The analysis incorporates quantitative and qualitative data, relying on information sources such as the databases of the University regarding research and teaching, institutional documents and interviews with key actors. This study argues that inter-institutional articulation is a key factor to integrate the increasing sustainable initiatives promoted in the last decade but also one of the main challenges in the consolidation of macro-universities as sustainable universities.

Keywords: sustainable university; public university; macro-universities; institutional design; global south; Mexico; UNAM

1. Introduction

The importance and potential contributions of higher education institutions (HEIs) to sustainable development were formally recognized since the early 1970s in the Club of Rome report (1972) [1] and the Stockholm Declaration (1972) [2]. However, it was not until the 1990s that universities began to formally commit themselves to the development of a sustainable world. One of the first and most important initiatives in this regard was the Talloires Declaration (1990) [3], a ten-point action plan for incorporating sustainability and environmental literacy in teaching, research, and campus management that has been ratified by more than 500 colleges and universities around the world. This first initiative was followed by many meetings, statements and reports, as well as the founding of international associations focused on promoting sustainability in universities. More recently, these efforts have been endorsed within the framework of the 2030 Agenda [4], composed by 17 goals and 169 targets through which the United Nations seek to promote sustainable development worldwide. This Agenda identifies universities as key actors for the generation of knowledge and the education of future leaders, decision makers, entrepreneurs and citizens and proposes that the incorporation of sustainability in the governance, management and culture of universities is valuable in itself and has potential value for the implementation of sustainable trans-sectorial initiatives.

Over the last two decades, HEIs have progressively introduced sustainability into research, academic plans and campus management [5,6]. Some of them have achieved substantial progress in this process; in general terms, however, the progress has been uneven if we consider the different topics included in the idea of a sustainable university or the realities of HEIs in the world, and there are still many challenges to overcome [7], especially for HEIs in the Global South, a subject that to date has received little attention.

This paper analyzes the challenges faced by macro-universities for integrating sustainability into their substantive tasks through the case of the Universidad Nacional Autónoma de México (UNAM). The preliminary results of this research were presented at the 2018 International Sustainable Campus Network Conference. We consider macro-universities as those universities that: Have the highest enrolment rates nationwide; cover different areas of knowledge in the natural and social sciences, technology, humanities, arts and culture; conduct research and postgraduate teaching tasks in national and international arenas; receive a significant percentage of the national budget of the higher education system; and are in charge of the custody and development of important national historical and cultural heritage [8].

For the development of our case study we propose the following research questions:

- What progress has the UNAM made in the incorporation of sustainability in its substantive tasks (teaching, research and extension of culture) and the management of its campuses in the last 10 years?
- How have these initiatives contributed to the transformation of UNAM into a sustainable university?
- What are the main challenges that this institution faces in order to consolidate itself as a sustainable university in the future?

2. Literature Review

The literature on sustainability in universities has developed widely in recent years. The main topics discussed in these studies are: Management tools for green campuses, contributions of universities to sustainability and education for sustainable development [9]. The analysis of the challenges faced by HEIs in consolidating themselves as sustainable universities has also been central topic in this literature. Following Brandli et al. (2015), we distinguish between external and internal challenges [10]. The main external factors identified are the lack of interest and commitment of government bodies and the public in sustainability [11,12]. Amongst internal factors, the lack of interest of university authorities and the consequent lack of resources dedicated to this area [9,13–15] stand out for their importance. The low priority given to sustainability in the management and development of universities translates, in turn, into the absence or inefficiency of a sustainability office responsible for promoting and coordinating activities linked to sustainability in universities [12,16]. The literature explains this situation by referring to the lack of knowledge on the importance and implications of the sustainability of universities [17,18] and on the potential of sustainable management strategies to minimize costs and recover investments. Other obstacles frequently mentioned in the literature are the lack of planning [10,15] and management instruments [15,19] to integrate sustainability into university activities, as well as the absence of specific goals [20] and monitoring mechanisms to measure the achievements made [21]. Some authors also point out that although a growing number of HEIs are making efforts to include sustainability in their planning and activities, the analysis of the sustainable development plans and strategies of universities shows that they often lack a holistic vision of sustainability [12,17] and that they usually prioritize the teaching and the operational management of university campuses [18], whereas they neglect research and culture [21]. In this investigation we are particularly interested in the discussion of the conditions that affect the organizational change for sustainability to become a "whole institutional approach" in higher education institutions, as outlined by the United Nations Educational, Scientific and Cultural Organization (UNESCO) Global Action Programme on Education for Sustainable Development [22]; an important emergent field of research [23,24].

Speaking specifically about research, the literature highlights that promoting interdisciplinarity has been difficult because universities still have a disciplinary structure [5,25–28] and academics have been trained in disciplinary traditions and lack epistemological, methodological and theoretical tools to establish an interdisciplinary dialogue and develop problem-oriented approaches [14]. Furthermore, publications and academic evaluations are mostly organized following disciplinary criteria and there are not enough incentives for researchers to become involved in interdisciplinary collective projects [29].

In regard to teaching, the importance of developing specialised study programs on sustainability issues is underlined and, at the same time, introducing sustainability in all the study programs. This process is considered a key indicator of universities' commitment to sustainability, yet it is recognized that universities face great challenges [30,31] in the construction of an interdisciplinary practice, and the integration of sustainability as a part of the knowledge and teaching tools of teachers [32]. To date, the development of new programs focused on sustainability issues has been successful, but the introduction of sustainability as a transversal dimension in academic offers shows slower progress. The main factors that have hindered this are the lack of a clear institutional mandate to consider sustainability as a transversal element of the academic offers of universities and the institutional capacity to act and acquire the necessary academic tools to do so [33].

Regarding the operational management of campuses, the literature identifies as central obstacles the diversity of uses of university facilities, including research offices, laboratories, classrooms, libraries, coffee shops, auditoriums, sports facilities, and administrative rooms; the divergence of interests between researchers, students and administrators [12–14]; and the lack of implementation of sustainable technologies. Such technologies, aside from improving the efficiency of resource use, contributes to the diffusion of sustainability principles in the university community and allows developing strategies that can be implemented in other contexts, following the model known as 'living lab,' where university campuses are considered privileged spaces for applied teaching and research around sustainability [34,35].

3. Case Study Description

As stated above, this paper reports a case study focused on the process of incorporating sustainability into the substantive tasks of UNAM, the main university in Mexico and one of the most important research and teaching institutions in Latin America. UNAM was formally constituted as a public university in 1910, although its history dates back to 1551 [36]. Its central campus is located in Mexico City, a large and complex urban area with important social and environmental challenges [37,38]. This campus, known as Ciudad Universitaria (CU), was inaugurated in 1952 and has an extension of 730 hectares, 32% of which is occupied by an ecological reserve. In 2007, the central area of CU was acknowledged by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as a world heritage site, describing it as:

> "[...] an exemplary monumental set of twentieth century modernity that integrates urbanism, architecture, engineering, landscaping and arts, associating these elements with references to local traditions and to the pre-Hispanic past of Mexico. The set embodies social and cultural values of universal significance and has become one of the most important symbols of modernity in Latin America." [39]

CU is home of an important part of the activities of UNAM, but the University also has other eight higher education campuses and 14 high schools in the metropolitan area of Mexico City, aside from six campuses for regional development and multiple research units in other states in the country, with a comprehensive community of more than 420,000 people comprising students, academics and administrative staff [40]. Given its public nature and its human, physical and financial resources, UNAM has a great potential to influence the sustainable development of the country through its activities of research, teaching and extension of culture.

Our analysis shows that UNAM has been a fruitful space for initiatives linked to sustainability in research, teaching and campus management over the last 10 years. However, it also suggests that until now the University has not succeeded in transforming the multiplicity of existing initiatives in the field of sustainability into a sustainable university project. Based on this case study, we suggest as a research hypothesis that the large size and organizational complexity of macro-universities scale up the organizational obstacles faced by universities to consolidate themselves as sustainable universities, and therefore, that inter-institutional coordination for sustainability it is a particularly important factor to consolidate sustainable university projects in this kind of higher education institutions.

Understanding the challenges and opportunities faced by macro-universities when integrating sustainability in their tasks is relevant for different reasons. Given the extent of their enrolment and resources, these institutions have an important potential to spread the principles of sustainable development, contribute to a better understanding of complex socio-environmental problems, develop innovative technological and organizational responses to address sustainability challenges, and train high-level professionals in this field. Moreover, given their social prestige, these universities can also have an important leadership for the promotion of sustainable practices in the cities where they are located [41–43]. In Latin America, we have identified 37 higher education institutions with these characteristics. There are, no doubt, similar institutions in other regions of the world, although, we do not have enough information to date to identify them. Taking into account only the number of students, there are at least 20 universities with an enrolment similar or superior to that of the UNAM worldwide, these are mostly located in Asia, it should be noted that an important part of the enrolment of some of these universities corresponds to distance education schemes.

4. Materials and Methods

The term 'sustainability' has been widely used in several fields, and different definitions have been developed over the past decades. Our analysis uses a broad definition of this concept that takes into account two of the elements around which there is greater consensus in the literature: (1) The reference to a scheme of use and management of ecosystems and natural resources that does not compromise their future survival persistence and (2) the integration of environmental, social and economic dimensions in academic analysis and problem-solving proposals. The operative definition of the areas and actions that can be categorized as 'sustainable' in a university implies methodological decisions that are reflected in the monitoring of their performance and the definition of priorities for their management. The present study considers in this field research, teaching and campus management activities linked to natural resource knowledge and management, environmental impacts of human activities and explicit references to the term 'sustainability.' The data for this research and its treatment are described below:

(1) We identified databases that contained information about the activities of research, teaching, culture and operation of university campuses in the last decade. To analyze these databases:

    - We defined over 100 keywords (in Spanish and English) from the analysis of the main international treaties linked to sustainable development.
    - We first undertook a categorization exercise based on an automated word search.
    - We conducted a qualitative review of the first classification to ensure that the selected records were associated with sustainability.
    - We graphed the databases resulting from this last step to infer the behavior of the number of initiatives linked to sustainability in the areas analyzed (teaching, research, extension of culture and campus management).

The databases analyzed with this procedure are listed below:

- The plans, study programs and courses were consulted in the database of the UNAM General Directorate of School Administration (DGAE).

- The theses were consulted in TesiUNAM, a database that digitally registers all the theses of the University.
- Research projects carried out by the UNAM researchers was consulted in the database provided to us by the UNAM General Directorate of Institutional Evaluation (DGEI).
- Publications of UNAM academics were consulted in the Web of Science database.
- The continuing education activities were consulted in the UNAM Coordination of Open University and Distance Education (CUAED) database.

To complete the information obtained through the analysis procedure previously described we consulted various qualitative sources that we analyzed through a content analysis approach:

(2) The institutional pages of all the academic dependencies of the UNAM, to know their research lines, programs and departments.
(3) The last 10 annual reports of all the academics and administrative entities of the University, to identify infrastructure initiatives related to sustainability, to know if they were documented as part of a larger project and whether they were followed up in the years after their first appearance.
(4) Meetings with data managers about campus operations and with different actors who have promoted or have been responsible for sustainability initiatives over the past few years.

The data collected in our research have different limitations, especially those that concern the operation of the campus. It should be noted that at the UNAM there are still no institutional practices concerning the reporting of initiatives linked to sustainability and, as result, information, when available, is scattered and fragmented. This situation imposed certain limits to the methodological design of our study, which is mainly an exploratory study that sought to make a diagnosis of the initiatives linked to sustainability that were carried out at the University over the last decade. For this same reason, we do not have the elements to thoroughly investigate our hypothesis and develop a strategy to accept or reject it. However, the information obtained allows us to better understand the analyzed process and provide valuable elements to improve the institutional design of the UNAM and other macro-universities to consolidate themselves as sustainable universities.

5. Results

According to the latest data, UNAM has 349,515 enrolled students, 40,578 academics and 30,024 administrative employees. The teaching and research activities of the University are articulated through 15 faculties, five multidisciplinary units and eight national schools, 14 high schools, 34 research institutes, 14 research centers and 10 research programs. UNAM also has 135 libraries, 26 museums and 18 historical precincts under its charge. This section describes the main initiatives linked to sustainability developed at the UNAM in the last 10 years. The presentation of this data is organized in five sections: Specialised Research and Teaching Centers, Teaching, Research, Continuing education and communication of science and Campus management; through this exercise our first research question was, namely: What progress has UNAM made in the incorporation of sustainability in its substantive tasks and the management of its campus over the past 10 years? The following section discusses some of the most important implications of the size and organizational complexity of the University in relation to efforts to foster processes of institutional innovation towards sustainability; addressing the other two questions that we initially raised: How do these initiatives contribute to the transformation of UNAM into a sustainable university? Finally: What are the main challenges facing the consolidation of these initiatives in the future?

5.1. Specialised Research and Teaching Centers

UNAM has five research entities focused on sustainability, their creation is one of the best examples of the institutional support for the development of research and teaching in the sustainability field at UNAM. Table 1 list their names, the years when they were founded, the year of their first institutional background and their location. Besides, there are also more than 30 entities with departments or lines of research related to sustainability that are explicitly mentioned in their official documents, as well as many other faculties and institutes with academics who individually work on research related to this field. The main research topics are climate change, biodiversity and biological conservation, sustainable technologies, analysis of pollutants, environmental restoration, political ecology, environmental governance and policy.

Table 1. Research entities specializing in the study of the environment and sustainability.

Name	Institutional Background	Foundation Year	Location
Ecosystems and Sustainability Research Institute	1996	2003	Morelia, Michoacán
Environmental Geography Research Center	2003	2007	Morelia, Michoacán
Climate Change Research Program	—	2009	CU, Mexico City
Renewable Energies Institute	1985	2013	Temixco, Morelos
National Laboratory of Sustainability Sciences [1]	—	2014	CU, Mexico City

[1] A part of the Institute of Ecology.

5.2. Teaching

UNAM has an enrollment of 349,539 students: 59% undergraduate, 9% graduate and 32% high school (DGAE, UNAM, 2018). The teaching activities and training opportunities at the University have evolved for more than a century, integrating a wide variety of perspectives and institutional actors. Its academic offer actually includes 41 postgraduate, 123 bachelor's degrees, 36 technical careers and two high school programs.

The international agreements linked to sustainability in universities consider both the inclusion of study programs specifically focused on this area and the inclusion of sustainability as a transversal dimension of the educational offer of HEIs as important, since all disciplines can contribute to sustainability. However, as it was noted above, the literature identifies this as one of the most complex areas in the process of building a sustainable university. During the past decade, UNAM has incorporated sustainability in its training offer both through the creation of programs focused on sustainability and by means of the incorporation of courses on sustainability in pre-existing programs. This process has taken place from the 2000s, and especially from 2010. Currently, 6% of undergraduate and graduate programs are focused on sustainability, 18% have an area of specialisation on this subject, 40% include courses related to the field while 36% have not yet incorporated the perspective of sustainability in any way. Figure 1 shows the distribution of undergraduate and graduate programs classified by their link to sustainability of their objectives and curricular plans.

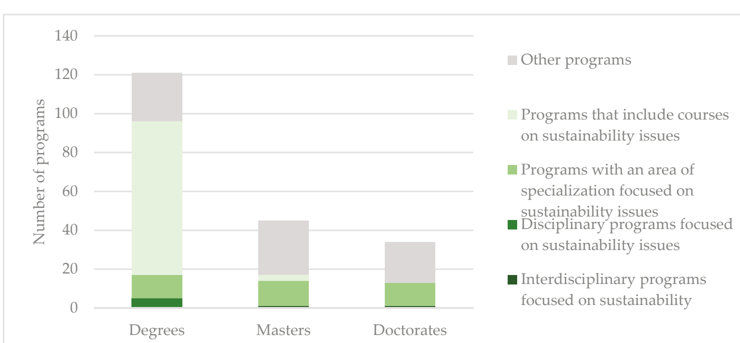


Figure 1. Study programs by their link with the environment and sustainability, Universidad Nacional Autónoma de México (UNAM) 2018. Note: PhD programs do not include obligatory courses. Elaboration based on http://www.posgrado.unam.mx.

These data show the contributions of UNAM to the training of experts on issues related to sustainability. However, the transversal incorporation of the topic in the academic offer of the University is still partial, and until now, disciplinary approaches have been privileged, both in the field of the natural sciences and in the social sciences. Considering the limits of disciplinary approaches in the field of sustainability, in 2015, the University created a postgraduate program in sustainability sciences, an interdisciplinary program focused on the study of sustainability problems and the development of applied research. Until 2017–2018, this postgraduate program had 157 Master's students (of which 26 had already graduated) and 57 PhD students. Table 2 lists the academic offers of UNAM linked to sustainability at the undergraduate and graduate levels.

Table 2. Specialised study programs and programs with an area of expertise in the environment and/or sustainability.

Interdisciplinary programs focused on sustainability	
Postgraduate programs	Sustainability Sciences
Specialised study programs on the environment and/or sustainability	
Undergraduate programs	Sustainable Management of Coastal Zones, Engineering in Renewable Energies, Environmental Sciences, Sustainable Materials Sciences, and Environmental Engineering.
Specializations	Savings and Efficient Use of Energy, Environmental Law and Environmental and Ecological Economics.
Study programs with an area of expertise in the environment and/or sustainability	
Undergraduate programs	Biology, Ecology, Earth Sciences, Geophysical Engineering, Technologies for Information in Sciences, Agricultural Engineering, Chemistry, Industrial Chemistry, Agricultural Administration, Law, Territorial Development, Geohistory and Architecture.
Postgraduate programs	Earth Sciences, Engineering, Physical Sciences, Biomedical Sciences, Teaching for Higher Secondary Education, Biochemical Sciences, Biological Sciences, Marine Sciences and Limnology, Chemical Sciences, Law, Economics, Geography, Architecture and Urbanism.

The incorporation of study plans and programs focused on sustainability has been reflected in the increase in thesis projects related to the topic, especially in programs focused on the environment. We identified 5594 theses linked to sustainability between 2008 and 2016, 5.6% of the theses concluded during this period. It should be noted that more than 200 of these theses were written within the framework of study programs that do not include any subject related to the environment or to sustainability, showing areas of opportunity to consolidate the inclusion of this topic in the curricular offer of the University. These theses come from different programs, such as Actuary, Visual Arts, Computer Science, Latin American Studies, Philosophy, History, Mathematics, Medicine and Odontology and Pedagogy.

5.3. Research

The UNAM reported 7783 research projects between 2008 and 2016. The research areas with the largest number of projects at the University are Physics, Engineering, Biochemistry and Earth Sciences. In this period, we identified 540 projects focused on issues related to sustainability. A total of 82% of the projects were focused on research and 12% were oriented to the development of teaching materials and knowledge dissemination activities. The main subjects addressed in the research were structure and functions of ecosystems (18%), pollution and sanitation (10%), sustainable technologies (7%), renewable energy (7%), climate and global change (6%), biodiversity (6%) and sustainable production systems (4%). Of these projects, 80% were financed by UNAM and the remaining 20% by the National Council of Science and Technology (CONACYT).

Figure 2 shows that since 2011, the number of projects developed in this field has significantly increased. Fifty percent of the research projects identified as related to sustainability belong to the areas of Biology and Chemistry, 31% to Physics and Mathematics and 10% to Social Sciences and humanities. Only 1% of these projects were registered as multidisciplinary research. The most frequent disciplines involved in these projects are ecology, biology and earth sciences, whereas Economics is the only discipline in the area of the Social Sciences and Humanities with 10 or more projects related to sustainability in the period analyzed.

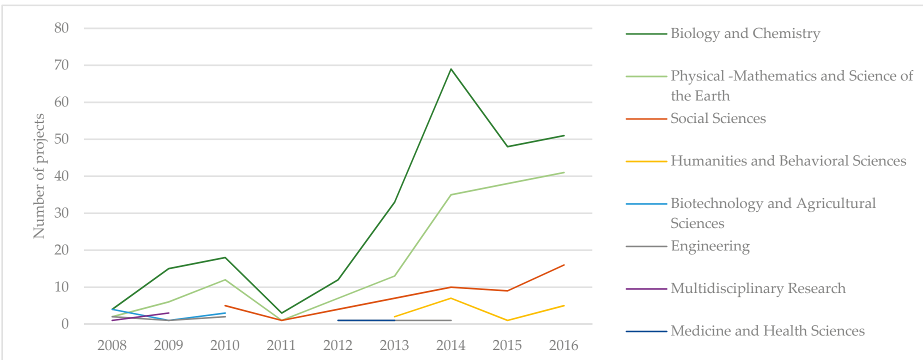


Figure 2. Research projects linked to sustainability by year and area of study, UNAM 2008–2016. Note: Elaboration based on the databases on research projects of SIIA, UNAM.

Based on the Web of Science database, we estimated that between 2008 and 2016 UNAM researchers published 39,881, these papers represent almost 28% of the scientific publications of the Mexican academy in that period. Between these, we identified 3346 publications related to sustainability, 8.4% of the publications produced by UNAM researchers in that period. Like the projects, the publications that deal with issues related to sustainability have also increased in recent years. Figure 3 shows the increase in the number of publications related to this field between 1980 and 2017, particularly accentuated in the areas of Biology and Chemistry.

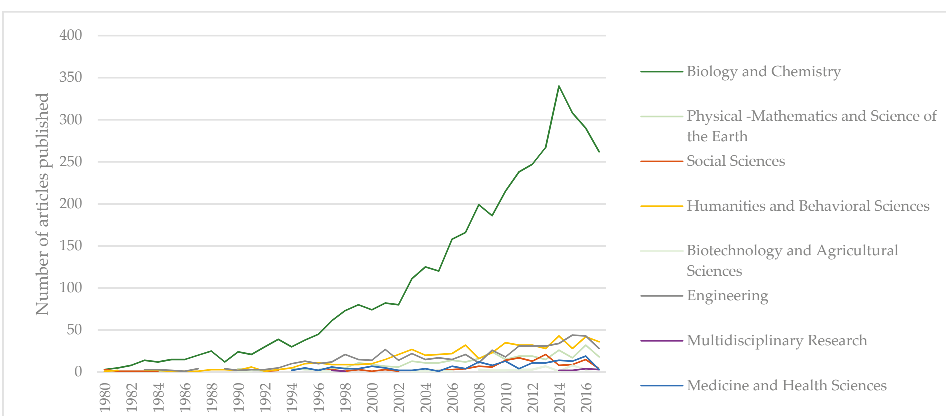


Figure 3. Publications related to the environment and sustainability written by UNAM academics by field of knowledge for the period 1980–2017 based on the Web of Science database. Note: Elaboration based on WOS, 2018.

Again, it is important to note the low number of publications in social sciences related to sustainability. These data show that research at UNAM still has a long way to go in order to build an interdisciplinary practice in sustainability studies and suggests the need for institutional guidance and support to promote and strengthen collaboration between research centers integrating social, economic, ecological and technical disciplines in the field of sustainability to consolidate UNAM's potential contributions to address sustainability issues.

5.4. Continuing Education and Communication of Science

UNAM holds more than 100 events a year related with sustainability open to the researches, the students and the general public, it should be noted that the CUAED database includes detailed information only of around 10% of these events. Figures 4 and 5 show some trends regarding these events in the last decade based on the available data.

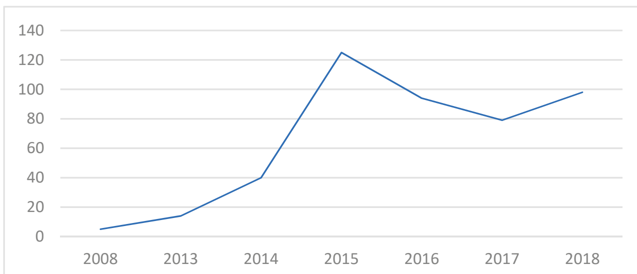


Figure 4. Continuing education and communication of science activities at UNAM by year. Note: Elaboration based on the databases on research continuing education of CUAED, UNAM.

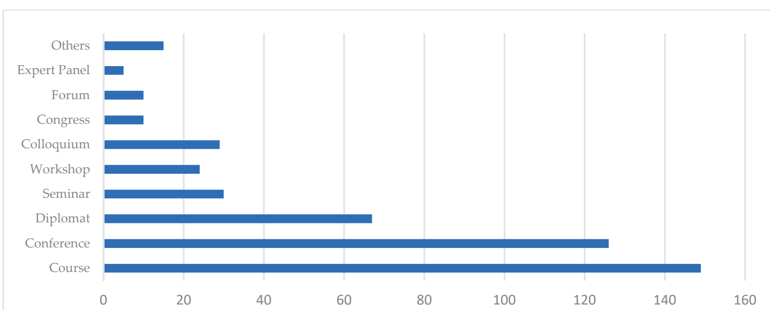


Figure 5. Continuing education and communication of science activities at UNAM by type. Note: Elaboration based on the databases on research continuing education of CUAED, UNAM.

The University also has three permanent seminars related to this field that organize periodic meetings on specific topics: The University Seminar on Hydrocarbon Research, the University Seminar on Socio-Environmental Risk Studies and the University Seminar on Society, Environment and Institutions. The last two of them have a multidisciplinary approach and have made various initiatives that seek to position the environmental agenda in the public debate.

The most important unit of the University in terms of communication activities related to sustainability is the Science Museum 'Universum,' located within the main campus, which houses several permanent and temporary exhibitions of these topics and offers courses and workshops related to environmental issues. The University has another four museums that focus on these subjects: The Zoology museum in CU, and the Geology museum, the 'Chopo' museum and the 'Casa del Lago'; all of them located in the downtown area of Mexico City.

5.5. Campus Management

In the last 10 years, different initiatives have been carried out to improve sustainability in the management of the UNAM campus. However, no database concentrates this information and no general report has been made to concentrate this data. Through a content analysis of the section dedicated to the infrastructure of the reports of the entities and dependencies, for the last decade we identify at least 24 different projects that address different areas of management and 854 mentions to different sustainable management initiatives. It should be noted that there is no follow-up mechanism to these initiatives, some of these are short-term initiatives and others have been ongoing for years, but this information is not available. The largest number of initiatives reported are linked with energy and, secondly, water. Figure 6 shows the distribution of these initiatives distinguishing them by area and the year they were reported. Most of these initiatives have taken place in CU, the main campus of the University, but some of the new campuses of the University have been important spaces of innovation for sustainable management.

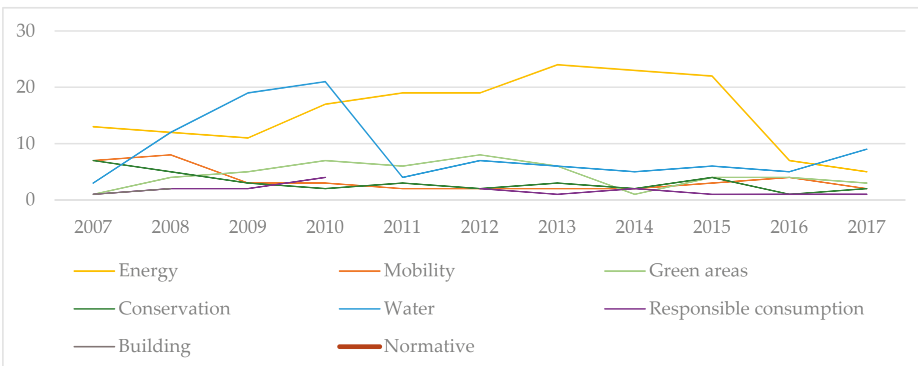


Figure 6. Reports of sustainable management of university spaces. Note: Elaboration based on the in the analysis of the annual reports of the entities and dependencies present in the "University Reports" published online (http://www.planeacion.unam.mx/Memoria/).

This section describes some of the most important initiatives for the sustainable management of campus operations at UNAM.

5.5.1. Ecological Reserves

The campus of CU includes a natural reserve of 237 hectares (just over 30% of the campus extension), established in 1983 in order to protect a unique high-elevation xerophilous scrub ecosystem that hosts at least 1500 native species and 317 exotic species [43]. In addition to its contributions as a habitat for biodiversity, this reserve is an important area of water catchment for the south of the city, an area with continuous urban growth. It also makes contributions in terms of noise and temperature damping and CO_2 uptake. The objectives of this reserve also include knowledge dissemination, research and teaching. In sum, this reserve is the only really protected natural area in the city of Mexico.

In addition, the UNAM is directly involved in the management of other five national reserves in the country, where it contributes to the study and conservation of ecosystems:

- The National Park Isla Isabel, Nayarit.
- La Isla Socorro, that is part of the Revillagigedo Biosphere Reserve, Colima.
- The Biosphere Reserve Chamela-Cuixmala, Jalisco.
- The National Park La Malinche, Tlaxcala.

- The Biosphere Reserve Los Tuxtlas, Veracruz.

5.5.2. Water Management at UNAM, Pumagua

The water supply in the main campus comes from three wells given to the University by the National Water Commission. Considering the serious problems in efficiency of the water supply system in Mexico City, where losses up to 40% are estimated [44], the University created the Program of Management, Use and Reuse of Water in 2008 with the goal of achieving efficient water management within the University. This program considers three aspects: Hydraulic balance, water quality and promotion of social participation. As a part of this initiative the University also created the UNAM's Water Observatory [45], an open-access digital platform that tracks consumption and water leaks in real time. So far, this program has been implemented in the CU campus, where it facilitated a decrease in the average volume of extraction from 100 to 70 L per second between 2008 and 2016, despite the increase in the number of users from 131,682 to 185,000. A similar initiative began to be implemented in two teaching and research units located in the eastern and northern parts of the Valley of Mexico (the Faculty of Higher Education of Zaragoza and the Faculty of Higher Education of Acatlán). Pumagua has also been involved in projects outside the University and has been a place for students training in water management topics.

5.5.3. Strategy for a Sustainable University at UNAM, EcoPuma

In 2009, the University created a Strategy for a Sustainable University at UNAM. The main activities carried out within the framework of this initiative were an environmental hallmark for the university dependencies that make efforts to reduce their environmental impact and the design and implementation of the "EcoPuma" program [46], an initiative that promotes practices to reduce the environmental impact of the university campuses in the following areas: Waste, energy, water, mobility, green areas, construction, purchases and electronic administration. This initiative has promoted the sustainable management of campuses in the University and implemented some valuable initiatives, such as a waste management program, replacement of a part of outdoor lighting, publication of guidelines for sustainable construction and purchases, and various outreach activities. Yet, to date its capacity to influence the management of university campus operations is limited both in CU and in the rest of the campuses of the University in Mexico City and in the country.

5.5.4. External Campus

As noted in previous sections, the UNAM has multiple academic units in the country, including three external campuses (Morelia, Michoacán; Cuernavaca, Morelos; and Juriquilla, Querétaro) that integrate various research institutes and four National Superior Study Schools (Escuela Nacional de Estudios Superiores -ENES). Below we describe the most important initiatives towards sustainability in some of these decentralized venues.

- Campus Morelia, Michoacán.

This campus includes seven research units, three of them address sustainability issues: The Institute for Research in Ecosystems and Sustainability, the Center for Research in Environmental Geography and a Unit of the Institute of Materials Research focused on sustainable materials. This campus also houses a National School of Higher Studies (ENES) that offers 13 bachelor's degrees and five postgraduate degrees. Several of these programs have a close link with sustainability, between these: The degrees in Environmental Sciences, Ecology, Geosciences, Sustainable Materials Science, Social Studies and Local Management; and the postgraduate degrees in Biological Sciences, Earth Sciences and Sustainability Sciences.

The operational management of the campus also include principles on sustainability, particularly in the ENES, that was built more recently and considered sustainability in its architectural design and planning, implementing various strategies, such as the establishment of a wastewater treatment plant, a rainwater harvesting system, the installation of drinking water fountains to avoid the use of plastic bottles, an energy saving program, a solar panels for water heaters, a landscape project that decreases the water used for irrigation and contributes to the conservation of plant species, a waste management program that includes garbage composting and recycling, and a bicycle loan service.

- Campus Cuernavaca, Morelos.

This campus also includes seven research units, among them the Institute for Renewable Energies, that offers a degree in Engineering in Renewable Energy and participates in the postgraduate courses in Energy Engineering, Engineering in Materials and Physics. This campus also has two other research units where key issues for sustainability are addressed: The Institute of Biotechnology and the Regional Center for Multidisciplinary Research.

The main initiative for the sustainable operation of the campus is the separation of waste and the composting of organic waste through the Integral Solid Waste Management Program [47], which has been operating since 2014. Through this program, in 2017, the campus recycled 8 tons of urban waste (paper/cardboard, PET, bags, glass, tin, aluminum, batteries and iron) and transformed 90% of its food waste and 100% of its gardening waste into compost.

- ENES León, Guanajuato.

This ENES does not have an academic profile oriented towards sustainability, but it has incorporated sustainability in its campus management since its foundation. Its campus has a sustainability office [48] that promotes different initiatives, such as the installation of solar panels for outdoor lighting, a system for the free use of bicycles and the design of a bike path, a garden area with native plants irrigated with treated water contributing to the capture of rainwater, the installation of drinking water fountains and an electronic waste collection campaign organized by the students.

6. Discussion

The previous section shows that, over the last decade, multiple initiatives related to the environment and sustainability have been initiated at UNAM. Some of these have had a short-term nature, but many others are the result of institutional efforts to include sustainability as a priority of the University. This is the case with the formation of several research centers and study programs specializing in sustainability issues reported in the first two sections of our results. Another example is the formulation and implementation of strategies to reduce the environmental impacts of University activities in the design of some of the new UNAM campuses in the country, such as ENES Morelia and ENES Leon. However, until now, many of these initiatives have remained isolated and this has made it difficult to consolidate them in the long term. Besides, the existing initiatives respond, to a large extent, to the projects and interests of particular actors within the University and are not based on a general diagnosis of the advances and pending of the University in this field. The lack of an overall vision of the advances, priorities and challenges of the University to become a sustainable university makes it difficult for the University to address, in a systematic way, the pending tasks and overcome the obstacles for its consolidation as a sustainable university. Among the areas that the University needs to strengthen for this purpose, the present study suggests: To extend the academic offer in subjects related to sustainability at the undergraduate level and include subjects on sustainability in those programs that do not yet consider the subject, for example: Administration, Arts, Computer Science, Philosophy, History, Mathematics, Medicine and Pedagogy; to promote interdisciplinary research agendas around contemporary socio-ecological challenges; reformulate the campus management schemes to give priority to sustainable strategies in all university campuses and define indicators to monitor the performance sustainable management strategies implemented; to include students and the university community at large as key actors in the sustainability strategies of the University; and to enhance collaboration with public and social actors in order to address the sustainability problems of the cities and regions where the university campuses are located.

The obstacles and opportunities that UNAM have faced and still faces in its efforts to incorporate sustainability into its substantive tasks and campus management are multi-faceted problems. From this case, we highlight the importance of a university joint project that guides the transition towards sustainability in universities [49–52] as part of the construction of a "whole institutional approach", as outlined by the UNESCO's Global Action Programme on Education for Sustainable Development [53]. Amongst the institutional challenges for the development of sustainable universities, researchers have identified the divergence between academics, students and administration staff members as a potential source of power struggles and divisions [54]. This discussion is relevant for all universities but is particularly important for macro-universities, such as UNAM, where visions and subgroups multiply, making the articulation of a sustainable university initiatives not only more complex but also more important. UNAM consists of more than 130 entities and dependencies with their own histories and contrasting visions about the priorities of the University and the role of and importance given to sustainability. The size and complexity of its organizational structure, the diversity of institutional actors and the institutional inertias that have developed over more than a century have hindered both the construction of a unitary sustainable university project and the implementation of a transversal program of sustainable campus management. At the same time, it is important to consider that the initiatives carried out in this field often receive positive responses from many members of the academic community and have a broad social demand, showing that there is a field of opportunity for the growth of these initiatives that the University has not yet fully responded to.

7. Conclusions

To better understand the process of incorporating sustainability into the substantial tasks of UNAM, one should begin by considering the common perception of sustainability in Mexico as an issue secondary to other social problems, such as poverty, lack of security and lack of democracy. This perception is present both in political areas and in multiple social spheres. It permeates the definition of research agenda and the teaching priorities within universities, underestimating the impacts of environmental degradation on quality of life and social welfare, as well as the fact that investments on sustainability are crucial for the present and for the future.

To contribute to the development of increasingly sustainable societies is one of universities' essential tasks in order to comply with their social responsibility, especially for public universities of the Global South. The UNAM Institutional Development Plan 2015–2019 acknowledges environmental crises amongst the main contemporary challenges faced by the University and commits to incorporate sustainability perspectives in teaching, research, communication and culture, as well as in the structural and operational aspects of its campus management. However, the lack of articulation of existing sustainable initiatives and the multiplicity of missing areas, discussed in the previous sections, suggest that the University faces institutional challenges in translating this political will and the broad set of initiatives implemented to date in a systematic and sustained process of transition towards sustainability.

This research confirms what has been exposed in other works that point out that to incorporate sustainability as a core dimension of academic activities and decision making in universities these institutions need to make important changes in their governance schemes [55] and identify organizational development as a key factor to strengthen transformational processes towards sustainability [23,24], institutionalize it and ensure the continuity and consolidation of the sustainability projects over time. From the meetings we had with actors who have promoted or have been responsible for sustainability initiatives at UNAM, it seems clear that this demands not only clear leadership and will from university authorities but also the support of key actors at all organizational levels of the universities, processes of dialogue and construction of agreements to articulate existing initiatives, and an inclusive and participative strategy that involves students, academics and administrative staff members and that encourages collaboration within university communities.

Among the topics of future research regarding the incorporation of sustainability in the substantive areas of the UNAM we consider important to highlight: A meta-analysis of research projects and publications to identify the most studied topics and those that still need to be promoted; a network analysis of the academics involved in these works and the extent to which they are incorporating inter- and trans-disciplinary methodologies; and the spaces and strategies used by researchers to link and influence local contexts.

Author Contributions: Conceptualization, K.O. and A.G.P.; Data curation, E.M.; Formal analysis, A.G.P. and E.M.; Funding acquisition, K.O.; Investigation, A.G.P.; Methodology, A.G.P.; Project administration, K.O.; Resources, E.M.; Supervision, K.O.; Validation, A.G.P.; Visualization, A.G.P., Writing—original draft, A.G.P.; Writing—review & editing, K.O. and A.G.P.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Meadows, D.H.; Meadows, D.L.; Randers, J.; Behres, W.W., III. *The Limits to Growth. A Report of The Club of Rome's Project on the Predicament of Mankind*; Universe Books: New York, NY, USA, 1972; ISBN 0-87663-165-0.
2. United Nations. *Declaration of the United Nations Conference on the Human Environment*; United Nations: Stockholm, Switzerland, 1972.
3. Association of University Leaders for a Sustainable Future. *The Talloires Declaration*; Association of University Leaders for a Sustainable Future: Pittsburgh, PA, USA, 1990.
4. United Nations General Assembly. *A/RES/70/1 Transforming Our World: The 2030 Agenda for Sustainable Development*; United Nations General Assembly: New York, NY, USA, 2015.
5. Lozano, R.; Lozano, F.J.; Mulder, K.; Huisingh, D.; Waas, T. Advancing higher education for sustainable development: International insights and critical reflections. *J. Clean. Prod.* **2013**, *48*, 3–9. [CrossRef]
6. Ramos, T.B.; Caeiro, S.; van Hoof, B.; Lozano, R.; Huisingh, D.; Ceulemans, K. Experiences from the implementation of sustainable development in higher education institutions: Environmental management for sustainable universities. *J. Clean. Prod.* **2015**, *106*, 3–10. [CrossRef]
7. Shiel, C.; Leal Filho, W.; do Paço, A.; Brandli, L. Evaluating the engagement of universities in capacity building for sustainable development in local communities. *Eval. Program Plan.* **2016**, *54*, 123–134. [CrossRef] [PubMed]
8. Estatutos de la Red de Macro Universidades de América Latina y el Caribe. Available online: http://www.redmacro.unam.mx/estatutos.html (accessed on 10 August 2018).
9. Labanauskis, R. Key Features of Sustainable Universities: A Literature Review. *J. Bus. Manag.* **2017**, *13*, 56–70.
10. Brandli, L.L.; Leal Filho, W.; Frandoloso, M.A.L.; Korf, E.P.; Daris, D. The environmental sustainability of brazilian universities: Barriers and pre-conditions. In *Integrating Sustainability Thinking in Science and Engineering Curricula*; Filho, W., Azeiteiro, U., Caeiro, S., Alves, F., Eds.; Springer International Publishing: Berlin, Germany, 2015; pp. 63–74. ISBN 978-3-319-09474-8.
11. Perkmann, M.; Tartari, V.; McKelvey, M.; Autio, E.; Brostr€om, A.; D'Este, P.; Fini, R.; Geuna, A.; Grimaldi, R.; Hughes, A.; et al. Academic engagement and commercialization: A review of the literature on university-industry relations. *Res. Policy* **2013**, *42*, 423–442. [CrossRef]
12. Leal-Filho, W.; Jim, Y.C.; Wu, L.; Londero Brandli, L.; Veiga Avila, U.; Miranda Azeiteiro, S.; Caeiro, L.; da Rosa Gama Madruga, R. Identifying and overcoming obstacles to the implementation of sustainable development at universities. *J. Integr. Environ. Sci.* **2017**, *14*, 93–108. [CrossRef]
13. Bero, B.N.; Doerry, E.; Middleton, R.; Meinhardt, C. Challenges in the development of environmental management systems on the modern university campus. *Int. J. Sustain. High. Educ.* **2012**, *12*, 133–149. [CrossRef]
14. Alnsour, J.A.; Meaton, J. The use of university research in planning decision making in Jordanian municipalities. *Habitat Int.* **2015**, *49*, 206–211. [CrossRef]
15. Dahle, M.; Neumayer, E. Overcoming barriers to campus greening: A survey among higher educational institutions in London, UK. *Int. J. Sustain. High. Educ.* **2001**, *2*, 139–160. [CrossRef]

16. Nidumolu, R.; Prahalad, C.K.; Rangaswami, M.R. Why sustainability is now the key driver of innovation. *Harv. Bus. Rev.* **2009**, *87*, 56–64. [CrossRef]
17. Ávila, L.; Rossato Facco, L.; Bento, M.; Mendes, A.; Obregon, L.; Trevisan, M. Sustainability and education for sustainability: An analysis of publications from the last decade. *Environ. Qual. Manag.* **2018**, *27*, 107–118. [CrossRef]
18. Lozano, R.; Ceulemans, K.; Alonso-Almeida, M.; Huisingh, D.; Lozano, F.J.; Waas, T.; Lambrechts, W.; Lukman, R.; Hugé, J. A review of commitment and implementation of sustainable development in higher education: Results from a worldwide survey. *J. Clean. Prod.* **2015**, *108*, 1–18. [CrossRef]
19. Ryan, A.; Tibury, D.; Corcoran, B.P.; Abe, O.; Nomura, K. Sustainability in higher education in the Asia Pacific: Developments, challenges, and prospects. *Int. J. Sustain. High. Educ.* **2010**, *11*, 106–119. [CrossRef]
20. Wright, T. Definitions and frameworks for environmental sustainability in higher education. *Int. J. Sustain. High. Educ.* **2002**, *3*, 203–220. [CrossRef]
21. Yarime, M.; Tanaka, Y. The issues and methodologies in sustainability assessment tools for higher education institutions: A review of recent trends and future challenges. *J. Educ. Sustain. Dev.* **2012**, *6*. [CrossRef]
22. UNESCO. *Global Action Programme on Education for Sustainable development*; United Nations Educational, Scientific and Cultural Organization: Paris, France, 2015.
23. Ceulemants, K.; Lozano, R.; Alonso-Almeida, M. Sustainability reporting in higher education: Interconnecting the reporting process and organizational change management for sustainability. *Sustainability* **2015**, *7*, 8881–8903. [CrossRef]
24. Schmitt, C.T.; Palm, S. Sustainability at German Universities: The University of Hamburg as a Case Study for Sustainability-Oriented Organizational Development. In *Handbook of Sustainability Science and Research*; Filho, W.L., Ed.; World Sustainability Series; Springer: Hamburg, Germany, 2018.
25. Cortese, A.D. The critical role of higher education in creating a sustainable future. *Plan. High. Educ.* **2003**, *31*, 15–22.
26. Winter, J.; Cotton, D. Making the hidden curriculum visible: Sustainability literacy in higher education. *Environ. Educ. Res.* **2012**, *18*, 783–796. [CrossRef]
27. Djordjevic, A.; Cotton, D. Communicating the sustainability message in higher education institutions. *Int. J. Sustain. High. Educ.* **2011**, *12*, 381–394. [CrossRef]
28. Moore, J. Barriers and pathways to crating sustainability education programs: Policy, rhetoric and reality. *Environ. Educ. Res.* **2005**, *11*, 237–555. [CrossRef]
29. Painter-Morland, M. Philosophical assumptions undermining responsible management education. *J. Manag. Dev.* **2015**, *34*, 61–75. [CrossRef]
30. Moore, J. Seven recommendations for creating sustainability education at the university level: A guide for change agents. *Int. J. Sustain. High. Educ.* **2005**, *6*, 326–339. [CrossRef]
31. O'Byrne, D.; Dripps, W.; Nicholas, K.A. Teaching and learning sustainability: An assessment of the curriculum content and structure of sustainability degree programs in higher education. *Integr. Sustain. Sci.* **2015**, *10*, 43–59. [CrossRef]
32. Geli de Ciurana, A.M.; Leal Filho, W. Education for sustainability in university studies: Experiences from a project involving European and Latin American universities. *Int. J. Sustain. High. Educ.* **2006**, *7*, 81–93. [CrossRef]
33. Lidgren, A.H.; Rodhe, D. A systemic approach to incorporate sustainability into university courses and curricula. *J. Clean. Prod.* **2006**, *14*, 797–809. [CrossRef]
34. Alshuwaikhat, H.M.; Abubakar, I. An integrated approach to achieving campus sustainability: Assessment of the current campus environmental management practices. *J. Clean. Prod.* **2008**, *16*, 1777–1785. [CrossRef]
35. Evans, J.; Jones, R.; Karvonen, A.; Millard, L.; Wendler, J. Living las and co-production: U iversity campuses as platforms for sustainability science. *Curr. Opin. Environ. Sustain.* **2015**, *16*, 1–6. [CrossRef]
36. Marisiske, R. La universidad de México: Historia y Desarrollo. *Rev. Hist. Educ. Latinoam.* **2006**, *8*, 11–34.
37. Ezcurra, E.; Mazari-Hirat, M. Are megacities viable? A cautionary tale form Mexico City. *Environment* **1996**, *38*, 6–15. [PubMed]
38. Keivani, R. A review of the main challenges to urban sustainability. *Int. J. Urban Sustain. Dev.* **2009**, *1*, 5–16. [CrossRef]
39. UNESCO WEB PAGE. Available online: https://whc.unesco.org/es/list/1250 (accessed on 22 June 2018).

40. Portal de Estadística Universitaria, UNAM. Available online: http://www.estadistica.unam.mx (accessed on 20 May 2018).
41. Zilahy, G.; Huising, D. The roles of academia in Regional Sustainability Initiatives. *J. Clean. Prod.* **2009**, *17*, 1057–1066. [CrossRef]
42. Trencher, G.; Bai, X.; Evans, J.; McCormick, K.; Yarime, M. University partnerships for co-designing and co-producing urban sustainability. *Glob. Environ. Chang.* **2014**, *8*, 153–165. [CrossRef]
43. REPSA. Available online: https://www.repsa.unam.mx (accessed on 20 May 2018).
44. PUMAGUA. Available online: http://www.pumagua.unam.mx (accessed on 25 May 2018).
45. Observatorio del Agua. Available online: http://www.observatoriodelagua.unam.mx (accessed on 25 May 2018).
46. ECOPUMA. Available online: https://ecopuma.unam.mx (accessed on 30 May 2018).
47. Basura Cero, UNAM Campus Morelos. Available online: http://www.morelos.unammx/basuracero/inicio (accessed on 27 May 2018).
48. ENES León. Available online: http://enes.unam.mx/?lang=es_MX&pl=el-campus-sostenible (accessed on 28 May 2018).
49. Ferrer-Balas, D.; Adachi, J.; Banas, S.; Davidson, C.I.; Hoshikoshi, A.; Mishra, A.; Motodoa, Y.; Onga, M.; Ostwald, M. An international comparative analysis of sustainability transformation across seven universities. *Int. J. Sustain. High. Educ.* **2008**, *9*, 295–316. [CrossRef]
50. Lukman, R.; Glavič, P. What are the key elements of a sustainable university? *Clean Technol. Environ. Policy* **2007**, *9*, 103–114. [CrossRef]
51. Amaral, L.P. Quest for a sustainable university: A review. *Int. J. Sustain. High. Educ.* **2015**, *16*, 155–172. [CrossRef]
52. Aleixo, A.M.; Leal, S.; Azeiteiro, U.M. Conceptualization of sustainable higher education institutions, roles, barrier, san challenges for sustainability: An exploratory study in Portugal. *J. Clean. Prod.* **2018**, *172*, 1664–1673. [CrossRef]
53. Ven Weenen, H. Towards a vision of a sustainable university. *Int. J. Sustain. High. Educ.* **2000**, *1*, 20–34. [CrossRef]
54. Sharp, L. Green campuses: The road from little victories to systematic transformation. *Int. J. Sustain. High. Educ.* **2002**, *3*, 128–145. [CrossRef]
55. Lotz-Sasitka, H. Stories of transformation. *Int. J. Sustain. High. Educ.* **2004**, *5*, 8–10. [CrossRef]

sustainability

MDPI

Article

Equal Opportunities in Academic Careers? How Mid-Career Scientists at ETH Zurich Evaluate the Impact of Their Gender and Age

Ralph Hansmann [1,*] and Dagmar Schröter [2]

1 ETH Zurich, Department of Environmental Systems Science (D-USYS), Transdisciplinarity Lab (TdLab), Universitätstrasse 22, CHN K 76.2, CH-8092 Zurich, Switzerland

2 ETH Zürich, Department of Environmental Systems Science (D-USYS), Forest Ecology & Transdisciplinarity Lab (TdLab), Universitätsstr. 22, CHN K 76.2, CH-8092 Zürich, Switzerland; dagmar.schroeter@usys.ethz.ch

* Correspondence: ralph.hansmann@env.ethz.ch; Tel.: +41-44-632-36-47 or +41-76-201-77-51

Received: 21 July 2018; Accepted: 15 September 2018; Published: 19 September 2018

Abstract: Gender equality is essential to social justice and sustainable development in the higher education sector. An important aspect thereof is to promote equal opportunities for academic careers. This study investigates the current situation and possibilities for improvement in this regard from the perspectives of mid-career scientists in a sustainability-oriented university department. A survey of scientists from the postdoctoral to adjunct professor level (N = 82) in the Department of Environmental Systems Science (D-USYS) of ETH Zurich (Swiss Federal Institute of Technology Zurich) was thus conducted to investigate judgements, experiences, and ideas for improvement concerning equal career opportunities. About 90% of the respondents perceived no disadvantages based on gender, ethnicity, race, or faith. However, about 30% felt disadvantaged due to their age. Comments revealed not a single case in which latter disadvantages were based on prejudice. Instead, ETH-wide or national age and time-based restrictions for certain positions caused the inequality perceptions. Furthermore, comments indicated that these restrictions can disadvantage scientists taking care of children. Some participants suggested a revision or removal of corresponding rules. Further suggestions included an improved availability of childcare places. ETH Zurich recently undertook great efforts to provide excellent and affordable childcare services, increasing the number of available places by about 30% in the year following this survey.

Keywords: equal opportunities; academic career; sustainable development; gender; age; discrimination; leaky pipeline

1. Introduction

Creating equal opportunities for people of different genders, races, nationalities, and ages represents a crucial goal of sustainable development in a society, as it includes justice regarding the possibilities of humans to satisfy their needs [1]. The higher education sector is taking a leading role for society's transition towards sustainable development, and should therefore be in the vanguard for creating equal opportunities as it is for other facets of sustainability [2–6]. However, barriers to women in science remain common worldwide, despite efforts at levelling the playing field [7–12].

In Switzerland, a Federal Equal Opportunity at Universities Program was launched in 2000 and has since been continued through various phases. The main foci of the program are gender equality and work–family–life balance; similar to other European countries also in Switzerland women are underrepresented in high academic positions. Thus, a long-term goal of the program is to prevent a loss of talent [13,14]. The Swiss Equal Opportunity Program included (i) an incentive (sub-)program for the promotion of female professors; (ii) a mentoring program for the promotion of female junior researchers; and (iii) a work–life program for greater balance between academic career and family, which prompted all of the Swiss universities to introduce childcare measures and take an additional focus on fostering support for dual-career couples at Swiss universities. Recently, an additional subprogram; (iv) "Gender Studies", was included that aimed to establish this field as a scientific discipline at Swiss universities. In response to this program, the Swiss Universities developed action plans, and positive trends on gender equality were observed since the start of the program [15–17].

For example, to increase the compatibility between work and family, in 2014, ETH Zurich (Swiss Federal Institute of Technology Zurich) introduced new possibilities for financial support for bearing the costs of childcare services and founded an internal service subdivision, "Hello Kids!", to support families with young children in an encompassing way by providing consultancy services, helping in the procurement of childcare services, and assisting in the access of financial support [18].

However, women remain underrepresented in higher academic positions, even though the share of females among the graduates of Master's and comparable programs in Switzerland has more than doubled during the last 40 years, and is now at approximately 50% [19]. The number of doctorates completed at Swiss universities continuously increased from 3320 in 2008 to 4151 in 2017, and the percentage of doctorates completed by females continuously increased from 41.3% to 44.8% during that period [20]. However, among the 3500 professorships at Swiss universities, only about 20% were held by female professors in 2016 [21], and the share of females among newly appointed professors was approximately 33%, still far from a 50% ratio.

The scientific community is faced with a well-documented phenomenon dubbed "leaky pipeline" [22], which means that high drop-out rates of women at each step of the job ladder in academic careers, particularly in the steps beyond postdoc, lead to a decline in the share of females with increasing positions.

Does the leaky pipeline phenomenon exist at ETH Zurich, a technology-oriented university with a share of 30.6% female students in 2016? A comparison of shares of women at increasingly senior career levels shows that it does: females constitute 31.2% of the doctoral candidates, 28.5% of the candidates on the postdoctoral level, 23.9% on the senior scientific assistant level, 14.9% of senior scientists, and 13.5% of professors [23]. These numbers refer to the average situation at ETH Zurich. However, there are, differences among its 16 departments as the percentages of female students range from 10.2% in the Department of Mechanical and Process Engineering (D-MAVT) and three further departments with less than 20% females (e.g., Department of Computer Science, Department of Information Technology and Electrical Engineering, and the Department of Physics) to slightly more than 50% in the Department of Biology and in the ETH Department of Environmental Systems Science (D-USYS) to 63.5% females in the Department of Health Sciences and Technology (D-HEST) [23].

The ETH Department of Environmental Systems Science (D-USYS)—where our study was conducted—has a considerably higher than average proportion of female students for ETH, with 54.4% in 2016. This may be due to the multi, inter, and transdisciplinary sustainability orientation of the study programs that D-USYS offers (Bachelor's and Master's degree programs in both Agricultural Sciences and Environmental Sciences), which take a systemic view on environmental systems and human–environment systems and comprise, next to education in natural sciences, also education in social sciences, environmental policy, and economics. Having the second highest percentage of female students among 16 departments, D-USYS cannot be regarded as representative for ETH Zurich. However, the dedicated sustainability orientation of the D-USYS mission, research, and teaching may be connected to a high sensitivity of its members, also in relation to the sustainability aspects of internal processes. The proportions of women on sequential career levels decrease at D-USYS from 48% on the doctoral candidate and postdoctoral levels, to 39% at the senior scientific assistant level, to 15% among female senior scientists, and 16% female professors overall in 2015 [24].

The factors causing the "leaky pipeline" phenomenon are not yet fully understood. It is likely a combination of traditional social roles, difficulties with reconciling work and family life, a reduced integration of women in professional academic networks, the lower career ambitions of women compared to men, and less self-confidence in their own academic capabilities [9,25,26]. Other contributing factors are negative biases in the perception of female applications [27–29], better working conditions for men as compared to females at universities [12,30,31], and a high workload of females with academic service activities negatively impacting research productivity [32].

A study based on Swiss data confirmed that the reconciliation of family and work—especially with the birth of a child directly after the doctorate—is a factor, which tends to disadvantage women in the development of their academic career, and also identified the poorer integration of emerging female researchers in international academic networks as an important interrelated and contributing factor [19]. Mentoring strategies have been applied to increase self-confidence of female researchers and enhance their embedding in scientific networks to support their careers, but gender imbalances still exist [9,14,25,26].

A global comparison of female-to-male ratios of papers published by country shows that Switzerland is in company with Austria and Germany at the lower end [11]. The authors of the latter study caution against simplistic explanations, but point to connections between gender issues and age discrimination, which are often subtle. They encourage institutions to analyse their local micromechanisms within the social, cultural, economic, and political contexts. Various studies show and explain how ageism and gender issues are related to each other [33–37]. However, apparently age-related stereotypes, generalisations, and discrimination have not caused the same public attention and academic attention as sexism or racism. Instead, age prejudice is to a considerable extent socially condoned, and even institutionalised [38]. The empirical basis on processes of age-related discrimination seems still underdeveloped, and the impact is under-reported [37,39]. Age discrimination mostly affects elder people, and may bear psychological, social, and economic costs for them, for example if they are not promoted or disadvantaged in an application process because of their age. There may also be negative macroeconomic impacts. According to Grossman [39], "society's lack of concern for this type of discrimination may prove more costly in the future as employers look more to older workers to fill projected workforce gaps (p. 71)".

An important aspect that merits attention in this regard is the formal age and time-based rules and restrictions on certain positions and/or career opportunities. Such formal limitations can in principle concern all people in certain phases of their lifespan and career path, which lends them a neutral appearance. However, they may nevertheless produce inequality, for example, if they favour people with "traditional" highly focussed career paths. A continuing dominance of masculine values and practices within the academic system, including aspects such as strong hierarchies and high competitiveness, has been criticized by various scholars [40–42]. Time and age-based rules that have been developed in the context of such values could pose a disadvantage to the increasing number of people with a higher diversity of life, responsibilities, and occupations. For example, people with a significant dedication to volunteer work and social service, sports, or other aspirations, or gave birth to children, helped to raise children, or took care of other dependents or people with health problems, may be discriminated against by time or age-based limitations if they are not designed with foresight. Even though much progress has been made, traditional social norms associating women with family and childcare are to some extent still operative in higher education institutions, and make it difficult to combine being a mother with advancement in the academic career [43]. Time and age-based rules may be one aspect perpetuating this problem.

In particular, in an academic setting, such age and time-based restrictions seem widespread. For example, at ETH Zurich, there is a 35-year rule for assistant professors and two six-year rules for other scientific staff [44,45]. Assistant professorships are usually not granted to persons older than 35 years at ETH Zurich. Exceptions from this rule can only be made if the applicant has (a) considerable industrial experience, or (b) served in the military for longer than usual, and/or if (c) his or her career has been delayed by parenthood. In addition, the upper age limit can be raised to 37 years in the case of extraordinary qualification of the applicant [45], but under such circumstances, applicants will normally be directly employed as tenured professors.

Temporal working contracts at the PhD/postdoctoral levels at ETH are restricted to a maximum of total six years, and temporal contracts at the senior scientific assistant/senior scientist levels are likewise restricted to a maximum of six years. These six-year rules have been summarized in a school-specific ordinance in 2001 as a result of a broad discussion within ETH Zurich about academic careers [44]. Together, both rules rule form a kind of 12-year rule, since exceptional prolongations granted for the first six years are subtracted from the potential duration of the second six-year period as a senior scientific assistant.

At the postdoctoral level, no open-ended contracts are offered, and only few permanent senior scientist positions are available. The situation at ETH Zurich is similar to other Swiss universities in this regard. A number of scientists have criticised that the Swiss academic system currently offers not enough open-ended positions apart from full professorships, which renders academic "Mittelbau" positions unattractive and even risky for a career, possibly impeding the scientific education of current and future generations [46–48]. According to a study by the State Secretariat for Education, Research, and Innovation, the provision of more open-ended contracts is as a major concern of Swiss mid-career scientists [15]. According to the survey, only 28% of the scientists with a completed doctorate working at Swiss universities (excluding professors) have an open-ended contract. The percentage among female scientists is about 20%, and is even lower than among males, with approximately 33% open-ended positions [15]. Among those still working in academia five years after their doctorate, 55% have time-limited contracts, 30% have open-ended contracts as scientists or lecturers, and 15% obtained a professorship. Half of these professorships were obtained outside Switzerland, 25% were obtained at Swiss universities and a further 25% were obtained at Swiss universities of applied sciences and elsewhere [21].

At D-USYS, there are currently 35 full professors, nine assistant professors, and 36 senior scientists with permanent contracts. However, there are more scientists with time-limited contracts, among them about 180 persons with completed doctorates (including 118 postdocs) and 255 scientists without completed doctorates (including 209 ongoing doctorates). Tenured ETH professors may typically employ not more than one senior scientist on an open-ended contract. Exceptions from this rule can be granted for certain professors and within certain departments, but of course, such exceptions need to be in line with financial constraints. For the access to the rare and timely unlimited positions, scientific excellence and employability are important, but age factors can play a role, as professors are only allowed to provide open-ended contracts to scientists who are considerably younger than they are themselves if the concerned ETH department commits to a long-term career development as an independent scientist, which includes commitment to funding the person beyond the retirement of the professor. Similar age rules also exist at other Swiss universities and in other countries. For example, in Germany, the position of a full professorship represents an official state position that can only be obtained up to a certain age, with the exact age limit varying between the federal states in the range from 45 years in Baden-Württemberg to 55 years in the federal states of Saarland and Bremen [49].

Apart from gender and age issues, further aspects of equal opportunities in science careers include possible disadvantages due to race, nationality, and faith. Indications of prejudice and other barriers to equal opportunities at higher education institutions based on ethnic and cultural aspects have been found in various studies [50,51].

On the outlined background, the present study investigates the perception of important aspects of equal opportunities among scientists working in the Department of Environmental Systems Science (D-USYS) at ETH Zurich regarding gender and family situations, as well as national, ethnic, religious, racial, and age-related factors. Thus, this study aims to improve the understanding of how existing structures work at this particular workplace, and of the resulting actual conditions in relation to equal opportunities.

D-USYS conducts research and teaching with a strong orientation towards sustainability. The department's activities thus include research on environmental systems and their relevance to society as well as training future generations of scientists and sustainability-oriented decision-makers in society, industry, and politics. Research into the professions of the graduates indeed showed that they enter a broad range of professional domains such as research institutes and universities, environmental planning and engineering companies, trade and insurance companies, public administration and environmental non-governmental organisations (NGOs), and that they have a considerable sustainability outreach through their activities [52,53]. Consistent with its mission, the department aims to be in the vanguard of sustainable development also regarding internal processes. In line with this aspiration, the study presented here was commissioned by the department leadership.

2. Materials and Methods

2.1. Survey among Advanced Academics Working at D-USYS

A survey was conducted among scientists within D-USYS who form part of the so-called academic "Mittelbau", which is a term used in Germany, Austria, and Switzerland to denote the graduated academic staff below the professorial level, with minor differences between these countries in the exact definition of the term. In Switzerland, the Mittelbau includes graduated persons working in a broad range of positions ranging from doctoral students, via scientific assistants and postdoc, to senior scientific assistants, senior scientists, titular professors, and also includes assistant professors [54]. The focus of the study was on scientists who already have advanced considerably on their academic career path, and have long-time experience and insight into working-life at D-USYS. Therefore, the survey exclusively targeted scientists who have already completed a doctorate or PhD (at D-USYS or elsewhere), and after its completion have been working for at least one year in the department. We refer to such scientists as "Mittelbau" here (though advanced Mittelbau would be more precise). Strategic research foci across the department's professorships, in which these mid-career scientists work, include climate change, food security, sustainable resource use, biological diversity, as well as adaptation and ecosystem processes and services [55], and in addition, their scientific activities focus diverse further sustainability-oriented research topics. They also contribute substantially to teaching in the degree programs that D-USYS offers.

Opinions, judgments, experiences, and ideas that are relevant to equal career opportunities were collected within an online survey that covered various aspects of work–life including the current position, tasks, and responsibilities as well as career perspectives and goals of the participants. The overall survey was comprised of 53 items in total, including open-ended and closed-ended questions. The first two items aimed to identify whether the responder belonged to the targeted group (see above). Thereafter, the main part addressed academic background, employment history, current tasks and responsibilities, and career planning, as well as aspects impacting equal opportunities with regard to gender, age, ethnic, religious, and family aspects. Subsequently, ideas were invited for improving work–life in general terms and ensuring equal career opportunities for employees with and without children or other dependents. Finally, demographic information (gender, age, nationality) was elicited.

The present article does not cover the entire questionnaire, but focusses on items related to equal opportunities. This includes first and foremost the specific questions addressing this issue directly as described in the following.

Participants were asked: "Do you feel that you are in any way disadvantaged at D-USYS due to gender, ethnicity, race, or faith?" The possible responses to this question were "yes", "rather yes", "rather no", "no", and "I don't know". These responses were coded as a four-point rating scale, from "yes" (= 1) to "no" (= 4), but the answer "I don't know" was considered apart from this scale. An additional, open-ended question asked for comments to explain their own rating. Furthermore, the participants were asked: "Do you feel in any way disadvantaged at D-USYS due to age?" Here, the possible responses were "yes", "no", and "I don't know". Those answering with "yes" were asked to provide a comment explaining the disadvantages that they perceived.

To investigate the equal opportunities of parents with young children as well as people who have to take care of other dependents, a filter question asked: "Do you have children or other dependents (e.g., elderly relatives etc.) that need taking care of in your household?" The possible responses were "yes, children", "yes, other dependents", and "no". Those responding with "yes" were addressed in an open-ended format by the additional item: "Did having children or other dependents in your household change your career path? If so, please specify." Furthermore, all participants were asked about possibilities for improving equal opportunities through the question "Could D-USYS or ETH do more to ensure equal career opportunities for employees with and without children or other dependents?" The possible responses were "yes", "no", and "I don't know", and a further open-ended question asked for corresponding suggestions or comments.

2.2. Recruitment and Number of Participants

The survey invitation was sent out on 5 November 2015 to 489 email addresses from a corresponding list containing all of the current members of the total D-USYS Mittelbau and technical staff. The survey was open from then on till 28 December 2015. In total, 156 members of D-USYS visited the online survey and responded to the first question. A majority of 62% of them had a doctorate (PhD) degree. These 96 persons were further asked whether they had been working at D-USYS for at least one year since the completion of the PhD/doctorate. The 82 who answered with "yes" therefore belonged to the target group at which the survey was directed (86% of 95 respondents to the second question).

All members of the target group responded to the survey, so that the maximum sample size available for the reported analyses was N = 82 (although the number of responses varies slightly between items). For some items, it was obligatory to respond in order to be able to proceed further with the survey, but for most items, responding was not defined as obligatory. For example, responses were not obligatory for the items on gender and nationality, as some people may not wish to respond to this on diverse grounds. Answering open-ended questions was likewise not defined as obligatory to prevent drop-outs and allow smooth proceeding through the questionnaire. Of the participants from the target group, 77 completed the whole questionnaire up to the last obligatory item "year of birth" (i.e., age after transformation for statistical analysis and reporting). The drop-out rate was thus 6%, which is very low in light of the considerable length and number of questions and sub-questions that the survey contained. Completing the survey took on average 26.6 min (SD = 12.8, median = 22.5, mode = 20), with a range from 10 min to 59 min.

2.3. Demographic Distribution of Participants

The item asking for the gender of the participants was answered by 77 people. The resulting gender distribution was 58.4% males, 39.0% females, and 2.6% "other". The average age of the participants was 39.3 years (SD = 8.3) with a median of 37 years, and a modulus of 35 years (12 persons). Considering persons with single nationalities, the majority of the 72 respondents to the respective question were either German (33.3%) or Swiss (27.8%), followed by British, French, and Austrian (with 4.2% each), and Italian with 2.8%. In addition, some persons had double nationalities: 4.2% were Swiss and German, and likewise, 4.2% were Swiss and French. The remaining 15.3% had nine different single nationalities from six European and three non-European countries, and two had double nationalities.

3. Results

3.1. Perceived Disadvantages Due To Gender, Ethnicity, Race or Faith

A large majority of 81.8% of the participants responded with a straight "no" to the question regarding whether they felt disadvantaged at D-USYS due to gender, ethnicity, race, or faith, and a further 7.8% responded with "rather no" (Figure 1). Still, in total, 9.1% of the participants responded with "yes" (6.5%) or "rather yes" (2.6%), and 1.3% responded with "I do not know". When considering the responses as ratings on a four point-scale (1 = no, 2 = rather no, 3 = rather yes, 4 = yes; excluding the one person responding "I don't know") the average rating of the Mittelbau members was with M = 1.3 (SD = 0.8) only slightly above "no". However, the average rating of the females was with M = 1.7 (SD = 1.2), which was significantly higher than that of the males with M = 1.0 (SD = 0.2; Mann–Whitney U-Test $p < 0.001$), reflecting more perceived disadvantages among females as compared to males.

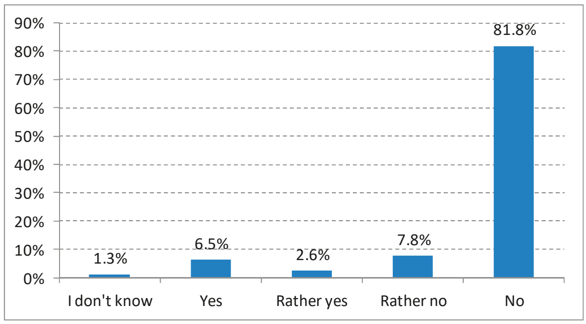


Figure 1. Do you feel that you are in any way disadvantaged in the Department of Environmental Systems Science (D-USYS) due to gender, ethnicity, race or faith? (N = 77).

Only 13 participants commented on their response (Table 1). Among them, seven had responded with "no" and four had responded with "yes", so those perceiving inequality were more inclined to give detailed comments. Various comments from participants who responded "yes" spoke of gender inequality (Table 1, comments #1–4). A male participant who responded "no", since the question asked if he felt disadvantaged due to gender, nevertheless perceived gender-based inequalities (comment #8). Two comments on "rather yes" (#5–6) referred to gender inequality, but additionally raised issues of ethnicity or nationality. Comments #4 and #7 pointed to the same issue of a woman's contract continuing when she takes maternity leave, which reduces the maximum contracted time allowing her to do research at ETH Zurich, because of the two sequential six-year rules described in the introduction. Both responses thus point to the distinct relationship between gender and academic or biological age that may result in a competitive disadvantage of females compared to men.

Table 1. Comments of the participants on their responses to the question: "Do you feel that you are in any way disadvantaged at D-USYS due to gender, ethnicity, race, or faith?" [1].

Comments on "Yes"	
1	As a woman, and as the spouse of a professor, I sometimes run into weird expectations, such that people are unaware of my own achievements and my genuine skills that justify my being here. Meeting times are not family-friendly.
2	Indirectly, being a woman at this age in research brings an undeniable conflict between family plans and career, which can be overwhelming. Support here is still unsatisfactory.
3	Men have better conditions than I have, especially regarding the rate of employment compared to workload.
4	My maternity leave lasted four months, after which I resumed 100%; nonetheless, I am disadvantaged compared to my male colleagues, because my contract cannot be prolonged for this period. But it is not my fault that I am female, the gender that gives birth.
Comments on "Rather yes"	
5	There is a subtle aggressiveness towards women and German people.
6	Sadly, I think ethnicity plays a role, and gender too, even if less than ethnicity.
Comments on "Rather no"	

Table 1. *Cont.*

Comments on "Yes"	
7	During my maternity leave, my contract continued, in other words, my maximum time at D-USYS is four months shorter than for people who did not take maternity leave.
Comments on "No"	
8	As a male, I do not, but I certainly feel there are some gender-based disadvantages.
9	This answer refers to D-USYS specifically. Not valid for ETH (e.g., biological age limits for professorships).
10	The question should be broader: the disadvantage in the academic system in Switzerland...
11	I am sure in our group, the research questions are not related to the experiences of the staff.
12	I find my group to be quite fair on such issues. I myself, having been trained in Canada, am quite aware and sensitive to such issues.
13	Very open-minded environment.

[1] Comments are sorted according to judgments from "Yes" to "No". All answers are listed; only 13 participants commented on their response.

Some comments of those who responded with "no" to the question of perceived disadvantages nevertheless mention corresponding issues. For example, comment #9 criticises biological age limits at ETH Zurich in general, and comment #10 hints to the even broader context of inequalities within the entire "Swiss academic system". So, both respondents refused to attribute existing inequalities to D-USYS, presumably recognising that D-USYS is legally required to apply the rules defined on higher levels. Finally, there are three purely positive comments, stressing the perception that D-USYS is a non-discriminatory environment (comments #11–13).

3.2. Perceived Disadvantages Due To Age

There exist various age limitations for career steps in the Swiss academic system based on academic age or biological age. Therefore, the question, "Do you feel in any way disadvantaged at D-USYS due to age?" was specifically asked in the survey. A clear majority of 61% did not feel disadvantaged because of their age. However, a substantial share of just under 30% of the respondents answered with "yes", while a further 9.1% were unsure and replied, "I do not know" (Figure 2). Among women, the percentage of "yes" responses was 33.3%, which was not significantly higher than among males with 26.7% (Chi-square test, df = 1, $p = 0.461$).

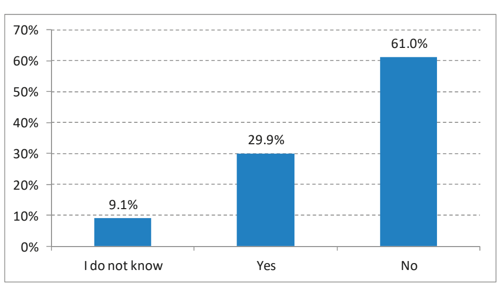


Figure 2. Do you feel in any way disadvantaged at D-USYS due to age? (N = 77).

The comments provided by those responding with "yes" are listed in Table 2. They show that feeling disadvantaged based on academic and biological age is an important topic in D-USYS, and hence presumably in the Swiss University system as a whole, since the age-based rules are predefined on the national level. Twelve of the comments directly mention the 35-year-rule [45], i.e., the age limit for becoming an assistant professor at ETH (comments #1–12, Table 2), possibly recognising that the specific exceptions that have been defined within this rule will not be applicable to them. Comments #13–15 criticise the six-year rules, which limit the duration of PhD, postdoc, and similar positions as well as those of (non-permanent) senior scientific assistants and similar employments [44]. Two of these comments link these rules to disadvantages for scientists with children (or illness, or other dependents, e.g., comments #14 and #15). Comments #17 and #18 criticise an age-related custom at ETH Zurich that disadvantages researchers who are considerably (typically more five years or more) younger than their employing professor, namely that open-ended employments are only granted to such scientists under the precondition that the concerned ETH department can ensure their scientific perspective, including financing also for the time after the professor has retired. Various responses doubt that age and time limits serve scientific quality or the institution as a whole. Comment #16 states that the issue of age discrimination is not addressed at USYS, but it should be.

Table 2. Comments of the participants feeling disadvantaged at D-USYS due to age [1].

Number	Response
1	35-year age limit for assistant professors.
2	As I started my PhD late, I am unable to apply for assistant professor or professor positions at ETH.
3	I see the age limit of 35 to become an assistant professor as a great career hindrance.
4	Cannot become (junior) professor here since I am older than 35.
5	I am over 35 so I feel like I am worthless according to the ETH hiring scheme.
6	I decided not to apply for ERC grants (European Research Council grants) because I was 36. Age limits (35) to get a position of assistant professor at ETH was the reason. I am not sure that the age-based discrimination has a robust motivation behind it.
7	I had a career before I became an academic and certainly feel that my age (not my academic age) has been a serious disadvantage; for example, I would be too old to apply for assistant professorships.
8	I was thinking about applying for a SNF (Swiss National Science Foundation) professorship. I was not restricted by age from SNF, but from ETH, because I would need to be not older than 35.
9	No chance to become assistant professor.
10	The ETH regulations on age (35 years for asst. prof.) prevent me from applying for ERC grants. The six-year constraint makes it practically impossible to attract external funds, as I am unlikely to be allowed to stay until the project ends.
11	Too old for becoming an assistant professor at ETH with own funding (e.g., ERC or SNF).
12	Employment regulations do not allow becoming permanent beyond a certain age limit. The 35-year rule for becoming an assistant professor does not always reflect personal career paths.
13	There is no future within the D-USYS that is foreseeable due to the maximum lifetime as postdoc (six years) or Oberassistent [2] (six years).
14	The age limits at ETH are definitely discouraging and counterproductive. Excellence has nothing to do with age. I feel that these limits also definitely discriminate researchers with families and children.
15	The academic age thing is just as academic-ageist as ageist rules. If you do anything after your PhD—injury, baby, even time off—then how does that make you a less good researcher than someone who had an injury/baby/sickness/time off before they completed?
16	There are age limits on opportunities that I do not understand. Age discrimination is not a topic here, but it should be.
17	No chance to get a permanent contract due to age difference to professor.
18	Permanent position not possible due to age difference to professor.
19	I am "old" and therefore disadvantaged in any kind of hiring process.
20	At 58, there is no real career to follow;-)

[1] 20 of the 23 participants feeling disadvantaged added such a comment. [2] The term "Oberassistent" literally translates to senior scientific assistant and denotes a common scientific position above the Postdoc level at ETH Zurich.

3.3. Perceived Disadvantages Due To Having Children or Other Dependents

A total of 44.2% of the respondents had children (42.9%) or other dependents (1.3%) that they needed to take care of at home. These participants were asked whether having children or other dependents changed their career path. Their answers are shown in Table 3.

Table 3. Responses of participants with children or other dependents in their household to the question whether and how this influenced their career path.

Comments indicating "No/rather no"	
1–3	No/No, not yet/Not yet
4	I don't think so. Maybe I don't dedicate as much time to work as I would have otherwise and maybe this reduces my academic output, and maybe this is the reason why I am not a professor. But I don't think so.
Comments indicating "Yes/rather yes"	
5	Yes of course!! I moved to Switzerland when we had our first child. It is much harder to move a whole family just because of your own career.
6	Yes, having a job abroad is much more difficult.
7	Yes, my decision to permanently stay in Switzerland.
8	Yes, I work part-time.
9	Yes—I reduced my workload to 80% (sometimes 70%) when the kids were small; this reduced my potential to compete against 130% devoted applicants for professorial positions, and hence I accepted the position at ETH that I am having now.
10	Yes, it did. I do not want to work full-time as long as my kids are smallish. One of my kids in particular did not agree with caretaking outside of the family very much. He could only be stretched so far with that.
11	Yes, it slowed down my career and reduced the number of following career steps (e.g., going abroad for a few months/years, only part-time jobs).
12	Yes. Less time for work, since family-unfriendly conditions in Switzerland make the balance between work and private life a constant struggle.
13	In some way, as other factors become more important than work and career.
14	Yes. I reassessed my priorities and am questioning the validity of staying in an academic career.
15	Yes. I am seeking a job that allows a better work/life balance.
16	Yes, without children, I would probably have gone for a professorship, but with them, I did not want to.
17	Yes, social responsibilities come at a cost: precious time.
18	Yes, I became very efficient and adaptive: nothing is projectable anyway.
19	Yes, but not regarding employment at ETH. [1]

[1] All answers are listed; only 19 participants provided a response.

Only one comment was a strict "no" (#1), whereas some responses reflected uncertainty around whether and how children have influenced or will affect their career (comments #2–4). The people who saw an impact on their careers explained this by reduced mobility (comments #5–7), reduced time available for work and/or a shift to part-time employment (e.g., comments #8–12), and shifted priorities when raising children (e.g., comments #13–15). Many of these respondents thus mentioned conscious shifts in career planning and time management as a consequence of having children.

3.4. Suggestions for Improving Opportunities of Employees with Children

When asked whether D-USYS or ETH Zurich as a whole could do more to ensure equal career opportunities for employees with and without children or other dependents, the majority of the participants (53.2%) responded with "I don't know"; only 6.5% responded "no", and 40.3% responded with "yes" (31 respondents). The high percentage of those who said "I don't know" shows a prevalent uncertainty amongst the participants.

In total, 22 participants commented on what D-USYS and ETH Zurich could do to improve equal opportunities, as listed in Table 4. Various comments expressed concerns about the current accounting of part-time employments and periods of maternity and paternity leave in relation to the two sequential six-year rules, and suggest changes that could make it fairer for employees with children (comments #1–4). Comment #1 thus suggests that the six-year rule should be based on the actual work time at ETH Zurich, and not the number of years with a contract, and comment #2 suggests that the time of maternity leave should be excluded from the six years. Further comments suggested increasing the duration of paternity and maternity leave and introducing the possibility of sharing it between partners, so that the father can have an equal and active role (comments #7–9). It was also suggested that working part-time should be appreciated by the employer, particularly after the birth of a child (comments #9–10). One of these comments (#9) explicitly mentioned the importance of the positive attitude of superiors towards employees becoming parents.

One participant spoke to the issue of working part-time and gaining recognition, expressing that having worked part-time should be taken into account when assessing performance, so that output is measured against required time (comment #5).

The availability of childcare was mentioned a lot, with people asking for more (comments #12–15) and more affordable (comments #12 and 16) and flexible (comment #17) options. One person criticised the Swiss childcare system in general, feeling that it restricts possibilities for combining family and career (comment #18). Other issues were the need for flexible working times and more job security (e.g., comments #11 and #20–21). Finally, one participant suggested that partner hire positions should be made available not only when professors are hired, but also on the level of hiring senior staff (comment #22).

Table 4. Suggestions of participants to promote equal career opportunities for employees with and without children/other dependents at ETH Zurich.[1]

Number	Response
1	Allow for part-time being counted towards the six-year limit (e.g., full-time means six years stay, 75% working time gives you a max. of eight years, etc.).
2	The duration of the contract should be prolonged for the period of the maternity and paternity leave; otherwise, there will be no gender equality at ETH.
3	The max. contract lengths is six years without taking into account whether you work full-time or part-time.
4	See my remark about my maternity leave. (cf. Table 1, comment 7)
5	Recognition of performance should be given in consideration of the level of employment (what did somebody achieve "in spite" of reduced working hours).
6	I think permanent academic staff should be given the opportunity to gain recognition for their academic and teaching achievements, as is the case in most universities. The Mittelbau are essentially lecturers, senior lecturers, and associated professors.
7	Being able to share parental leave would be great. It should not necessarily be the mother who can only take leave.[2]
8	Increase the parental leave for fathers so that it can be more equally shared between couples. Increase the parental/maternity leave in general, and ensure a reduced percentage of employment after parental leave.
9	Longer maternal and much longer paternal leave. Official support and encouragement for part-time positions. Transparent accounting for time for parenting when assessing career achievements. Positive attitude of bosses towards employees becoming parents.
10	It should be easier for the parents/more accepted in general to work 50–80% for a year or so after the baby is born.
11	For active parents, it is necessary that meetings are early in the day. Work needs to be flexible to some extent (I have that privilege, but it depends a lot on your professor).

Table 4. *Cont.*

Number	Response
12	More and affordable day care centers, so that everyone gets a place who needs one. A longer maternity break of six months would also help.
13	More child care options.
14	Offer child care.
15	I find it strange that there are so few day care spaces (“Krippenplätze”) offered by ETH. A real problem in my eyes.
16	Fair handling of ETH day care (more focus on socioeconomic aspects; seems to be for professors primarily and the “lucky ones”).
17	We would have profited from a system where you can bring your children to daycare *when needed* (e.g., when I was travelling), but the system was either full package day care or no day care at all. This does not help if partner is *not* a scientist.
18	I don’t know if D-USYS could do something in particular. But the child care system in Switzerland makes it quite prohibitive to combine.
19	Clearer career options for technical/IT employees (or positions in-between research and technical support).
20	More security
21	Permanent Mittelbau positions
22	Offer potential hiring for spouses of senior staff as well, not just professors.

[1] All answers are listed; 22 participants provided a response. [2] According to the personnel laws of the ETH domain [56]: “1. Female employees are entitled to four months’ full pay during maternity leave. 2. Maternity leave may commence, upon the employee’s request, one month prior to the expected birth. 3. The second half of the maternity leave may, after consultation with the competent instance, be taken in the form of a reduction of the contractually agreed activity rate. If the father also works in the ETH domain, the parents can share this suspension of work (Article 37.1-3)”. This means that splitting the second half of parental leave time between the mother and father is (only) possible if both parents work in the ETH domain, which includes ETH Zurich, École Polytechnique Fédérale de Lausanne (EPFL), Paul Scherrer Institute (PSI), Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Swiss Federal Institute of Materials Science and Technology (Empa), and the Swiss Federal Institute of Aquatic Science and Technology (Eawag). In addition, 10 days of paid paternity leave are granted to workers within the ETH domain who are becoming fathers (Article 52).

4. Discussion

This study asked academic employees of D-USYS at ETH about their experiences, perceptions and judgements concerning the actualisation of equal career opportunities considering ethnic, racial, nationality, religious, and gender aspects, the compatibility of work and family, as well as age-related aspects. About 90% of participants perceived “no” or “rather no” disadvantages based on ethnic, racial, religious, and gender aspects. However, whereas the respective share amongst male participants is nearly 100% perfect, at 76.6%, it is substantially lower among women, which raises some concern.

The specific comments in this regard revealed not a single indication of any discrimination with relation to religious aspects. There were also very few—in total only two—comments reflecting the perception of disadvantages connected to ethnic or nationality-based aspects (Table 1, #5, #6). Accordingly, there were no substantial indications of major problems in that regard. Instead, the outcome of the survey reflects a positive image of D-USYS as an enlightened internationally oriented university department. This reassuring interpretation is also supported by a few comments stating that D-USYS is a very open-minded environment, which is quite fair on such issues.

However, there were eight comments describing the perception of gender-based discrimination (Table 1, #1 to #8, i.e., about 10% of all respondents and 61% of those adding a free response). Five of these comments refer to gender-based discrimination as such (#1, #3, #5, #6, #8). Here, two aspects already reported in previous literature, namely negative prejudice on women and better working conditions for men [12,27,28,30,31] are addressed, but only by one response each. In addition, four comments address a lack of compatibility between career perspectives and family life, and are hence indirectly related to gender imbalances (#1, #2, #4, #7). These latter imbalances are further substantiated by comments on age-related disadvantages and suggestions for improving the compatibility of work and family life. These responses can be related to the leaky pipeline and must be taken seriously. It also needs to be acknowledged in this regard that further gender-oriented cognitions of the participants may possibly have been cognitively suppressed by unconscious processes, as they do not fit with the prevailing masculine-dominated conception of the academic world as rational, according to Raewyn Connell's theory of masculinity [57,58]. Jewkes et al. [59] thus argued that in masculine-dominated contexts, "discussions of gendered power often need to be approached indirectly, lest resistance is encountered to processes that may be variously seen as outrageous in questioning men's power, or ridiculous, where men's power is 'taken for granted'" (p. 117). Although negative consequences for the expression of critique were excluded for our participants through the guaranteed anonymity of the survey, unconscious cognitive repression processes could be operative here according to Connell's theory. The orientation of ETH Zurich towards the rational subjects of science and technology and its high prestige as a scientific higher education institution may be aspects that strengthen the psychological tendencies preventing the perception of unjustified gender inequalities. The impact of gender and family aspects on career opportunities may thus be underestimated by members of ETH Zurich and of other higher education institutions.

The perceived disadvantages based on biological and/or academic age were quite prevalent, with about 30% "yes" responses. These perceived age-related disadvantages appear to be unrelated to experiences within the direct working environment, such as personal relationships to superiors or peers within the professorships or institutes of D-USYS. Instead, all of the detailed explanations of age-based disadvantages refer to formally institutionalised rules defined at the university or federal levels. Rules defined at these superior levels hinder people who surpassed a certain age to acquire certain positions or limit the duration of staying in certain academic positions at ETH Zurich. Notably, the age limit of 35 years as an eligibility threshold for applications to become an assistant professor was mentioned frequently, even though the rule entails exceptions (e.g., regarding parenthood) [45]. The six-year rules defining the maximum duration of limited professional engagements as PhD/postdoc-level scientists, and/or as senior scientific assistants [44] were also frequently criticized. The shortage of open-ended senior scientist positions may have amplified this critique, as it greatly limits the chances of transcending to a fixed position after the completion of these 12 years (six years PhD/postdoc plus six years senior scientist). Furthermore, some research experience outside of ETH Zurich is usually expected in order to achieve permanent employment. The shortage of permanent scientific positions is not limited to ETH Zurich, and some experts thus argue for more such positions and more tenure track assistant professorships at Swiss universities in general [47,48].

Some comments describing the gender-based disadvantages of women were related to time-based rules, turning the latter into a gender sensitive issue. For example, after taking maternity leave, female academics often prefer working part-time in order to have more time for taking care of their small children. Therefore, they have less time to spend on professional scientific work than scientists without children. The two sequential six-year rules, which do not compensate for parental leave times or part-time work periods, thus lower their chance to reach the academic record that is required for acquiring an assistant or a full professorship at universities worldwide. Corresponding disadvantages for academics with children are partly compensated at ETH Zurich by granting exceptions from the 35-year age limit for applicants on assistant professorships [45]. However, the comments of a number of scientists with young children indicate that these exceptions are felt to be insufficient to provide equal opportunities. Age and time-based restrictions for certain positions may thus help to explain why in particular the birth of a child after the doctorate adds to the leaky pipeline [19]. Previous studies have shown that female scientists have on average a somewhat lower publication rate as compared to males [60], need more time to advance in their career [61], and often have to cope with both children and career [43]. These and possibly further aspects make females particularly vulnerable to the excluding effects of age barriers.

It is clear that young mothers (and fathers) who are working in science have to balance the responsibility for their children with their career ambitions, and cannot devote themselves fully to both. Various suggestions for improving the career opportunities of scientists with children favoured a revision of time limits in ways that discount for maternity leave time and adjust for phases of part-time employment.

When formal age and time limitations for scientific positions combine with gender issues, micromechanisms are created that contribute to the leaky pipeline problem.

Various links between gender issues and age related disadvantages due to formal institutionalised rules—as explained by several participants of the survey—add a new perspective to the discussion of gender-specific issues of age discrimination, which has so far focussed to a large extent on prejudice, gender roles, and gender-sensitive collective ideals and expectations of youth, beauty, and effectiveness [33–36].

Several participants wished for the provision of more child care places, more acceptance of and possibilities for part-time employment, or the introduction of partner hire recruitment on the senior scientist level, and not only when hiring professors to promote equal opportunities. ETH Zurich recently undertook great efforts to provide excellent and affordable child care services by increasing the number of available places by about 30% in the year following this survey [62]. Furthermore, ETH Zurich now facilitates the flexible time management of scientific personnel through allowing e.g., for official home office arrangements between employees and their superiors [63]. Nevertheless, generally, there still is a need for additional measures to be taken within the Swiss academic system to better support young researchers with families [14,48].

Time limits are generally advantageous for people who are able to focus "totally" on science, and proceed with their scientific work on the fast lane. Thus, the existing age limits may pose disadvantages to society as a whole, since they may hinder researchers from leading a socially more active and responsible life (e.g., raising children, engaging socially and politically). Age limits for applicants to professorship positions have also been criticised because they give age aspects priority over scientific excellence, experience, and expertise. These and similar age-based restrictions may inhibit sustainable societal development, since they can cause injustice by denying equitable access to valuable positions, and because they may hinder young researchers from combining their scientific career with social or environmental engagement. Such age-based restrictions and inequalities are by no means confined to Switzerland. The same is true for the interrelationships between formal employment restrictions based on biological or academic age and compatibility between career and family life. Furthermore, it needs to be considered in this regard that apart from the public academic sector, similar processes linking formal or informal age barriers to gender and family aspects may also exist and produce inequalities in the private sector and in non-academic public institutions. Therefore, the findings of this study are of general importance for sustainable development, as their meaning goes beyond the specific institution and country where it was conducted.

Author Contributions: R.H. and D.S. designed and conducted the survey, analyzed the data and wrote the paper. D.S. had the lead in the design of the survey. R.H. had the lead in writing the paper.

Funding: This research received no external funding.

Acknowledgments: We thank Doris Guhl (ETH Zurich Institutional Research), Nina Buchmann, Peter Frischknecht and Tom Peter (D-USYS), Cornelia Kutasi and Lukas Vonesch (ETH Zurich Human Resources), and Renate Schubert (ETH Zurich Equal!) for valuable comments on former versions of this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. World Commission on Environment and Development (WCED). *Our Common Future (Brundtland Report)*; Oxford University Press: Oxford, UK, 1987.
2. Adomssent, M.; Godemann, J.; Michelsen, G. Transferability of approaches to sustainable development at universities as a challenge. *Int. J. Sustain. High. Educ.* **2007**, *8*, 385–402. [CrossRef]

3. Hansmann, R. Sustainability learning: An introduction to the concept and its motivational aspects. *Sustainability* **2010**, *2*, 2873–2897. [CrossRef]
4. United Nations Educational, Scientific and Cultural Organization (UNESCO). *Education for Sustainability, from Rio to Johannesburg: Lessons Learnt from a Decade of Commitment*; UNESCO: Paris, France, 2002.
5. United Nations Educational, Scientific and Cultural Organization (UNESCO). *World Atlas of Gender Equality in Education*; UNESCO: Paris, France, 2012.
6. Velazquez, L.; Munguia, N.; Platt, A.; Taddei, J. Sustainable University: What can be the matter? *J. Clean. Prod.* **2006**, *14*, 810–819. [CrossRef]
7. Aiston, S.; Jung, J. Women academics and research productivity an international comparison. *Gend. Educ.* **2015**, *27*, 205–220. [CrossRef]
8. Austin, H.M. Women in education, science and leadership in New Zealand: A personal reflection. *Stud. High. Educ.* **2016**, *41*, 914–919. [CrossRef]
9. Davies, C.; Healey, R. Hacking through the Gordian Knot: Can facilitating operational mentoring untangle the gender research productivity puzzle in higher education? *Stud. High. Educ.* **2017**. (published online first). [CrossRef]
10. European Commission. *Strategy for Equality between Women and Men 2010–2015. European Commission Strategy adopted in September 2010*; Publications Office of the European Union: Luxembourg, 2011. [CrossRef]
11. Larivière, V.; Ni, C.; Gingras, Y.; Cronin, B.; Sugimoto, C.R. Global gender disparities in science. *Nature* **2013**, *405*, 211–213. [CrossRef]
12. Shen, H. Mind the gender gap. *Nature* **2013**, *495*, 22–24. [CrossRef] [PubMed]
13. Schweizerische Universitätskonferenz (SUK + CUS). *Bundesprogramm «Chancengleichheit» 2000–2003 [Federal Equality of Opportunities Program 2000–2003]*; SUK CUS: Bern, Switzerland, 2002.
14. Swiss Universities. *Bundesprogramm Chancengleichheit 2000–2012 [Federal Equality of Opportunities Program 2000–2012]*; Swiss Universities: Bern, Switzerland, 2016.
15. Dubach, P.; Graf, I.; Stutz, H.; Gariol, L. *Evaluation Bundesprogramm Chancengleichheit von Frau und Mann an den Universitäten 3. Phase 2008–2011 [Evaluation of the Third Phase of the Swiss Federal Equal Opportunity at Universities Programme (2008–2011/2012)]*; SERI: Bern, Switzerland, 2012.
16. Swiss Universities. *Bundesprogramm Chancengleichheit 2008–2012/13 Modul 1: Professorinnen [Federal Equality of Opportunities Program 2008–2012/13 Module 1 Female Professors]*; Swiss Universities: Bern, Switzerland, 2013.
17. Swiss Universities. *SUK-Teilprogramm P-4 Chancengleichheit TPC 2013–2016 Professorinnen [SUK-Subprogramme P-4 Equality Opportunities 2013–2016]*; Swiss Universities: Bern, Switzerland, 2015.
18. Schmits, A. Werden die Eltern gut betreut, sind es auch die Kinder [If parents are cared for well, so are the children]. *ETH Life* **2014**, *12*, 13.
19. Leemann, R.J.; Dubach, P.; Boes, S. The leaky pipeline in the Swiss university system: Identifying gender barriers in postgraduate education and networks using longitudinal data. *Swiss J. Sociol.* **2010**, *36*, 299–323.
20. Bundesamt für Statistik (BFS) [Federal Statistical Office Switzerland]. *Ausgewählte Bildungsabschlüsse. Entwicklung Dargestellter Zeitraum: 1980–2017 [Selected Educational Qualifications. Development of the Period 1980–2017]*; BFS: Neuchâtel, Switzerland, 2018.
21. Dubach, P.; Legler, V.; Morger, M.; Stutz, H. *Frauen und Männer an Schweizer Hochschulen: Indikatoren zur Chancengleichheit in Studium und Wissenschaftlicher Laufbahn [Women and Men at Swiss Universities: Indicators on Equal Opportunities in Studies and Academic Careers]*; Staatssekretariat für Bildung, Forschung und Innovation (SBFI): Bern, Switzerland, 2017.
22. European Commission. *Mapping the Maze: Getting More Women to the Top in Research*; Publications Office of the European Union: Luxembourg, 2008.
23. Schubert, R.; Kaczykowski-Patermann, H. *Gender Monitoring 2016/17: Report on the Gender Balance between Women and Men in Studies and Research at ETH Zurich*; ETH Zurich Equal! (Office of Equal Opportunities for Women and Men): Zurich, Switzerland, 2017.
24. ETH Zurich Equal! (Office of Equal Opportunities for Women and Men). *Gender Monitoring 2015/16, Department Report: Environmental Systems Science*; ETH Zurich Equal! (Office of Equal Opportunities for Women and Men): Zurich, Switzerland, 2016.
25. Nikunen, M. Changing university work, freedom, flexibility and family. *Stud. High. Educ.* **2012**, *37*, 713–729. [CrossRef]

26. Wunsch, M.A. Mentoring probationary women academics: A pilot programme for career development. *Stud. High. Educ.* **1993**, *18*, 349–362. [CrossRef]
27. Sarsons, H. Recognition for Group Work: Gender Differences in Academia. *Am. Econ. Rev.* **2017**, *107*, 141–145. [CrossRef]
28. Tiainen, T.; Berki, E. The re-production process of gender bias: A case of ICT professors through recruitment in a gender-neutral country. *Stud. High. Educ.* **2017**. (published online first). [CrossRef]
29. Wolfers, J. When Team-Work Doesn't Work for Women. *The New York Times*. 8 January 2016. Available online: http://www.nytimes.com/2016/01/10/upshot/when-team-work-doesnt-work-for-women.html (accessed on 20 May 2017).
30. Bailyn, L. Academic careers and gender equity: Lessons learned from MIT. *Gend. Work Organ.* **2003**, *10*, 137–153. [CrossRef]
31. Knights, D.; Richards, W. Sex discrimination in UK academia. *Gend. Work Organ.* **2003**, *10*, 213–238. [CrossRef]
32. Guarino, C.M.; Borden, V.M.H. Faculty Service Loads and Gender: Are Women Taking Care of the Academic Family? *Res. High. Educ.* **2017**, *58*, 672–694. [CrossRef]
33. Angervall, P.; Beach, D. Dividing academic work: Gender and academic career at Swedish universities. *Gender Educ.* **2017**. (published online first). [CrossRef]
34. Granleese, J.; Sayer, G. Gendered ageism and 'lookism': A triple jeopardy for female academics. *Women Manag. Rev.* **2006**, *21*, 500–517. [CrossRef]
35. Jyrkinen, M. Women managers, careers and gendered ageism. *Scand. J. Manag.* **2014**, *30*, 175–185. [CrossRef]
36. Jyrkinen, M.; McKie, L. Gender, age and ageism: Experiences of women managers in Finland and Scotland. *Work Employ. Soc.* **2012**, *26*, 61–77. [CrossRef]
37. Ojala, H.; Pietilä, I.; Nikander, P. Immune to ageism? Men's perceptions of age-based discrimination in everyday contexts. *J. Aging Stud.* **2016**, *39*, 44–53. [CrossRef] [PubMed]
38. Nelson, T.D. (Ed.) *Ageism: Stereotyping and Prejudice against Older Persons*; Massachusetts Institute of Technology: Cambridge, MA, USA, 2002.
39. Grossman, R.J. The under-reported impact of age discrimination and its threat to business vitality. *Bus. Horiz.* **2005**, *48*, 71–78. [CrossRef]
40. Archer, L. Younger academics' constructions of 'authenticity', 'success' and professional identity. *Stud. High. Educ.* **2008**, *33*, 385–403. [CrossRef]
41. Leathwood, C.; Francis, B. *Gender and Lifelong Learning*; Routledge: London, UK, 2006.
42. Monroe, K.; Ozyurt, S.; Wrigley, T.; Alexander, A. Gender equality in academia: Bad news from the trenches, and some possible solutions. *Perspect. Politics* **2008**, *6*, 215–233. [CrossRef]
43. Acker, S.; Armenti, C. Sleepless in academia. *Gend. Educ.* **2004**, *16*, 3–24. [CrossRef]
44. ETH Zurich. *Ordinance Governing Scientific Employees of the Swiss Federal Institute of Technology Zurich (Date: 16 September 2014)*; ETH Zurich: Zurich, Switzerland, 2014.
45. ETH Zurich. *Richtlinien des Präsidenten über das Assistenzprofessuren-System an der ETH Zürich (vom 1 February 2015) (Rechtssammlung RSETHZ 510.21). [Guidelines of the President on the Assistant Professorship System at ETH Zurich (from 1 February 2015). (Collection RSETHZ 510.21)]*; ETH Zurich: Zurich, Switzerland, 2015.
46. Battegay, C. Chancen für Postdocs? Chancen für die Wissenschaft! [Chances for postdocs? Chances for science!]. *Swiss Acad. Hum. Soc. Sci. Bull.* **2017**, *3*, 51–52.
47. Epiney, A. Universitäre «Karrierewege»: Für eine Diversifizierung der Stellenstruktur [University careers: For a diversification of positions]. *Swiss Acad. Hum. Soc. Sci. Bull.* **2017**, *3*, 45–46.
48. Hirschi, C. Vision 2020—Eine Bilanz nach fünf Jahren [Vision 2020—A review after five years]. *Swiss Acad. Hum. Soc. Sci. Bull.* **2017**, *3*, 39–40.
49. Preissler, U.; Detmer, H. Einstellungsaltersgrenzen für Professoren—Eine Länderübersicht [Hiring Age Limits for Professors—An Overview of Countries]. 2010. Available online: https://www.academics.de/wissenschaft/einstellungsaltersgrenzen_fuer_professoren_-_eine_laenderuebersicht_37406.html (accessed on 4 January 2017).
50. Hill, R.D.; Castillo, L.G.; Ngu, L.Q.; Pepion, K. Mentoring ethnic minority students for careers in academia: The WICHE Doctoral Scholars Program. *Couns. Psychol.* **1999**, *27*, 827–845. [CrossRef]
51. Turner, C.S.V.; González, J.C.; Wood, J.L. Faculty of color in academe: What 20 years of literature tells us. *J. Divers. High. Educ.* **2008**, *1*, 139–168. [CrossRef]

52. Hansmann, R.; Jödicke, A.; Brändle, U.; Guhl, D.; Frischknecht, P. How the Bologna reform influenced learning outcomes: Analysis of perceived qualifications and professional requirements of environmental sciences graduates. *Stud. High. Educ.* **2017**. (published online first). [CrossRef]
53. Mieg, H.A.; Hansmann, R.; Frischknecht, P.M. National sustainability outreach assessment based on human and social capital: The case of Environmental Sciences in Switzerland. *Sustainability* **2012**, *4*, 17–41. [CrossRef]
54. Bundesamt für Statistik (BFS) [Federal Statistical Office Switzerland]. *Personal der Universitären Hochschulen 2010 [Personnel of Universities 2010]*; BFS: Neuchâtel, Switzerland, 2011.
55. ETH Zurich. *Strategie und Entwicklungsplan 2017–2020 [Strategy and Development Plan 2017–2020]*; ETH Zurich: Zurich, Switzerland, 2016.
56. ETH Board [Board of the Swiss Federal Institutes of Technology]. *Personnel Law. Ordinance of the ETH Board Concerning Personnel in the Swiss Federal Institutes of Technology Domain*; ETH Board: Zurich, Switzerland, 2018.
57. Connell, R. *Gender and Power: Society, the Person and Sexual Politics*; University of California Press: Palo Alta, CA, USA, 1987.
58. Connell, R. Masculinities in global perspective: Hegemony, contestation, and changing structures of power. *Theor. Soc.* **2016**, *45*, 303–318. [CrossRef]
59. Jewkes, R.; Morrell, R.; Hearn, J.; Lundqvist, E.; Blackbeard, D.; Lindegger, G.; Quayle, M.; Sikweyiya, Y.; Gottzéni, L. Hegemonic masculinity: Combining theory and practice in gender Intervention. *Cult. Health Sex.* **2015**, *17*, 112–127. [CrossRef] [PubMed]
60. Rørstad, K.; Aksnes, D.W. Publication rate expressed by age, gender and academic position—A large-scale analysis of Norwegian academic staff. *J. Inform.* **2015**, *9*, 317–333. [CrossRef]
61. Van den Besselaar, P.; Sandström, U. Gender differences in research performance and its impact on careers: A longitudinal case study. *Scientometrics* **2016**, *106*, 143–162. [CrossRef] [PubMed]
62. Schmits, A. Mehr Plätze für die Kleinen [More places for the small people]. *ETH Life* **2016**, *1*, 13.
63. ETH Zurich Human Resources. *Regelmässiges Home Office für Mitarbeitende der ETH Zürich. Merkblatt [Regular Home Office for Staff of ETH Zurich. Information]*; ETH Zurich Human Resources: Zurich, Switzerland, 2016.

sustainability

MDPI

Article

Challenges of Promoting Sustainable Mobility on University Campuses: The Case of Eastern Mediterranean University

Abolfazl Dehghanmongabadi [1,*] and Şebnem Hoşkara [1,2]

1 Department of Architecture, Faculty of Architecture, Eastern Mediterranean University, North Cyprus, 99450 Famagusta, Mersin 10, Turkey; sebnem.hoskara@emu.edu.tr or sebnem.hoskara@utsa.edu
2 Urban and Regional Planning Program, Department of Architecture, College of Architecture, Construction and Planning, the University of Texas at San Antonio, San Antonio, TX 78207, USA
* Correspondence: abolfazl.dehghan@emu.edu.tr; Tel.: +90-533-886-1449

Received: 9 November 2018; Accepted: 15 December 2018; Published: 18 December 2018

Abstract: Universities have the extraordinary ability to generate awareness regarding all aspects of sustainability in communities. To be successful, they must first adopt and model sustainable concepts within their own campuses. Transportation is one of the most affective sectors on the level of sustainability on university campuses. In recent decades, numerous universities around the world have begun encouraging usage of active modes of transportation through various strategies. This research has a multi-faceted approach to researching proven strategies, sampling local conditions, and making context-driven recommendations. The literature review outlines the most effective strategies related to Transportation Demand Management (TDM) for promoting usage of active modes of transportation inside university campuses. After that, the condition of existing facilities and strategies as well as commuters' propensities related to active modes of transportation in the Eastern Mediterranean University (EMU) campus are evaluated using both qualitative and quantitative methods. The results include a set of recommendations and a framework for administrating, implementing, and enhancing a sustainable transportation system thereby increasing the commuter's use of sustainable active modes of transportation to, from, and within the university campus.

Keywords: sustainability; transportation; sustainable modes of transportation; university campus; EMU

1. Introduction

Amid the range of its modes, transportation is capable of providing the basic requirements of safety, well-being, comfort, health, economic growth, and social development to communities in varying degrees. Some modes do so more efficiently than others but all modes increase mobility and access to services, resources, other people, opportunities, and markets [1–5]. Unfortunately, the transportation systems and planning approaches currently used in developing and developed countries harbor pressing concerns and menace sustainability at the global level [3,5]. Due to the ramifications of poor transportation systems, it is widely accepted that urgent changes in travel modes, policies, and behaviors are crucial for mitigating transportation's externalities and reducing negative transport-related impacts [3,6,7]. Based on the concept of sustainable development, sustainable transportation emerged from the transportation sector to address these issues [3,6,8].

Universities are unique communities with rapidly-expanding populations in need of transportation options; simultaneously they are capable of engendering an educational milieu for sustainability [9–12]. As a result of increased university attendance, the number of commuters to and from university campuses has likewise increased. Disproportionately, the majority of these commuters use private automobiles [13]. The dependency on private automobiles is directly related to the lack of appropriate infrastructures and strategies for shared other modes of transportation [14].

This level of automobile usage directly and indirectly impacts the quality of the environment in university campuses and their surrounding neighborhoods. Spatial impacts include congestion; poor- or inaccessibility; occupation of land area for parking; air and noise pollution; energy consumption; and deterioration of visual and natural conditions. In addition to these environmental impacts, there are also many tangible and intangible social impacts such as declining health of staff, students, and neighbors; disturbance of work, study, living, and teaching environments; reduced personal safety and increased number of accidents; waste of time during periods of traffic congestion; and growth of mental health problems [14–16]. These are all externalities of unsustainable transportation systems. Fortunately, awareness about their negative impacts has greatly increased along with special attempts by university planners to supply sustainable transportation options [9,13,17]. Consideration of concerns related to the transportation sector is a first step in moving towards achieving sustainability on university campuses.

The aim of this research is to promote active modes of transportation for commuting to and from as well as transiting within university campuses in response to the challenges of enhancing sustainability in the transportation sector. In order to achieve this aim, the objectives are:

1. Outline and argue for the benefits of sustainable transportation within university campuses;
2. Identify successful strategies for promoting the use of active modes of transportation;
3. Isolate challenges related to existing active modes of transportation inside the Eastern Mediterranean University (EMU) campus;
4. Collect input from university staff and students to ascertain and explain recommendations that increase the use of active modes of transportation inside university campuses; and
5. Provide a planning framework towards achieving sustainable transportation on university campuses.

The following research questions helped form the aim and its objectives:

1. What are the ways of enhancing usage levels of active modes of transportation inside university campuses?
2. What are the determinative steps that must be considered to achieve an efficient, sustainable transportation sector within university campuses?

2. Literature Review

Over recent years, the population of universities has increased throughout the world and a considerable number of institutions have moved toward becoming more sustainable in order to reduce their own negative impacts on the environment, economy, and society [18,19]. These educational institutions, with an interest in developing their role in society, aim to be sustainable models for other communities [12]. Unwittingly, one of their weakest points in modelling sustainability is the daily movement of their populations by automobiles to and from, and within the campus [18,20,21]. Transportation issues are, therefore, one of the biggest challenges within university campuses and their surrounding communities [22]. For these reasons, numerous universities have started to plan a shift in their transportation sectors away from the use of private automobiles and towards the use of sustainable modes of transportation [18,22,23].

Promoting sustainable modes of transportation for university campuses has many environmental, social, and economic benefits, but the educational benefits of this effort are most profound since internally they have a duty to educate and foster the next generation of decision makers [19,23] and externally they have a duty to spread the most progressive knowledge into general usage. In view of this influential position, they should act as a laboratory for testing new ideas and strategies related to active modes of transportation [9,12,13,21]. Besides, transportation strategies which are introduced in university campuses are often transferred to and promoted in other parts of the community when students, having studied and lived in the campus environment, carry what they learned both inside and outside the classroom to the rest of the world. For both students and staff, opportunities to learn about and become familiar with sustainable transportation systems and strategies influence their attitudes and behaviors in the future [24].

Since promoting a multimodal and efficient transportation system within university campuses will be the main tool for altering the transit attitudes and behaviors of graduates for eventual transfer of strategies into their communities and daily life [25–27], there is an indispensable need for inclusion of Transportation Demand Management (TDM) strategies in comprehensive transportation system plans for university campuses. TDM appeared as a package in a series of executive strategies to solve problems related to the transportation sector. TDM encourages strategies for better management to promote more effective and environmentally-conscious attitudes about transportation. It is defined as the art of changing transportation behavior [28]. TDM strategies have numerous benefits such as diminished consumption of energy resources, preservation of natural resources and the environment, efficient use of land, decreased traffic accidents and congestion, a decline in pollution, increased transport options, and overall improvement in livability and social equity [28,29]. TDM strategies must also provide a balance between travel choice and the motivation to decrease trips using private cars [23]. The following sections describe several TDM strategies commonly used on university campuses: parking management and utilization, public transportation, carpooling and vanpooling, encouraging the use of bicycles, and providing a pedestrian-friendly campus [22,30].

(A) Parking Management and Utilization

In contemporary life, issues related to parking are one of the greatest common problems faced by users and planners of university campuses. Issues related to parking facilities can be divided into two different categories: supply and management [23,31]. Management approaches play a crucial role in the solution of the parking problem and they need not only supply solutions, but also support and provide more strategies which move toward a more efficient use of existing parking capacity.

Management approaches are also essential to a parking supply program [26,32]. Effective parking management within TDM has a significant influence, leading to declines in requests for parking spaces and decreases in parking costs on university campuses [22,31]. Additionally, good parking management offers social, environmental, and economic benefits meaning, for example, increasing livability, supporting social equity, improving service efficiency and quality, decreasing land use, increasing walkability, and saving costs [20,28,31]. Three proven approaches to parking management within university campuses are described as follows [23,26,30].

One of the most effective strategies within densely populated areas such as university campuses is parking supply and restriction. This strategy has a direct effect on travel behavior and the total number of automobiles with access to the campus [23,33]. When parking supply within the campus does not meet the demand, users adapt to using parking outside the campus or choose alternate modes of transportation for their commutes [34]. In most cases, the supply of fewer parking areas within university campuses encourages commuters to use sustainable modes of transportation such as walking, cycling, and public transportation [22,23].

Pricing of parking spots is another approach within university campuses that deters use because it means private car owners must pay fees to use parking areas. Universities that charge both staff and students for usage of parking facilities have better coverage of the costs of parking supply and management as well as reductions in demand for parking and increased usage of sustainable modes of transportation by commuters [23,26,34].

Inside university campuses, the location of parking areas can play a key role in the number of private car users; if parking areas are located only in the central or peripheral areas of the campus, commuters are denied the opportunity of convenience parking close to buildings and their destinations [23]. In weighing their options, this strategy encourages car users—especially ambivalent commuters—to choose sustainable modes of transportation to save their time and potentially gain more direct access to their destination. Besides reducing private car usage, strategic parking locations can save transportation costs for both the commuters and the universities [22,33].

(B) Carpooling and Vanpooling Program

One of the more recognized TDM strategies is the carpool and vanpool program, which provides the opportunity for users of single-occupancy private automobiles to move away from the need for individual car trips. This strategy suggests that two or more people, who share a common source, route, and destination, can use a single automobile [35]. This strategy usually involves people who live and work in the same and/or nearby neighborhoods [22,36]. Joint users of this strategy have a responsibility to share the costs of fuel and parking. This strategy is the most common mode used for trips that are not well supported by public transportation. The carpool program is most useful in small towns and rural areas and when people are commuting from peripheral areas where there are less public transportation services. This system can also be very useful for university campuses which are unique and uniform communities [22]. It has many tangible and intangible benefits such as cost cutting for fuel and parking, time saving, opportunities for more social interactions, reductions in stress, reduction in congestion and emissions, the conservation of energy, and support of a healthier future [22,35].

(C) Public Transportation Strategy (U-Pass Program)

Public transportation strategies like the U-Pass Program are one of the most popular of the TDM strategies for university campuses. The U-Pass Program's main goal is to encourage all participants to use public transportation modes (buses, trains, or light rail) and/or active transportation modes (bicycles, walking, etc.) rather than commuting by private cars [27,37]; it does so by subsidizing the costs of public transportation and increasing accessibility for more potential users. The U-Pass strategy has been effective and successful in terms of increasing the number of public transportation users and decreasing the demand for parking facilities on university campuses [33,38]. According to American University Officials, the top five reasons to apply the U-Pass Program are: declines in parking demand and traffic; improved access to housing and the university campus by all members; decreased costs of travel and student education; increased transportation justice, and enhanced usage levels of sustainable, active modes of transportation [37,38].

In addition, the U-Pass program has several advantages for universities such as Supports universities in achieving their environmental responsibilities; Diminishes the demand for parking areas, hence universities have more land to use for educational goals and Reduces parking spaces and traffic impact on surrounding areas [22,33,38].

Importantly, for university–community relations, U-Pass programs offer many benefits to the surrounding community like reducing motorized vehicle trips, enhancing physical activity, reducing traffic, and minimizing air and noise pollution [22,38]. There are several affective factors in the process of promoting use of public transportation that they have influence on the quality of services such as quality of shelters, number and location of shelters, lighting, seating elements, route/schedule information, signage, and timing [18,20–23].

An example of a U-Pass Program was created by the University of British Columbia (UBC)—the third largest university in Canada and one of the major traffic generators in the Vancouver region [22]. In September 1997, UBC established, "the Trip Reduction, Research, Education, and Knowledge (TREK) program center [27]." The main aim of TREK was to identify convenient and cost-effective approaches for commuting to and from the university campus without the use of private cars. While UBC's daytime population increased 51 percent during the 16 years between 1997 till 2013, TREK continued to follow the guidelines of TDM, focusing on the increase and improvement of effective transit services and transportation alternatives for university students and staff. The growing numbers of transit riders to and from the UBC campus was supported by increases in parking costs, a reduction in the supply of parking spaces, and transit fare discounts leading to further reductions in parking demand and traffic congestion [27]. According to a UBC Transportation Status Report from 2013, the U-Pass program was successful; there had been a significant increase in transit ridership and a decrease in private vehicle traffic. The main challenge TREK implementation faced was the increased demand for bus services, which demonstrated that UBC community members were very keen to join the program [22,27].

(D) Promoting Bicycle Use and Creating a Pedestrian Friendly Campus

The best modes of transportation to substitute for private car trips, particularly within university campuses, are walking and cycling [22,39,40] because these modes preserve independent choice of route and schedule. Walking is potentially the easiest adaptation because during any other mode of transit to university campuses, all commuters also become pedestrians to reach their final destination from parking place for drivers, bike station for cyclists, and bus or train station for users of public transportation. Already, because walking is an inseparable mode and an intrinsic part of all modes of transportation with suitable pedestrian accommodations at least partially in place, a university's promotion of this mode will be more cost efficient and spatially feasible. For promoting walking among university's members, various affective factors must be considered that the main of them are related to the quality of infrastructures and safety. These main factors include continuity of pedestrian paths, quality of pavements, safety along sidewalks, lighting, safety at interaction points, pedestrian signage, width of pedestrian paths, disabled-users' accessibility, quality of crosswalks, and shading element [22,34,41,42]. Similarly, the promotion of cycling needs motivator factors such as safe and separate bike lines, well-defined network among bike lines, appropriate lighting, signage and shading, safe and well-designed bicycle stations and racks, showering facilities, and repair and accessory facilities [22,36,42–46]. Bicycle infrastructure can be low-cost and accommodated spatially on university campuses by initially employing on-street striping and placing simple bike racks near high-traffic nodes. Still, convincing commuters to walk or cycle over longer distances and consume more time may require more complex pairings of TDM strategies with pedestrian and bicycle amenities. Pairing these modes with public transportation by providing well-defined walking and cycling facilities has been shown to be effective for longer travel; numerous researchers noted that commuters to university campuses use public transport more when such facilities are conveniently provided [22,32,40]. Planners' utilization of TDM guidelines for pedestrian- and bicycle-friendly campuses is a widely-used means of enhancing usage levels of active modes of transportation at university campuses [22].

In this respect, this study by focusing on the strategies and their main factors in Table 1 assesses the quality of service related to existing active modes of transportation in the case study.

Table 1. Transportation Demand Management (TDM) strategies commonly used on university campuses and effective factors.

Strategies	Factors	References
Parking Management and Utilization • Parking supply and restriction • Pricing of parking spots • Location of parking areas	-	[23,26,30]
Carpooling and Vanpooling	-	[22,35,36]
Public Transportation	• Quality of shelters • Number and location of shelters • Lighting and seating elements • Route/schedule information • Signage and timing	[18,20–23]

Table 1. *Cont.*

Strategies	Factors	References
Promoting Bicycle Use	• Safe and separate bike lines • Well defined network among bike lines • Appropriate lighting, signage, and shading • Safe and well-designed bicycle stations and racks • Showering facilities • Repair and accessory facilities	[22,36,42–46]
Creating a Pedestrian Friendly Campus	• Continuity of pedestrian paths • Quality of pavements and safety along sidewalks • Lighting and pedestrian signage • Safety at interaction points width of pedestrian paths • Disabled-users accessibility • Quality of crosswalks and shading element	[22,34,41,42]

3. Materials and Methods

The frame of this research is based on the case study method. Material for the case study was gathered from the study-area profile with a questionnaire survey and interviews reflecting the aim, objectives, and questions [47,48]. Four techniques made it possible to gather the necessary information: literature review, semi-structured key informant interviews, photo-elicitation, and questionnaire survey. After that, "Statistical Package for the Social Sciences (SPSS) Statistics software" was employed to analyze the collected data. To assure the quality of the research, the triangulation method was used to collect sufficiently diverse data sets increasing the dependability of the conclusions drawn from this research. Via these complementary methods, the necessary information for recognizing the determinative factors was obtained. The determinative factors influence achievement of a sustainable transportation system based on promoting active modes of transportation within university campuses.

(a) Literature Review

The literature reviewed in this study consists of choosing sources for investigation, and comparing related works of others to develop answers to the main research questions. The review covered indexed journal articles (SCI and SSCI), books, published conference papers, and published research works (theses). The key words and phrases used to search the literature include "sustainable transportation", "university campuses", and "TDM Strategy". The literature review pursued answers to the research questions of this study and particularly subjects to incorporate into the semi-structured interviews.

(b) Semi-Structured Interviews

Semi-structured interviews are normally planned around a set of predefined open-ended questions plus additional questions that may be employed during the dialogue between interviewer and interviewee(s). Here, five questions were the focus of individual interviews with six Eastern Mediterranean University (EMU) staff members: an Environmental Affairs Administration staff member, the Campus Services coordinator, the Rector's office coordinator, the director of the Security Unit, the director of the Transportation Services Unit, and the director of the Traffic Education and Research Center. Group interviews employed the same five questions with ten professors who have expertise in the fields of urban design, transportation, architecture, and civil engineering. Questions were geared toward gaining a comprehensive understanding of university strategies and plans as well as individual perceptions of existing and potential future conditions of active commuting within and to or from the EMU campus. The five main questions are presented in the following:

- Is there any future plan to decrease commuting to the campus by private car?
- Is there any program to improve the quality of services related to active modes of transportation inside the campus? How do you see the quality of services?

- Is there any program to encouraging carpooling and vanpooling among students and staff?
- Is there a Campus Planning Unit in the University?
- How are the decisions about any development in campus being taken?

During each interview, the personal suggestions of the interviewees on related topics based on their expertise have also been asked. Although the same questions were asked to all groups, during the interviews with the professors, the discussions have been deeper about the future of planning and transportation modes within EMU campus.

(c) Photo Elicitation

Photo elicitation is a method that uses photos, videos, and other forms of visual symbols and provides the opportunity for researchers to elicit comments from participants based on what they observe in the imagery [49,50]. In the context of this study, photos and maps were shown to participants to assist them in expressing their awareness of elements of or concerns, issues, and opportunities for active transport within EMU campus. This method helped respondents to focus on and improve the communication of important details to the interviewer [49,50]. The presented map of EMU delineated districts, building distribution, streets within the campus, and boundary lines of the campus. Photographs, as presented to the participants, displayed features of motor vehicle streets, pedestrian pathways and sidewalks, junctions, street design features, bicycle lanes, transit facilities, and parking areas. By using this imagery, richer awareness and clearer interpretation of respondents' viewpoints about existing conditions were possible. All these photos used in the interview were taken by the authors.

(d) Questionnaire survey

A questionnaire survey was conducted with the aim of obtaining feedback from EMU students, faculty and staff regarding their dominant modes of transportation and their feelings about the current infrastructure and commuting environment of the EMU campus. Feedback from these groups, the target users, is indispensable in making certain that their needs and concerns are addressed in the future planning, strategies, and policies. The four-section questionnaire survey focused on active modes of transportation and their relevant facilities at the EMU campus. Section 1 consisted of eleven general questions, for instance, gender, age group, level of study, and location of living. Section 2 asked each respondent to select different modes of transportation for commuting within and to or from the campus. Section 3 focused on the quality of infrastructure and service related to active modes of transportation with 26 rating scale questions associated with walking, cycling, and public transport. Finally, at the end of the questionnaire survey, participants were asked to list their personal expectations and suggestions with four open-ended questions (Appendix A). This questionnaire survey was completed in the spring academic semester of 2018. Participants were selected to represent all of the 39 academic departments to adequately represent every part of the campus; 15 students and five staff members were selected randomly from each department to fill-in the questionnaire survey resulting in the sample size of 585 students and 195 staff members. Although the questionnaire survey included, in its first section, general but detailed questions about the users such as their gender, age groups, and education level, the authors have decided to limit the demographic perspectives of the users within the scope of this paper, with the belief that, these would not serve directly for the main purpose of the research presented here. Table 2 shows a summary of the demographic profiles of the respondents.

Table 2. The demographic profile of the respondents (Sample size 780). EMU: Eastern Mediterranean University.

Characteristic		Staff		Students	
		N	Sample (%)	N	Sample (%)
Gender					
1	Female	101	51.8	275	47
2	Male	94	48.2	310	53
Age group					
1	Under 25 years	-	-	378	64.6
2	26–35 years	24	12.3	207	35.4
3	36–45 years	65	33.3	-	-
4	46–60 years	100	51.3	-	-
5	61 and above	6	3.1	-	-
Location of living					
1	Area 1 (< 1 Km from the EMU campus)	0	0	396	67.7
2	Area 2 (1 < 5 Km from the EMU campus)	92	47.17	167	28.5
3	Area 3 (> 5 Km from the EMU campus)	103	52.83	22	3.8

4. Introducing and Assessing EMU Campus' Existing Quality of Services and Strategies Related to Active Modes of Transportation

Eastern Mediterranean University (EMU), established in 1979, is the largest employer in Famagusta, North Cyprus, with a daily population of approximately 20,000 students and 1100 faculty and staff members. Famagusta is located on the east coast of the Mediterranean island and has a population of approximately 55,000. As such, one third of the population of Famagusta is somehow connected to EMU.

The area of the campus, which is divided into the adjacent though segregated north and south sections, is around 2200 acres. The northern section is primary in terms of the density of the buildings and facilities while the southern section houses fewer buildings and facilities but has undeveloped land for future development and campus expansion. The campus is approximately five kilometers from the historic city center (the Walled City) but is well-connected by continuous development along two arterial roads, Salamis Road and Lefkosa Road (Figure 1).

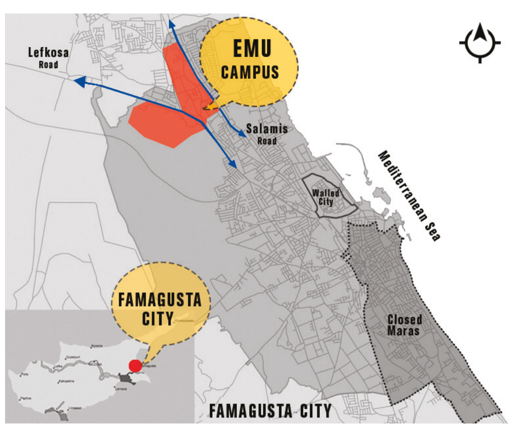


Figure 1. The Location of Eastern Mediterranean University Campus in Famagusta (Source: Authors).

EMU's social, economic, and spatial relationships with Famagusta shape its desire to adopt sustainability into its transportation sector and facilitate accessibility while helping to cultivate the interactions and conditions that make its campus a vibrant place of intellectual exchange and innovation. Existing transportation system for EMU and Famagusta city is planned more around automobiles than active modes. Within the scope of this research, an assessment of the existing situation of the transportation sector and related strategies at EMU campus was conducted. The assessment sought to identify and understand existing weaknesses, strengths, and opportunities of integration and implementation of sustainable transportation for the campus. At EMU, existing strategies and facilities related to active modes of transportation include parking controls, walking, cycling, and public transportation within the campus while the provision of carpooling and vanpooling elements are considered.

5. Results

There are four transportation modes that EMU's students and staff utilize for commuting to, from, and inside the campus: walking, cycling, public buses, and personal automobiles. The levels of commuting by each mode among students and staff are based on results of the questionnaire survey and presented in Table 3.

Table 3. Commuting Patterns of EMU's Students and Staff.

Modes	Commuter Category	Commute between Campus and City	Commuting inside Campus
Pedestrian	Staff	1%	60%
	Students	47%	80%
Bicycle	Staff	0%	0%
	Students	8%	5%
Public Transport	Staff	2%	0%
	Students	29%	7%
Private Cars	Staff	97%	40%
	Students	16%	8%

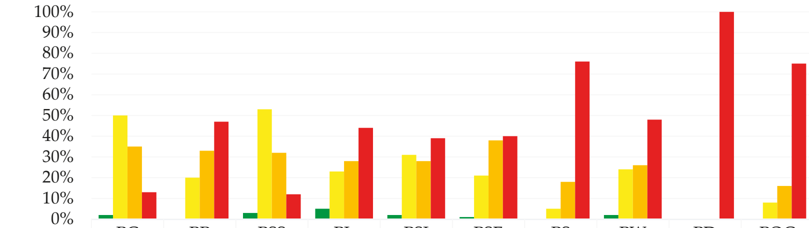
Percentages show that most EMU students commute to the campus from the city and transit inside the campus by walking. According to the questionnaire survey, most students live in on-campus dormitories or in nearby (within five kilometers) residential districts. On the other hand, most staff commute to campus by private car; they mostly live in suburban areas without sufficient public transport and travel more than five kilometers to reach the university.

5.1. Quality of Services Related to Existing Sustainable Modes of Transportation

To assess the quality of services of existing active modes of transportation within the EMU campus, each mode was evaluated. From the questionnaire survey and interviews of EMU's students and staff, their perspectives of the physical conditions of infrastructure and facilities related to the active modes of transportation are compiled and described in the following sections.

5.1.1. Quality of Services Related to Pedestrians

The level of users' satisfaction related to quality of physical components and the general existing situation of facilities related to pedestrians inside EMU campus include continuity of pedestrian paths (PC), quality of pavements (PP), safety along sidewalks (PSS), lighting (PL), safety at interaction points (PSI), pedestrian signage (PS), width of pedestrian paths (PW), disabled-users accessibility (PD), quality of crosswalks (PQC), and shading element (PSE) were evaluated and are summarized in Figure 2.



	PC	PP	PSS	PL	PSI	PSE	PS	PW	PD	PQC
Excelent	2%	0%	3%	5%	2%	1%	0%	2%	0%	0%
Good	50%	20%	53%	23%	31%	21%	5%	24%	0%	8%
Fair	35%	33%	32%	28%	28%	38%	18%	26%	0%	16%
Poor	13%	47%	12%	44%	39%	40%	76%	48%	100%	75%

Figure 2. Quality of facilities and services related to pedestrian inside EMU campus (Source: Authors). Pedestrian paths (PC), quality of pavements (PP), safety along sidewalks (PSS), lighting (PL), safety at interaction points (PSI), pedestrian signage (PS), width of pedestrian paths (PW), disabled-users accessibility (PD), quality of crosswalks (PQC), and shading element (PSE).

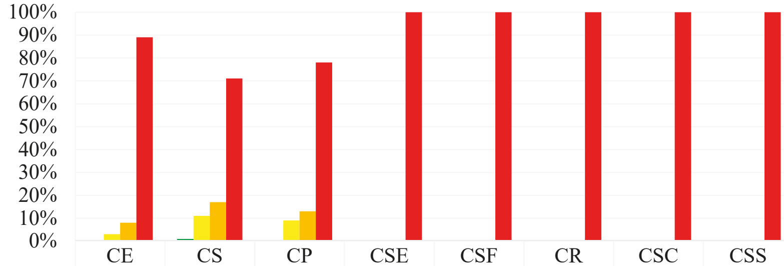
According to the results, continuity and safety along pedestrian paths are mentioned by respondents as the only motivating factors that encourage commuting by walking. Meanwhile the quality of the pavement, lighting, shading elements, pedestrian signage, width of pedestrian paths, accessibility by disable users, and crosswalk quality along the pedestrian paths are declared by responders to be barriers that directly affect efficiency of walking on the campus. Figure 3 includes four pictures is showing the quality of payments, shading elements and width of pedestrian paths inside the EMU campus. These pictures are taken from different places inside the campus.

Figure 3. Quality of payments, shading elements and width of pedestrian paths: **P1** Quality of payments along pedestrian paths within EMU Campus; **P2**–**P3** Trees being the only elements providing shade for pedestrians along the sidewalks; **P4**—Insufficient width of pedestrian paths along the main axis (Source: Authors).

5.1.2. Quality of Services Related to Cycling

The level of users' satisfaction related to the quality of existing facilities for cycling include bike lane efficiency (CE), safety along bike-share lanes (CS), bicycle parking and racks (CP), shading elements (CSE), showering facilities (CSF), repair and accessory facilities (CR), safety of bike stations (CSS), and signage for cyclists (CSC). These were observed and are summarized in Figure 4.

Based on findings of the questionnaire survey and visual analysis carried out on the site, there are no appropriate motivating factors to encourage cycling among EMU commuters. Besides the fact that bike lanes are considered to be inappropriately-shared space on vehicular roads, bicycle parking and racks is efficiently located around campus and their conditions are not always suitable for use. There is also a lack of security for bike stations, shading elements, signage for cyclists, showering facilities, and ancillary services. Figure 5 includes 6 pictures in which quality of bike lanes and stations are represented.



	CE	CS	CP	CSE	CSF	CR	CSC	CSS
Excelent	0%	1%	0%	0%	0%	0%	0%	0%
Good	3%	11%	9%	0%	0%	0%	0%	0%
Fair	8%	17%	13%	0%	0%	0%	0%	0%
Poor	89%	71%	78%	100%	100%	100%	100%	100%

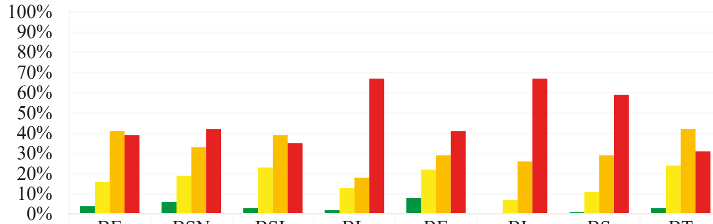
Figure 4. Quality of facilities and services related to cycling (Source: Authors). Bike lane efficiency (CE), safety along bike-share lanes (CS), bicycle parking and racks (CP), shading elements (CSE), showering facilities (CSF), repair and accessory facilities (CR), safety of bike stations (CSS), and signage for cyclists (CSC).

Figure 5. Quality of bike lanes and stations: **P1–P2–P3** Insufficient and unsafe bike lanes only partially painted with no appropriate separation from motorized vehicles; **P4–P5–P6** Bike stations and racks lacking of quality and safety within EMU Campus (Source: Authors).

5.1.3. Quality of Services Related to Public Transportation

The quality of the public transportation system on the EMU campus was evaluated for only the bus services provided by the university. EMU bus service is free of charge to students and staff and is the only heavy public transportation service in Famagusta. Assessment depended on efficiency of bus services (BE), quality of bus shelters by focusing on number of shelters on the campus (BSN) and location of shelters (BSL), quality of lighting (BL), quality of seating elements (BE), existence of route/schedule information (BI), bus signage (BS), and bus timing (BT) (Figure 6).

Results revealed that there is an overall lack of quality related to the bus service provided by EMU. Figure 7 includes 5 pictures illustrating the quality of buses and bus shelters inside EMU campus.



	BE	BSN	BSL	BL	BE	BI	BS	BT
Excelent	4%	6%	3%	2%	8%	0%	1%	3%
Good	16%	19%	23%	13%	22%	7%	11%	24%
Fair	41%	33%	39%	18%	29%	26%	29%	42%
Poor	39%	42%	35%	67%	41%	67%	59%	31%

Figure 6. Quality of facilities and services related to public transportation (Source: Authors). Bus services (BE), quality of bus shelters by focusing on number of shelters on the campus (BSN) and location of shelters (BSL), quality of lighting (BL), quality of seating elements (BE), existence of route/schedule information (BI), bus signage (BS), and bus timing (BT).

Figure 7. Quality of facilities related to bus service: **P1**–**P2** Low quality bus stop shelters lacking of aesthetics within EMU Campus; **P3**–**P4** Bus-stops with no shelters, no route/schedule information and seating discouraging users to use public transportation; **P5** Quality of buses within EMU Campus (Source: Authors).

Many respondents indicated that the bus service covers all destinations inside Famagusta, but that there is a lack of service for commuters who live in the suburbs. Mainly, most of the staff members living in the suburban areas do not have the opportunity to use or evaluate the services of this public transportation system.

5.2. Management Strategies Related to Transportation Context of EMU

According to the interviews conducted to understand the university's strategies and future plans in respect to the transportation sector, generally, and specifically in relation to active modes of transportation, there are no efficient and clear strategies or plans for the campus' transportation system. As explained by interviewees, decisions regarding campus transportation were made on an as-needed basis; there is no designated committee or administrative unit to investigate and make final decisions concerning campus transportation, nor to define transportation strategies.

However, there is one authority, the Security Department, responsible for decisions or proposals related to vehicular traffic and car parking areas on the campus, and another authority, the Transportation Services Unit, manages bus transportation. The Security Department is also responsible for the maintenance and security of the car parking areas and general commuting to and from university. Besides, there are no efficient and clear strategies regards parking management and utilization. Whereas the Transportation Services Unit controls all dimensions of the bus transportation services provided to students and staff by the university.

Without decision-making authority or administrative control over campus transportation, there is also the Traffic Education and Research Center within the academic body of the university. This center was established in 1998 by the University Board of Executives with the following mission components:

- Assist the foreign EMU students and academic and administrative staff in adapting to the traffic rules and regulations of the Turkish Republic of Northern Cyprus (TRNC) by offering educational seminars.
- Conduct research and organize symposiums, congress, and conferences on traffic problems.
- Increase the awareness of people living in North Cyprus about the importance of traffic.
- Establish links with organizations working on traffic safety both in North Cyprus and abroad.

Related to the strategies for carpooling and vanpooling, the results show EMU does not have any control over or supportive strategies related to encouraging carpooling among students or staff. However, several professors are privately arranging and using carpooling for commuting to and from the campus without interference of the university management system. As for vanpooling, the Transportation Services Unit mentioned that the university does organize vanpooling for lecturers who come from other cities such as Lefkosa and Kyrenia. Despite this, there are no strong supportive strategies for this service and this service is not always provided by EMU.

During the process of this research, Urban Research and Development Center (URDC) of EMU, which was assigned by the Rectorate in November 2015 to prepare the Campus Master Plan of EMU has also conducted a broader questionnaire survey for the overall campus. The research and analysis conducted by the Campus Master Plan team, coordinated by one of the authors of this paper, also corresponds with the findings of this research which indicate that, EMU does not have an adequate transportation management body nor a sustainable traffic and transportation plan; the future of the physical development of the campus, including its traffic and transportation development strategies is still unknown. Lack of planning, until recently, can be regarded as the basic problem of the transportation system for the EMU campus. Although there is an attempt to plan the future of the Campus, the unplanned development attempts seem to continue, until the Master Plan gains a legal status.

6. Discussion and Recommendations

Based on results of the questionnaire survey, behavior observations, site surveys, and interviews, the existing motivators and barriers related to use of the active modes of transportation at EMU campus have been clarified and summarized in Table 4.

The table shows that there are many more barriers to use of active modes of transportation within the EMU campus than there are motivators. Therefore, this study, based on existing conditions and the opinions of students, faculty, and staff, provides a set of recommendations by also examining some good university practices of sustainable transportation policy, strategy, and plan establishments mainly included in the European Platform on Sustainable Urban Mobility Plans (SUMPs) under the Urban Mobility Observatory. The authors believe that, this set of recommendations may also be generalized or adopted for other cases based on their specific characteristics, which should be identified through a thorough analysis.

These recommendations are divided into two groups: those focusing on the quality of physical infrastructure and those suggesting changes in the management structure to create an overarching authority and to provide direction for implementation and use of current and future active modes of transportation inside the university campus.

Table 4. Existing motivators and barriers factors of using active modes of transportation at EMU campus based on opinions of students and staff.

	Motivators	Barriers
Pedestrian	■ Safety along pedestrian paths ■ Continuity along pedestrian paths and sidewalks	■ Suitable pavements ■ Appropriate width for pedestrian paths ■ Main/legible pedestrian path ■ Suitable shading elements ■ Safety in interaction points ■ Appropriate crosswalks ■ Appropriate lighting at night ■ Signs along pedestrian routes ■ Appropriate accessibility and facilities for disable users ■ Pedestrian zone to provide a safer area for pedestrians
Cycling	**No Motivators**	■ Appropriate and safe bike lanes and bike stations ■ Safety in interaction points ■ Appropriate lighting at night ■ Ancillary services
Public Transportation	■ Existence of free bus services	■ Appropriate bus stations ■ Appropriate timing ■ Number of bus stations along the campus ■ Facilities related to bus shelters include lighting, seating elements, route/schedule information
Management strategies	**No Motivators**	■ Lack of plan for future development ■ Control and maintenance on existing facilities ■ Strategies to encourage the use of sustainable modes of transportation ■ Lack of expert committee to get appropriate decisions

Creating a successful sustainable transportation network for university campuses is achievable through the formation of a comprehensive and efficient university management structure. University transportation management has direct influence over and the ability to provide a successful and comprehensive sustainable transportation network with appropriate strategies for the university campus. Utilizing the following indispensable phases, this process will enhance the level of sustainability in the transportation sector of university campuses.

- Provide a sustainable master plan (SMP) for the university campus., since having a master plan by considering all aspects of sustainability is main way, which a university expresses its vision for future development and utilization of campus environment.
- Create a stable, sustainable transportation committee (STC) that has control and will make decisions about all aspects of transportation on the university campus, as well as undertake consistent efforts to promote sustainable transportation strategies by focusing on shifting to sustainable modes of transportation.
- Design a University Sustainable Transportation Master Plan (U-STMP) and University Sustainable Urban Mobility Plan (U-SUMP) corresponding with a general sustainable master plan along with strategies and policies confirmed by the STC.
- Increase the level of collaboration between the STC and local organizations, especially the municipality, to make decisions promoting successful sustainable transportation strategies between the university campus and the city to encouragement of active transportation.

- Increase the level of collaboration between the university administration, STC, and governmental agencies in order to establish a price-control mechanism for public transportation modes and connect the university's efforts to city's projects in order to increase the efficiency of both.
- Develop representation of students and staff within the STC to make better decisions and provide efficient strategies that meet their needs.
- Provide a series of educational programs focusing on enhancing knowledge of students and staff about environmental, social, cultural and economic benefits of commuting by sustainable modes of transportation.

To enhance the quality of services related to active modes of transportation, the most recent version of existing standards must be considered and applied. Accordingly, development of a Sustainable Urban Mobility Plan (SUMP) which is a strategic plan aimed to provide high-quality and sustainable mobility and transport to, through and within an area, as a recent guideline in European Union is considered within recommendations. Thus, the actions listed in Table 5 are recommended for university campuses, both for EMU campus and other university campuses with no transportation policy and plans, to improve the quality of services related to active modes of transportation. The study of sustainable mobility and transportation in some European examples of university campuses indicates that, although a number of actions have been taken on the issue, which have resulted in positive improvements with in the concerned campuses (such as, a bike sharing scheme at the Aristotle University in Thessaloniki, Greece; public bicycles in the university campus of Poznan in Poland; promotion of public transport by providing information and a tax-saver commuter ticket in Cork, Ireland, etc.); none of these actions covers a comprehensive approach for improving the quality of services related to active modes of transportation. Therefore, the authors suggest that the recommendations presented above and in Table 5 should be organized within the framework of a University Sustainable Transportation Master Plan (U-STMP) and University Sustainable Urban Mobility Plan (U-SUMP) specifically prepared for the concerned university.

Active modes of transportation work most efficiently when there is strong collaboration between all modes. Convenient connections and legible access in the physical infrastructure of active modes play a crucial role in providing and encouraging use of an effectual sustainable transportation system. The following framework clarifies the general process that a university can consider when developing an efficient and sustainable transportation sector (Figure 8).

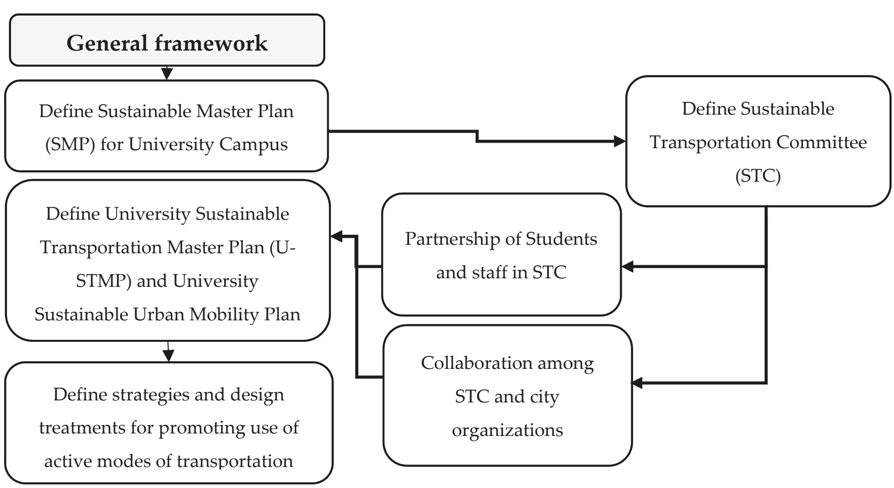


Figure 8. A general framework towards achieving an efficient, sustainable transportation sector in university campuses (Source: Authors).

Table 5. Recommendations for university campuses to improve the quality of services related to active modes of transportation under University Sustainable Transportation Master Plan (U-STMP) and University Sustainable Urban Mobility Plan (U-SUMP).

	Measures	
Pedestrian Enhancements	▪ **Pedestrian areas & paths**	▪ Provide pedestrian paths of appropriate width for pedestrian volumes throughout the campus; ▪ Provide appropriate pedestrian-scale lighting along pedestrian paths and at intersections to increase visibility and safety; ▪ Make available suitable signals and signage to help pedestrians find their way easily and safely between origins and destinations.
	▪ **Enhance pedestrian crossings**	▪ Design appropriate crosswalks and techniques to alert other users where pedestrians are crossing; ▪ Design appropriate corner radii at intersections to balance the needs of all users and maximize the safety of pedestrians. Small-radii curbs benefit pedestrians by slowing down speeds of turning vehicle, decreasing the crossing distance, and increasing the size of waiting areas.
	▪ **Design suitable curb extensions**	▪ Extending the sidewalks into the street space at intersections or mid-street crossings. Curb extensions benefit pedestrians by reducing distance of pedestrian crossing, providing space for pedestrian to queue before crossing the streets, increasing visibility of pedestrians; and reducing speed and calming traffic of vehicles.
	▪ **Enhance safety**	▪ Design treatments such as widen sidewalks for pedestrians and provide enough space that is capable of supplying utilities and amenities for example benches, trash cans, and signs; ▪ Use flashing yellow lights and different pavement textures in intersections to alert motorists to the presence of pedestrians; ▪ Increase shading elements as well as archways and canopies along pedestrian ways to protect pedestrians from extreme sun exposure and precipitation; ▪ Define a main pedestrian path through the campus that does not have any conflicts with motorized traffic; and ▪ Define a major pedestrian-only zone in the central part of campus to provide a safe area for pedestrians.
	▪ **Increase accessibility for disabled people**	▪ Consider disabled users by creating appropriate pavements, signage, and curb ramps.
Cycling Enhancements	▪ **Cycling lanes**	▪ Design appropriate separated bike lanes or provide marked shared lanes by using clear signage to alert drivers to the presence of bicyclists; ▪ Include attractive scenery around bike lanes and distance them from vehicular traffic and noise and air pollution wherever possible.
	▪ **Cycling amenities**	▪ Design appropriate bike stations and placing them in accessible and suitable locations; ▪ Provide suitable signage and maps to show direct routes for bicyclists; install suitable lighting and shading along bike lanes; ▪ Provide ancillary bike services such as shower facilities, repair and accessory shops, and storage for student and staff bicycles during the summers.
	▪ **Cycling strategies**	▪ Develop strategies for bike sharing among students and staff to encourage them to commute by bicycle or at least move around campus by bicycle; ▪ Develop strategies to increase integration of cycling with public transport.

Table 5. *Cont.*

Measures		
Public Transportation Enhancements	▪ **Public transport amenities**	▪ Design public transportation shelters/stops to have harmony with the campus environment and be more comfortable and safe for users by providing suitable lighting, seating elements, and clear schedule information; ▪ Increase the number of public transportation stations throughout the campus and select locations for shelters offering a good access to pedestrians and bicyclists infrastructure.
	▪ **Public transport timing** ▪ **Public transportation strategies**	▪ Pay special attention to the timing of public transportation to comfort and encourage users. ▪ Providing mobility packs, including information about public transport services to inform students and staff that it has a strong influence on university users' transport behavior.

7. Conclusions

Encouraging sustainable commuting in university has become an important movement around the world. There have been several studies focused on transportation modes used by commuters to, from, and within universities in addition to studies on the affective factors on commuters' propensity to use active modes of transportation. This research reviewed existing literature and studied data collected through a real case study to set out a process of encouraging university commuters to use active modes of transportation. Encouragement is possible through the supply of convenient, comfortable, and well-designed physical infrastructure and facilities. Considering the transportation context of the infrastructure and facilities is a first step toward success but it is not sufficient.

An authoritative transportation management structure to define appropriate strategies based on existing conditions and user demands is necessary to plan and provide higher quality, more coordinated, more sustainable, and better utilized campus transportation services. Moreover, implementing strategies to limit use of private automobiles and to support existing users of active modes of transportation will encourage more commuters to shift to active modes of transportation. Furthermore, employing transportation-education strategies through workshops and seminars expands awareness and knowledge of the advantages of commuting by active modes of transportation.

Finally, this paper is a useful reference for future researchers who are interested in undertaking new case studies for enhancing the level of sustainability in transportation sector on other university campuses. The results are provided in a framework that can guide researchers as well as the leadership and decision-makers of universities towards developing plans and strategies that encourage university populations to use active modes of transportation. Besides, for future studies, through the other findings of this research, the influences of demographic factors (e.g., gender, age, location of living, and education level) on improving level of sustainability in transportation sector through encouraging use of active modes of transportation must be thoroughly investigated and considered.

Author Contributions: The research was designed by A.D. in collaboration with co-author, Ş.H. The first and final drafts were written by A.D. The defects of both drafts were critiqued, corrected, and improved by Ş.H. The improvements suggested by the reviewers were implemented by both authors. All authors read and approved the final manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest with respect to the research, authorship, and/or publication of this article.

Appendix A. Sample of Questionnaire

Appendix A.1. Personal Information

1- Gender: ☐ Male ☐ Female
2- What is your age group? ☐ Under 25 years ☐ 26 to 35 ☐ 36 to 45 ☐ 46 to 60 ☐ 61 and above
3- Country:
4- Nationality:
5- Are you a ☐ Student ☐ Staff
6- Which faculty/department are you studying at or a member of?
7- What is your field of study? (If you are a student)
8- What is your highest degree or level of study? (If you are a student) ☐ Undergraduate student ☐ Graduate student
9- How long have you been studying or working at the EMU? ☐ Less than 1 year ☐ 1 to 2 year ☐ 3 to 4 year ☐ More than 4 years
10- Where do you live? ☐ Area 1 (<1 Km from the EMU campus) ☐ Area 2 (1 < 5 Km from the EMU campus) ☐ Area 3 (>5 Km from the EMU campus)
11- What kinds of accommodation are you living in? ☐ Dormitory ☐ Shared flat ☐ Apartment ☐ Villa ☐ Other . . . . (Please specify)

Appendix A.2. Modes of Transportation for Commuting within and from/to the Campus

1- What kind of transportation modes do you usually use for commuting to or from the campus? ☐ Private car ☐ Public transportation ☐ Bicycle ☐ Walking
2- What kind of transportation modes do you usually use to move from one place to another within the campus? ☐ Private car ☐ Public transportation ☐ Bicycle ☐ Walking

Appendix A.3. The Quality of Infrastructure and Service Related to Active Modes of Transportation inside EMU Campus

Appendix A.3.1. Quality of Services Related to Pedestrians

1- How do you see the continuity among pedestrian paths inside the campus? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
2- What do you think about the condition and quality of pedestrian paths' pavements? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
3- What do you think about safety along the pedestrian paths? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
4- What do you think about quality of lighting along pedestrian paths at nights? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
5- How do you see the safety in interaction points between pedestrians and vehicles inside the campus? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
6- How do you see the quality of pedestrian signage? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
7- What do you think about the width of pedestrian paths? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
8- What do you think about the quality of services for accessibility of disabled users? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
9- How do you see the quality of crosswalks along the campus? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
10- How do you see the quality of shadings elements along the pedestrian paths? ☐ Poor ☐ Fair ☐ Good ☐ Excellent

Appendix A.3.2. Quality of Services Related to Cycling

1. How do you see the bike lane efficiency inside the EMU campus? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
2. What do you think about safety along bike-share lanes? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
3. What do you think about quality of bicycle parking and racks? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
4. What do you think about the quality of shading elements along the bike lanes? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
5. What do you think about the quality of showering facilities? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
6. What do you think about quality of repair and accessory facilities? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
7. What do you think about safety of bike parking and racks? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
8. How do you see the quality of signage for cyclists? ☐ Poor ☐ Fair ☐ Good ☐ Excellent

Appendix A.3.3. Quality of Services Related to Public Transportation

1. What do you think about efficiency of bus services? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
2. What do you think about quality of bus shelters by focusing on number of shelters on the campus? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
3. What do you think about quality of bus shelters by focusing on location of shelters? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
4. What do you think about quality of lighting inside bus shelters? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
5. What do you think about quality of seating elements inside bus shelters? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
6. How do you see the existence of route/schedule information? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
7. What do you think about quality of bus signage? ☐ Poor ☐ Fair ☐ Good ☐ Excellent
8. What do you think about the bus timing? ☐ Poor ☐ Fair ☐ Good ☐ Excellent

Appendix A.4. Personal Expectations and Suggestions

1- What is your expectation and suggestion for improving the service quality of pedestrian facilities?
2- What is your expectation and suggestion for improving the service quality of cycling facilities?
3- What is your expectation and suggestion for improving the quality of bus service?
4- Which type of active modes of transportation do you prefer to use if all facilities about it be in a good condition?

References

1. Hickman, R.; Hall, P.; Banister, D. Planning more for sustainable mobility. *J. Transp. Geogr.* **2013**, *33*, 210–219. [CrossRef]
2. Litman, T. Developing indicators for comprehensive and sustainable transport planning. *J. Transp. Res. Board* **2007**, *2017*, 10–15. [CrossRef]
3. Qureshi, I.A.; Lu, H. Urban transport and sustainable transport strategies: A case study of Karachi, Pakistan. *Tsinghua Sci. Technol.* **2007**, *12*, 309–317. [CrossRef]
4. Steg, L. Sustainable transportation a psychological perspective. *IATSS Res.* **2007**, *31*, 58–66. [CrossRef]
5. Zuidgeest, M.H.P. *Sustainable Urban Transport Development: A Dynamic Optimisation Approach*; University of Twente: Enschede, The Netherlands, 2005.
6. Babalik-Sutcliffe, E. Urban form and sustainable transport: Lessons from the Ankara case. *J. Int. J. Sustain. Transp.* **2013**, *7*, 416–430. [CrossRef]
7. Prillwitz, J.; Barr, S. Moving towards sustainability? Mobility styles, attitudes and individual travel behaviour. *J. Transp. Geogr.* **2011**, *19*, 1590–1600. [CrossRef]

8. Bayramoğlu, G. *Planning and Design Criteria to Make Urban Transport More Sustainable: The Case of Baku*; LAP LAMBERT Academic Publishing: Riga, Latvia, 2012.
9. Cortese, A. *Education for Sustainability: The University as a Model of Sustainability*; Second Nature: Boston, MA, USA, 1999.
10. Čiegis, R.; Gineitienė, D. The role of universities in promoting sustainability. *Eng. Econ.* **2006**, *3*, 56–62.
11. Abubakar, I.R.; Al-Shihri, F.S.; Ahmed, S.M. Students' assessment of campus sustainability at the University of Dammam, Saudi Arabia. *Sustainability* **2016**, *8*, 59. [CrossRef]
12. Beringer, A. Campus sustainability audit research in Atlantic Canada: pioneering the campus sustainability assessment framework. *Int. J. Sustain. High. Educ.* **2006**, *7*, 437–455. [CrossRef]
13. Guasch, C.; Domene, E. Sustainable transport challenges in a suburban university: The case of the Autonomous University of Barcelona. *Transp. Policy* **2010**, *17*, 454–463. [CrossRef]
14. Limanond, T.; Butsingkorn, T.; Chermkhunthod, C. Travel behavior of university students who live on campus: A case study of a rural university in Asia. *Transp. Policy* **2011**, *18*, 163–171. [CrossRef]
15. Xu, J.; Zhang, Z.; Rong, J. The campus road planning and design research. *Procedia Soc. Behav. Sci.* **2012**, *43*, 579–586. [CrossRef]
16. Emanuel, R.; Adams, J.N. College students' perceptions of campus sustainability. *Int. J. Sustain. High. Educ.* **2011**, *12*, 79–92. [CrossRef]
17. Lidstone, L.; Wright, T.; Sherren, K. Canadian STARS-rated campus sustainability plans: Priorities, plan creation and design. *Sustainability* **2015**, *7*, 725–746. [CrossRef]
18. ISCU. *Best Practice in Campus Sustainability*; The World Economic Forum Annual Meeting: Davos-Klosters, Switzerland, 2014.
19. Velazquez, L.; Munguia, N.; Sanchez, M. Deterring sustainability in higher education institutions: An appraisal of the factors which influence sustainability in higher education institutions. *Int. J. Sustain. High. Educ.* **2005**, *6*, 383–391. [CrossRef]
20. Fund, A.; Hall, A.; Gorby, C.; Siegel, D.; Wolf, E.; Burdett, J.; Gathunguri, M. *Sustainable Transportation at the University of Kansas*; Center for Sustainability University of Kansas: Lawrence, KS, USA, 2012.
21. Norzalwi, N.; Ismail, A. Public Approach towards sustainable transportation in UKM's campus. *Aust. J. Basic Appl. Sci.* **2011**, *5*, 1332–1337.
22. Toor, W.; Havlick, S.W. *Transportation and Sustainable Campus Communities*; Island Press: Washington, DC, USA, 2004.
23. Bond, A.; Steiner, R.L. Sustainable campus transportation through transit partnership and transportation demand management: A case study from the University of Florida. *Berkeley Plan. J.* **2006**, *19*, 125–142.
24. Dehghanmongabadi, A.; Shirkhanloo, N. Questioning the contribution of higher education institutions to the cultural sustainability of local communities. In Proceedings of the People and the Planet 2013, Transforming the Future, Melbourne, Australia, 2–4 July 2013; pp. 1–12.
25. Lim, C.C. The status of transportation demand management in Greater Vancouver and energy implications. *Energy Policy* **1997**, *25*, 1193–1202. [CrossRef]
26. Litman, T. The online TDM encyclopedia: Mobility management information gateway. *Transp. Policy* **2003**, *10*, 245–249. [CrossRef]
27. Senft, G. U-Pass at the University of British Columbia: Lessons for effective demand management in the campus context. Proceedings of Emerging Best Practices in Urban Transportation Planning (A) Session of the 2005 Annual Conference of the Transportation Association of Canada, Calgary, AB, Canada, 18–21 September 2005; pp. 1–21.
28. Ferguson, E. Transportation demand management planning, development, and implementation. *J. Am. Plan. Assoc.* **1990**, *56*, 442–456. [CrossRef]
29. Berman, W.; Radow, L. Travel demand management in the USA: Context, lessons learned and future directions. *Energy Policy* **1997**, *25*, 1213–1215. [CrossRef]
30. Litman, T.; Burwell, D. Issues in sustainable transportation. *Int. J. Glob. Environ. Issues* **2006**, *6*, 331–347. [CrossRef]
31. Aoun, A.; Abou-Zeid, M.; Kaysi, I.; Myntti, C. Reducing parking demand and traffic congestion at the American University of Beirut. *Transp. Policy* **2013**, *25*, 52–60. [CrossRef]
32. Litman, T. *Mobility Management: Innovative Management Strategies to Transport Problems*; Victoria Transport Policy Institute: Victoria, BC, Canada, 2006.

33. Azzali, S.; Sabour, E.A. A framework for improving sustainable mobility in higher education campuses: The case study of Qatar University. *Case Stud. Transp. Policy* **2018**, *6*, 603–612. [CrossRef]
34. Bowman, A. "You can get there from here": Campus transportation practices: What they are, and what they could be. *Coastlines* **2018**, *1*, 5.
35. Erdoğan, S.; Cirillo, C.; Tremblay, J.-M. Ridesharing as a green commute Alternative: A campus case study. *Int. J. Sustain. Transp.* **2015**, *9*, 377–388. [CrossRef]
36. Balsas, C.J.L. Sustainable transportation planning on college campuses. *Transp. Policy* **2003**, *10*, 35–49. [CrossRef]
37. Hickman, R.; Lopez, N.; Cao, M.; Lira, B.M.; Biona, J.B.M. "I drive outside of peak time to avoid traffic jams—Public transport is not attractive here." Challenging discourses on travel to the university campus in Manila. *Sustainability* **2018**, *10*, 1462. [CrossRef]
38. Brown, J.; Hess, D.B.; Shoup, D. Fare-free public transit at Universities. *J. Plan. Educ. Res.* **2003**, *23*, 69–82. [CrossRef]
39. Karanikola, P.; Panagopoulos, T.; Tampakis, S.; Tsantopoulos, G. Cycling as a smart and green mode of transport in small touristic cities. *Sustainability* **2018**, *10*, 268. [CrossRef]
40. Murwadi, H.; Dewancker, B. Study of Quassessment Model for campus pedestrian ways, case study: Sidewalk of the University of Lampung. *Sustainability* **2017**, *9*, 2285. [CrossRef]
41. Killingsworth, R.E.; De Nazelle, A.; Bell, R.H. *A New Role for Public Health in Transportation Creating and Supporting Community Models for Active Transportation*; University of North Carolina: Chapel Hill, NC, USA, 2003.
42. Lovasi, G.S.; Schwartz-Soicher, O.; Neckerman, K.M.; Konty, K.; Kerker, B.; Quinn, J. Aesthetic Amenities and Safety Hazards Associated with Walking and Bicycling for Transportation in New York City. *Ann. Behav. Med.* **2013**, *45*, 76–85. [CrossRef] [PubMed]
43. Freeman, L.; Neckerman, K.; Schwartz-Soicher, O.; Quinn, J.; Richards, C.; Bader, M.D.M.; Lovasi, G.; Jack, D.; Weiss, C.; Konty, K.; et al. Neighborhood walkability and active travel (walking and cycling) in New York City. *J. Urban Health* **2013**, *90*, 575–585. [CrossRef] [PubMed]
44. Basu, S.; Vasudevan, V. Effect of bicycle friendly roadway infrastructure on bicycling activities in urban India. *Procedia-Soc. Behav. Sci.* **2013**, *104*, 1139–1148. [CrossRef]
45. Pucher, J.; Dill, J.; Handy, S. Infrastructure, programs, and policies to increase bicycling: An international review. *Prev. Med.* **2010**, *50*, S106–S125. [CrossRef] [PubMed]
46. Snizek, B.; Nielsen, T.A.S.; Skov-Petersen, H. Mapping bicyclists' experiences in Copenhagen. *J. Transp. Geogr.* **2013**, *30*, 227–233. [CrossRef]
47. Zainal, Z. Case study as a research method. *J. Kemanus. Bil* **2007**, *9*, 1–6.
48. Yin, R.K. *Applications of Case Study Research*; SAGE: Los Angeles, CA, USA, 2011.
49. Banks, M. *Visual Methods in Social Research*; Sage Publications Inc.: New York, NY, USA, 2001.
50. Gill, P. *Framing a Complete Streets Checklist for Downtown Historic Districts and Character Neighbourhoods: A Case Study of the Warehouse District, Winnipeg, Manitoba*; The University of Manitoba: Winnipeg, MB, Canada, 2014.

sustainability

MDPI

Article

Carbon Footprint of Academic Air Travel: A Case Study in Switzerland

Joachim Ciers [1,*,†], Aleksandra Mandic [2,*,†], Laszlo Daniel Toth [1] and Giel Op 't Veld [3]

1 School of Basic Sciences, École Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland; toth.mester@gmail.com
2 School of Life Sciences, École Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland
3 School of Computer and Communication Sciences, École Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland; gieloptveld@gmail.com
* Correspondence: joachim.ciers@epfl.ch (J.C.); amandic@hathor.xyz (A.M.)
† These authors contributed equally to this work.

Received: 31 October 2018; Accepted: 15 December 2018; Published: 24 December 2018

Abstract: Relatively low travel costs and abundant opportunities for research funding in Switzerland and other developed countries allow researchers large amounts of international travel and collaborations, leading to a substantial carbon footprint. Increasing willingness to tackle this issue, in combination with the desire of many academic institutions to become carbon-neutral, calls for an in-depth understanding of academic air travel. In this study, we quantified and analyzed the carbon footprint of air travel by researchers from the École Polytechnique Fédérale de Lausanne (EPFL) from 2014 to 2016, which is responsible for about one third of EPFL's total CO_2 emissions. We find that the air travel impact of individual researchers is highly unequally distributed, with 10% of the EPFL researchers causing almost 60% of the total emissions from EPFL air travel. The travel footprint increases drastically with researcher seniority, increasing 10-fold from PhD students to professors. We found that simple measures such as restricting to economy class, replacing short trips by train and avoiding layovers already have the potential to reduce emissions by 36%. These findings can help academic institutions to implement travel policies which can mitigate the climate impact of their air travel.

Keywords: carbon footprint; CO_2 emissions; air travel; environmental footprint mitigation

1. Introduction

Aviation is one of the fastest growing sources of greenhouse gas (GHG) emissions. Over the last four decades, the number of passenger-kilometers in worldwide civil aviation increased at an average rate of 5% per year, while the corresponding carbon dioxide (CO_2) emissions have increased by 2% per year on average [1]. The emissions are increasing at a slower rate than the number of passenger-kilometers due to improvements in fuel efficiency. This continuous increase has brought global annual civil aviation CO_2 emissions up to 900 Mt in 2016, which is 2.8% of the world's total CO_2 emissions [2]. Besides the global warming effect through the emission of greenhouse gasses such as CO_2 and NO_x, airplanes cause additional radiative forcing (RF) through the generation of condensation trails (contrails), which eventually form cirrus or altocumulus clouds, and the formation of tropospheric ozone by NO_x. At the same time, NO_x facilitates the destruction of methane, lowering the RF. The total RF from aviation is therefore estimated to be two to four times higher than that induced by GHG emission alone [3]. In 2005, aviation was responsible for 4.9% of anthropogenic global warming [4]. A three- to four-fold increase in aviation RF is expected by 2050, compared to the year 2000 [4]. Despite the ever-increasing environmental impact of air travel, these emissions, together with international shipping, are not regulated under the 2015 Paris climate agreement.

Globally, only a small fraction of people participate in air travel. It was estimated that only about 2% to 3% of the world population take an international flight over the course of a year [5]. This illustrates that air travel is very unequally distributed with a small number of high-footprint hypermobile travelers. One group of people with a particularly high air travel footprint are academics. Indeed, many researchers are frequent travelers due to the importance of conferences, workshops, international collaborations, visiting positions, etc., for their career advancement. At the École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland, air travel accounts for one third of the institute's total CO_2 emissions (corresponding to at least half of the total RF), similar to the CO_2 emissions of electricity and heating, and daily commuting.

In many academic institutions worldwide, awareness of these issues has increased, but a detailed quantitative analysis of academic air travel behavior is challenging due to the lack of comprehensive datasets. Therefore, in this study we retrospectively quantify the air travel habits of EPFL researchers and we identify carbon footprint reduction opportunities. This work is limited to air travel performed by EPFL academic staff in the period of 2014 to 2016.

2. Materials and Methods

In order to describe the professional travel habits of EPFL's academic staff, flight data from 2014 to 2016 was retrospectively collected from Carlson Wagonlit Travel (CWT), the official EPFL travel agency [6]. This dataset comprises approximately 80% of all travel made by EPFL researchers during the specified time period. The remaining 20% of air travel was booked directly by the researchers. For the latter category, only ticket price and airline company are known, and these air travels are therefore excluded from the present analysis. A coverage of 80% is sufficiently large to draw representative quantitative conclusions from this data. The dataset was anonymized and includes GHG emissions, distance, price, exact flight route, and service class for every trip. GHG emissions were calculated using the yearly DEFRA metrics [7] and include CO_2 and NO_x. These annual metrics provide average emissions of the aviation industry. This allows us to make a good estimate of a flight's GHG emissions, without knowing the technical details of the airplane, which are not provided upon booking. Here, we only consider the direct GHG emissions from the airplane, which are well-known. The additional RF related to the formation of contrails, which eventually form cirrus or altocumulus clouds, the generation of ozone by NO_x, and the negative RF from the destruction of methane by NO_x are not included since the exact magnitudes of these impacts are still under debate. The overall RF generated by the air travel discussed here will therefore be two to four times larger than the GHG emissions quoted in this work [3]. The GHG emissions are expressed in kg of CO_2 with an equivalent global warming power, which is noted CO_2e. The CO_2e emission of a flight is calculated as

$$\text{Emission } (CO_2e) = \text{distance} \times \text{uplift} \times CO_2e \text{ intensity}, \quad (1)$$

where the distance is determined as the great circle distance between the airport locations, i.e., the shortest path between two points on the surface of a sphere. The distance flown is multiplied with the uplift parameter, to account for takeoff, circling and non-direct routes and it represents 1.09. The year and service class of the flight determines the CO_2e intensity. Note that business and first class flights cause two to four times more emissions per person, compared to economy class due to the increased floorspace requirements, as can be seen in Supplementary Table S1. Note also that the CO_2e intensity of a flight in a given year is determined by flights from the previous year. The quantitative analysis was performed using the Python language and the NumPy package. The data was loaded from a .csv file.

3. Results

3.1. General Aspects of the Data

During the examined time period, 3334 members of academic staff (of which 46% PhD students, 29% postdocs, 1.7% senior scientists and 8.3% professors) took 14,949 flights over a total of 100 million km. This led to 14.6 kt CO_2e emitted, which represents 27% of EPFL's total GHG emissions. More detailed statistics can be found in Table 1. Supplementary Figure S1 shows the distribution of trips as a function of distance. We see that most trips are continental, with a second intercontinental peak. Continental travel is mostly direct, whereas intercontinental travel is mostly indirect.

Table 1. Overview of the travel impact for intra- and inter-continental travel in economy, business and first class.

Travel Type		Number of Flights	CO_2e Emitted (t)	Distance Travelled (Mm)	CHF/km	Avg. CO_2e kg/CHF	Avg. CO_2e kg/km	Total Cost (kCHF)
Total		14,949	14,603	98,975	0.120	1.235	0.148	11,809
Intra-continental	Economy	9030	2300	14,004	0.184	0.893	0.164	2577
	Business and First	324	100	600	0.296	0.562	0.167	178
Inter-continental	Economy	4690	7958	69,356	0.075	1.524	0.115	5220
	Business and First	905	4245	15,015	0.255	1.107	0.287	3834

Figure 1 shows the relationship between CO_2e emission and distance travelled. We can clearly see the increased emission from higher service classes. In Figure 2, we observe a higher correlation between the amount of money spent and CO_2e emitted (correlation coefficient of 0.89) than between distance travelled and CO_2e emitted (correlation coefficient of 0.64).

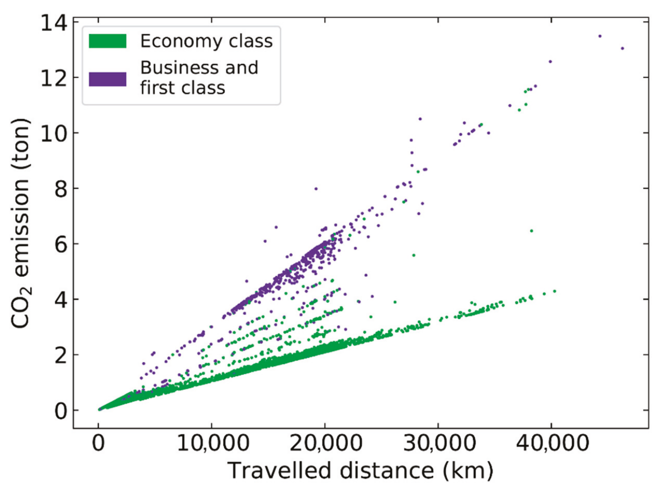


Figure 1. CO_2 emission as a function of the distance travelled for all trips in the dataset. Economy class trips are marked in green, while business and first class flights are marked in purple. This figure visually illustrates the increased greenhouse gas (GHG) emissions of higher service class.

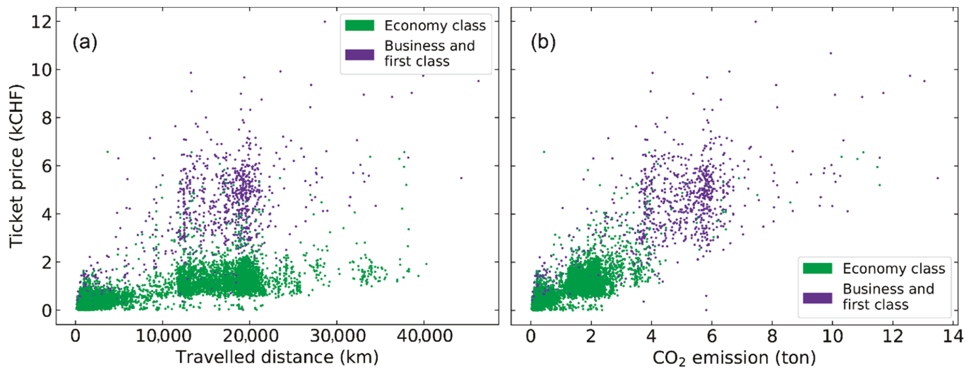


Figure 2. (**a**) Ticket price as a function of distance travelled for the entire dataset; (**b**) ticket price as a function of CO_2 emission, again for the entire dataset. We observe a much stronger correlation in (**b**); compared to (**a**). The correlation coefficients are 0.89 and 0.64, respectively.

3.2. Travel Behavior of EPFL Researchers

Upon investigation of the travel habits of the different groups of researchers, which are shown in Figure 3, we observe that carbon footprint increases dramatically with seniority (Figure 3a). Professors emit on average 10 and 5 times more GHGs compared to PhD students and postdocs, respectively. Moreover, professors—and to a smaller extent senior scientists—are the main users of business and first class travel, which is negligible for PhD students and postdocs. A similar increase with seniority can be observed for the distance travelled and money spent, as is shown in Supplementary Figure S2.

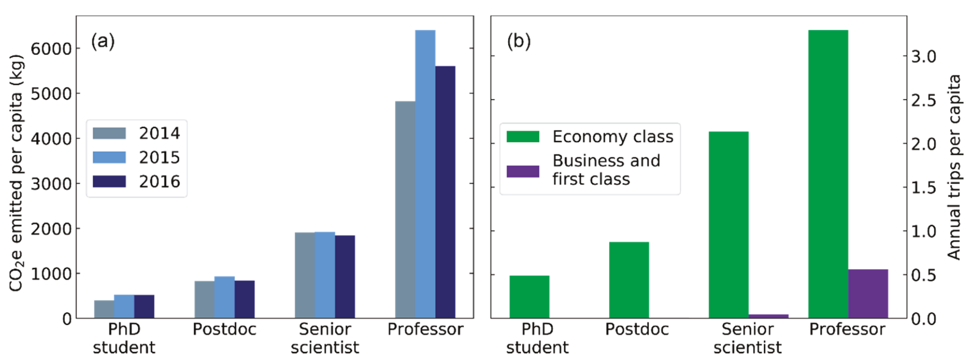


Figure 3. (**a**) Average annual air travel carbon footprint of a PhD student, Postdoc, senior scientist and professor at École Polytechnique Fédérale de Lausanne (EPFL); (**b**) annual number of trips in economy and business class for the same categories. We clearly see the increase of travel footprint with seniority.

Figure 4 shows the inequality in footprint between individual travelers and research units or labs. We observe very high levels of inequality in terms of GHG emissions, money spent, and distance travelled, with a small number of individuals traveling over an order of magnitude more than the median, and a small number of labs traveling almost an order of magnitude more than the median. Table 2 shows two quantities that represent inequality for the three types of footprints discussed here, namely the share of the top 10% biggest travelers, and the Gini coefficient, both for individual researchers and for laboratories. We observe that the 10% of most traveling individuals are responsible for 58.3% of EPFL's GHG emissions from air travel, while the 10% of most traveling labs emit 40.2% of EPFL's air travel GHGs. Looking at the Gini coefficient, a measure of statistical dispersion most commonly used measurement of inequality, we observe a larger inequality in individual carbon footprint (0.722) than for worldwide income (0.65, World bank [8,9]). The Gini coefficient for CO_2e emission per lab (0.607) is slightly lower than that of the worldwide income. We observe a systematically lower inequality for the distance travelled, compared to CO_2e emissions and money spent. This observation is due to increased business and first class travel among the largest consumers.

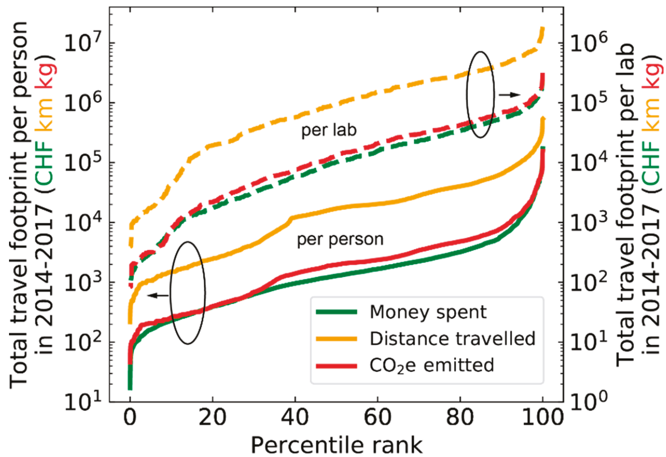


Figure 4. Total travel footprint from 2014 to 2016 of individual researchers (solid line, corresponding to the left-hand vertical axis) and laboratories (dashed line, corresponding to the right-hand vertical axis). Individuals and laboratories are ranked from low to high on a scale from 0 to 100. The footprint is expressed in money spent (green), distance travelled (orange), and CO_2 emitted (red) and the data are ranked in increasing order. All quantities show a large inequality with a spread over more than two orders of magnitude.

Table 2. Inequality quantifiers for GHG emissions, distance traveled and money spent, both per person and per lab.

	Share of the Top 10% Biggest Travelers		Gini Coefficient	
	Per Person	**Per Lab**	**Per Person**	**Per Lab**
CO_2e emission	58.3%	40.2%	0.722	0.607
Distance travelled	49.8%	39.0%	0.678	0.588
Money spent	64.0%	42.3%	0.749	0.622

3.3. Reduction Opportunities

Based on the relationships that emerged from the data analyses, we were able to identify and quantify three pathways to reduce GHG emissions without compromising travel.

First, due to the difference in CO_2 intensity between service classes, a reduction of 17% in EPFL's air travel GHG emissions, amounting to 840 t CO_2e per year could be obtained by replacing all business and first class trips by economy class.

A second pathway would consist of replacing short flights by rail travel. In order to quantify this reduction, one should observe the cumulative CO_2e emissions as a function of distance travelled in Figure 5a. We see that approximately 15% of EPFL's air travel GHG emissions are coming from continental travel. Zooming in on the short trips below 1000 km, as well as short connection flights during indirect trips, allows us to determine the reduction potential of this replacement. The cumulative impacts of short direct trips and short flights during indirect trips are shown in Figure 5b. Replacing both of them over distances below 800 km could reduce EPFL's air travel GHG emissions by up to 15% or 730 t CO_2e per year. We assumed that the replacing train trip would emit 0.02 kg of CO_2e per km.

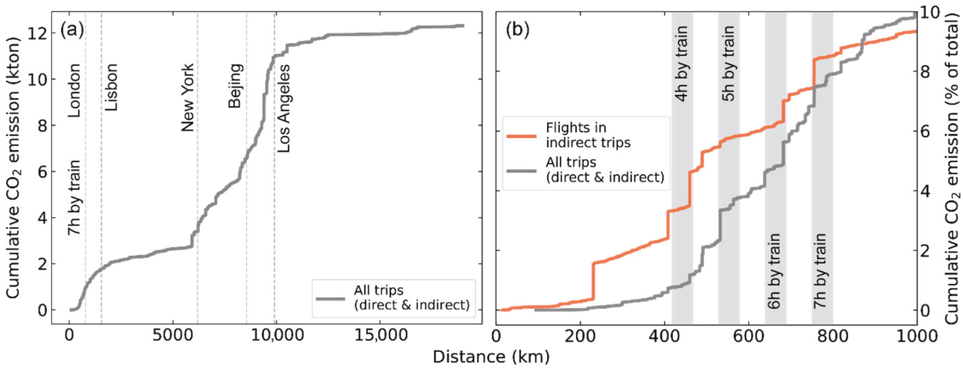


Figure 5. (**a**) Cumulative CO_2 emission as a function of distance between departure and arrival airports for the entire dataset; (**b**) zoom of the data shown in (a) for short distances (grey), together with the cumulative CO_2 emission of short-distance flights in indirect trips (coral). The vertical grey bands show the distance that can be covered by train in the indicated amount of time.

Third, we considered replacing all indirect trips by direct ones. Two effects are influencing the GHG impact of this substitution. On one hand, indirect trips always cover more distance than a direct equivalent, causing increased emissions. On the other hand, typical flights are most efficient (in terms of fuel consumption per unit of distance) over distances of around 5000 km [10]. For shorter distances, taxiing and takeoff is proportionally more important, while for longer distances, the increased weight of the fuel leads to increased energy expenditure. This implies that, e.g., the emissions of a single 10,000 km flight could be reduced by splitting it up in two 5000 km flights, but only if the extra distance which is covered as a result of the intermediate touch-down is negligible. If we look at the flights in our database, we see that only 1.7% of the indirect trips have lower emissions than an equivalent direct trip would have. In these cases, the difference is in the order of a few percent. The vast majority of indirect trips in our database (98.3%) has much higher emissions than an equivalent direct trip, as can be seen in Supplementary Figure S3. Here, we supposed that all flights were flown in economy class to avoid the influence of service class, which we already discussed above. We can therefore conclude that the extra distance covered by indirect trips is much more important than the potential small gains in fuel efficiency in almost all cases. In total, we found a potential 9% reduction in EPFL's air travel GHG emissions, corresponding to 440 t CO_2e per year by replacing all indirect travels with direct flights. Note that it is likely not all of the direct flights required for this replacement are available on the commercial market.

4. Discussion

The observation that GHG emissions are more closely correlated to ticket price than to distance travelled, leads to the interesting phenomenon that a reduction in carbon footprint could lead to a cost reduction and vice versa. This means that a travel budget restriction could be used as a simple but effective measure to reduce carbon footprint of an institution. Additionally, reducing the carbon footprint of air travel could be a net negative cost measure, contrary to other sustainability measures.

The large inequality in travel footprint between individuals and laboratories raises the question whether all travel by the researchers with the largest footprint is useful and contributing positively to the institution and to their career. The time and energy spent traveling, in addition to fatigue from jetlags, could jeopardize the overall professional performance and quality of life. Future work should aim to answer the question whether increased traveling leads to improved academic performance.

Adding up the potential reductions in GHG emissions that could be achieved by replacing business and first class trips by economy class, short flights by train trips, and indirect journeys with direct flights, we find that the carbon footprint could be reduced by up to 36%. This significant amount shows that substantial reductions are possible by making the appropriate choices. This figure represents a theoretical upper boundary for the reduction in emissions that could be achieved for the present dataset without any reduction in travel. It does not take the reductions in GHG emissions into account that could result from avoided travel, e.g., by replacing it with videoconferencing. This is outside the scope of this work. In practice, there are several challenges in achieving the reduction figures presented here. Economy class travel can be less comfortable for long journeys, and train connections or direct flights are not always available and are in some cases more expensive. However, additional measures, such as the promotion of videoconferencing to replace physical travel, could lead to reductions not taken into account in this study. These results show which choices should be preferentially made when choosing a travel itinerary, and can be the basis for travel guidelines or policies within institutions, academic or otherwise.

Even though the present work focuses exclusively on researchers from EPFL, the results and conclusions are likely relevant for other academic institutions as well. Given the relatively large amounts of funds available for research and development in Switzerland (3.374% of GDP in 2015) [11], researchers might have less restrictions to travel compared to other countries. Nevertheless, qualitatively similar trends to the ones reported here could be expected elsewhere in academia. Moreover, most of the points raised in this work are also relevant for other communities. The high correlation between a flight's GHG emissions and its ticket price can be used by anyone as a tool to limit air travel GHG emissions. The highly unequal distribution of air travel is a general trend throughout the human population [5]. Any individual or organization wishing to reduce their air travel GHG emission should, in cases where physical travel is absolutely required, favor economy class, train travel, and direct flights where comfort and/or availability allow to do so.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/1/80/s1. Supplementary Figure S1: Number of direct (brown) and indirect trips (coral) as a function of distance between the departure and destination airport. Supplementary Figure S2: (a) Average per capita annual distance travelled by a PhD student, Postdoc, senior scientist and professor at EPFL. (b) Annual amount of money spent per capita on air travel for the same categories. Supplementary Figure S3: Carbon footprint of direct (brown) and indirect (coral) trips. Supplementary Table S1: Used DEFRA metrics to calculate CO_2e emission over the studied time period.

Author Contributions: Conceptualization, G.O.V., A.M. and J.C.; Formal Analysis, J.C.; Investigation, J.C. and A.M.; Writing-Original Draft Preparation, J.C., A.M.; Writing-Review & Editing, L.D.T. and G.O.V.; Supervision, L.D.T. and G.O.V.; Project Administration, A.M.; Funding Acquisition, L.D.T. and G.O.V.

Funding: This research was funded by EPFL Sustainable Campus.

Acknowledgments: The authors thank D. Zhao and L. Bellocchi for valuable discussions.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. *Aviation and Climate Change—The Continuing Challenge*. Available online: https://onlinelibrary.wiley.com/doi/10.1002/9780470686652.eae1031 (accessed on 26 October 2018).
2. International Energy Agency. *Global Energy & CO_2 Status Report*. Available online: https://www.iea.org/publications/freepublications/publication/GECO2017.pdf (accessed on 26 October 2018).
3. *Carbon Offsetting & Air Travel Part 2: Non-CO_2 Emissions Calculations*. Available online: https://www.sei.org/publications/carbon-offsetting-air-travel-part-2-non-co2-emissions-calculations/ (accessed on 26 October 2018).
4. Lee, D.S.; Fahey, D.W.; Forster, P.M.; Newton, P.J.; Wit, R.C.N.; Lim, L.L.; Owen, B.; Sausen, R. Aviation and global climate change in the 21st century. *Atmos. Environ.* **2009**, *43*, 3520–3537. [CrossRef]

5. Peeters, P.; Gossling, S.; Becken, S. Innovation towards tourism sustainability: climate change and aviation. *Int. J. Innov. Sustain. Dev.* **2006**, *1*, 184. [CrossRef]
6. *Carlson Wagonlit Travel—Business Travel Management Company*. Available online: https://www.carlsonwagonlit.com/ (accessed on 26 October 2018).
7. *Government Emission Conversion Factors for Greenhouse Gas Company Reporting*. Available online: https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting (accessed on 26 October 2018).
8. *Income Inequality*. Available online: http://www.worldbank.org/en/topic/poverty/lac-equity-lab1/income-inequality (accessed on 26 October 2018).
9. *Inequality—Income Inequality—OECD Data*. Available online: http://data.oecd.org/inequality/income-inequality.htm (accessed on 26 October 2018).
10. Green, J.E. Civil aviation and the environment—The next frontier for the aerodynamicist. *Aeronaut. J.* **2006**, *110*, 469–486. [CrossRef]
11. *Research and Development (R&D)—Gross Domestic Spending on R&D—OECD Data*. Available online: http://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm (accessed on 26 October 2018).

sustainability

MDPI

Article

New Dimensions for Circularity on Campus—Framework for the Application of Circular Principles in Campus Development

Birgit Hopff [1,*], Steffen Nijhuis [2] and Leendert A. Verhoef [3]

[1] Independent Researcher, Stadsruim BV, 2613 EB Delft, The Netherlands
[2] Faculty of Architecture and the Built Environment, Delft University of Technology, 2628 BL Delft, The Netherlands; S.Nijhuis@tudelft.nl
[3] Amsterdam Institute for Advanced Metropolitan Solutions, 1018 JA Amsterdam, The Netherlands; leendert.verhoef@ams-institute.org
* Correspondence: mail@hopff.nl; Tel.: +31-612-981-189

Received: 29 November 2018; Accepted: 22 January 2019; Published: 24 January 2019

Abstract: To what extent can transformation and development processes on a university or other campus fit in with the principles of circularity? This paper builds a bridge between the more theoretical approach of the circular economy and daily practice in campus development, using semi-structured in-depth interviews with a broad range of stakeholders in university management in Dutch universities. The study aims to show possible perspectives and offers insight into which factors are important for the sustainable development of a university or other campus, taking into account the principles of the circular economy. The paper introduces a framework for understanding the various dimensions and scales of campus operations. The aim is to make a practical contribution to the implementation of circular principles in campus development. The main conclusions are that circularity is an organisational issue, complexity must be reduced, and integral policy and specialised knowledge are required. Five recommendations towards an integrated strategy for circularity in campus development are given.

Keywords: area development; campus development; circularity; circular economy; sustainability

1. Introduction

The circular economy is a new field of research and the number of articles has grown rapidly over the past 10 years. These have usually involved establishing a close link between the concepts of the circular economy and sustainability, without this relationship being precisely defined in scientific terms [1]. While energy efficiency issues in the construction sector have been extensively researched, circularity remains a relatively new issue [2]. No clear definitions of the concept of 'the circular economy' are used in science and literature [3]. Various studies [2,4–6] have shown that circularity is a complex subject with many facets. Scientific studies on the circular economy often focus on the macro scale of a region or city, or on the micro scale of product development [6,7] and individual projects with an experimental character or limited circularity aspects [8].

1.1. Objective

To date, there has been no systematic application of circular principles in Dutch campus development. Construction, development and redevelopment projects usually focus on limited aspects of circularity and are separate from each other. In the area of sustainable development of the physical campus, there is a need for the elaboration of practice-oriented strategies for an integrated approach. This study establishes a connection between the subjects of a campus environment, area development and the circular economy. The central research question in the research is: To what extent and in what way are principles of the circular economy applied in the area development of (university) campuses in the transformation to a sustainable campus? By looking beyond the boundaries of a single building, structural links and a systematic approach are sought within the campus area. For this study, the Dutch university campuses are studied. The complexity and breadth of the concept of the circular economy pose a major challenge for organisations in terms of structurally applying circularity in existing processes. This paper introduces a framework for understanding the various dimensions and scales of campus operations. It shows which dimensions in the area development of university and other campuses influence the application of circular principles in the transformation to a sustainable campus. In this respect, the study provides insight into:

- How the principles of circularity can be systematically applied in practice in area (and other) development and transformation of a campus;
- What conditions must be met to develop/redevelop a university campus in accordance with the principles of the circular economy.

1.2. Method

The application of circular principles is being researched on university campuses in the Netherlands, with a focus on real estate and area development processes, as opposed to facility processes. The paper develops a framework from theory. It validates to what extent the framework works in practice. As such it is not a qualitative study, nor is it grounded in theory. It develops a framework for future research. In the first stage, a literature review is based on scientific literature and practice-based research on the circular economy and campus development to answer research questions. The preliminary research was aimed at finding leading dimensions in campus development that are characteristic of a campus and that influence circularity. These studies have revealed a number of principles that are relevant for campus systems to meet the requirements of circularity. The principles have been filtered according to their significance for the spatial sector and possible applications in campus development.

In terms of area development, the campus can be regarded as a defined system, of which buildings are a part. The system perspective is again seen as an important aspect in the approach to circularity. The aim is to be able to identify structures and processes within the 'campus' system that influence the application of circular principles. The complex relationships between flows and levels of scale, criteria for circularity, development processes and relevant actors are investigated in order to identify the mutual influence. The following factors were related in an analysis matrix (Table S1) with the aim to discover which processes influence circularity and to make possible patterns visible: principles of circularity such as minimizing raw material consumption and waste; value preservation of raw materials, high quality reuse material/product, use of renewable energy sources, minimizing CO_2 emissions and toxic substances, climate adaptability, biodiversity and social balance; related to the production process, product design, material selection, disposal process, construction process and assembly, transport and distribution, system design, development process, demand specification, product choice, management process and user behaviour and policy. In the first step of the analysis, the different spatial scales, flows of resources and principles of circularity were linked to development processes which influence the circular principles. To make patterns transparent, three categories were applied in the matrix fields for the different groups of actors and processes, based on the division of [9]:

- The creation process—with the producer, supplier and builder/contractor;
- The design process—with the architect, designer and consultant;
- The development process, management and use—with client, owner, user and manager.

A more in-depth analysis in the following step also includes more detailed criteria and indicators for circularity such as footprint, efficient land use, building flexibility (multifunctional), dismountable constructions, modular buildings, energy performance, policy reuse, environmental performance and origin of materials and information management, in order to investigate the relationship between the process and circularity principle. By naming these criteria and indicators per flow and per scale level, it is clarified which factors in the process can have an impact. By means of a theoretical analysis, stakeholders such as producers or clients, who exert a special degree of influence on circularity in specific processes, come into the picture. To test the theoretical concepts found earlier in an analytical way, the assumptions derived from the analysis were translated into interview questions. The 13 interviews with various stakeholder groups are used as a means to see how the principles work and whether the problems and conclusions from the theoretical research are also valid in practice.

During the interviews, it was investigated how sustainability aspects and circularity are implemented in the campus developments. The questions focus on the scale level of a specific project, vision and policy, development processes, instruments used and actors involved. Questions were asked about objectives and factors relevant to circularity, to what extent specific criteria are consistently applied in projects with a circular approach, which aspects are missing and why certain factors are not taken into account. The question of where obstacles are experienced in the application of circular principles in campus development was also asked. The interviews were conducted with employees involved in sustainability, procurement and area development at six Dutch universities.

The Netherlands has 13 universities, about half of which are involved in technological research. A representative selection of these universities has been approached. On the campuses, subprojects were investigated, where within the scope of project development, attention was paid in various ways to a possible circular approach with a spread of aspects and factors. Each subproject has a different focus with respect to the development phase, scale and development task.

Given the broad problem definition, the research has an exploratory character. The insights from the theoretical research and the interviews have been translated into a more generic approach and relevant process steps for the structural application of circular principles. The steps which must be taken to systematically apply circularity in campus development and to be able to guarantee it for future developments have been mapped out by means of a framework. The framework provides a structure and overview to apply the principles of circularity in a systematic way. The process of how to integrate the various dimensions and area scale levels is an important aspect of the new knowledge this article delivers.

2. Building Blocks for a Circular Approach

2.1. Evolution of the Concept of the Circular Economy

The idea of circularity is essentially not new and until the industrial revolution, the economy was predominantly circular [5]. That there are limits to the extent to which human activity can deplete the natural environment and that population growth affects the earth's finite resources was noted by the Club of Rome in its first report [10]. The idea of a circular economy is largely rooted in the concept of cradle-to-cradle [11]. Drawing from the function principle of ecosystems, this design philosophy focuses on optimising systems instead of components to minimise the loss of value of raw materials. The publication 'Towards the Circular Economy. Economic and business rationale for an accelerated transition' by the Ellen MacArthur Foundation [12] is in line with the cradle-to-cradle concept and is considered one of the founders of the circular economy.

There is no unequivocal definition of the term 'circular economy' [3]. There is a close link between the concepts of the circular economy and sustainability [13], but this relationship is not precisely defined in scientific terms [14]. Circularity is seen in some concepts as a prerequisite for sustainability [1]. According to the analysis of Kirchherr et al. [3], the 'Circular Economy' is an economic system based on business models that replace the concept of 'end-of-life' with reducing, reusing and recovering raw materials in production, distribution and consumption processes, by operating at different levels of scale and with the aim of achieving sustainable development for present and future generations. Often a link can be found with the three pillars of sustainability: economy, environment and society [6,14].

The circular economy pertains to the careful and sustainable use of existing resources. The principle of cyclical material cycles and their closure remains an important aspect in the different definitions and concepts of the circular economy [15]. In their conclusions, Kirchherr et al. [3] stressed that the circular economy should be seen as a fundamental systemic change. Pauliuk [16] and Preston [17] also referred to the theoretical background of systems theory [18] and the relationship with Industrial Ecology. By involving all stages of life in development and by using products, components and materials within the cycles on a permanent basis, the linear economy becomes a circular economy [8].

2.2. The Circular Economy in the Spatial Sector

The spatial sector plays an important role in the circular economy in view of the large flows of raw materials involved. Area development concerns the physical adaptation of a specific location and always takes place in a specific socio-economic context, but transformations within the area also have effects on the external environment and vice versa. The aim of area development is to create 'integral environmental quality' [19]. There is a direct link between the quality of the living environment and sustainability in terms of environmental quality, health issues and social values on the one hand and the future value of spatial quality on the other. In addition to site-specific elements, flows such as water, energy and mobility form part of area development. Wientjes [20] concludes that spatial planning does play a role in making a region circular. Too often the emphasis of the circular economy is on business (and other) processes and the initiative is generally left to companies and citizens, without making a link with the function that spatial planning has in achieving sustainability. To make the circular economy a guiding principle, spatial plans must have a circular approach from the initial phase, otherwise little usually remains of the sustainability ambitions [20].

The circular economy goes beyond recycling and, in order to achieve maximum environmental benefits, strategies that involve the entire production and consumption chain are preferable [21]. In order to achieve maximum economic and ecological effects based on circular principles, sometimes more radical changes and innovations to existing systems are needed. This requires a new way of thinking about designing products and services, adapting production methods, but also concerns procurement processes [8].

In the search for possibilities to make ever-growing cities more sustainable, in recent years, increasing attention has been paid to the concept of 'urban metabolism' [22,23]. The totality of urban flows such as energy, food or waste is considered as a metabolic process of the city organism [24]. Urban metabolism can be defined as "the sum total of technical and socio-economic processes occurring in cities" [22]. It not only relates to internal transformation processes within the urban system itself (the organism), but also to the balance of the inflow and outflow, the exchange with the environment. With a view to sustainable urban development, Tjallingii [25] formulated the Ecopolis strategy: The city is seen as a dynamic and complex ecosystem which consists of a number of smaller ecosystems on the one hand and is itself part of a larger ecosystem on the other hand. Plan development not only concerns the quality of a specific area, but also the inflow and outflow of the system and the quality of the environment outside those areas. Because the management of flows depends on the actors involved, but the flows also influence the design of areas and vice versa, these three areas of attention cannot be seen in isolation [24].

The application of circular principles in the spatial sector is more complex than in product development. Indicators of circularity usually relate to different levels: The micro level of construction (and other) products, the meso level at the local scale with neighbourhoods and the macro level of cities, regions or the whole country [16]. In the built environment, each material has its own specific life cycle and is part of different processes and changing uses over its lifetime [6]. The transition to a circular economy in the spatial sector therefore requires different perspectives of scale and a broader view of the dimensions in research and planning.

2.3. Circular Construction Production

The demand for materials is high: Around 50% of the raw materials used in the Netherlands are processed in the construction sector [26]. However, the scarcity of materials is seldom a motive for the circular economy in construction [27]. With around 40% of all waste in the Netherlands, the sector is responsible for large waste flows and around 35% of CO_2 emissions [26]. In the Netherlands, more than 95% of construction and demolition waste is recycled [28], usually in a low-grade manner [9]. However, a large proportion of the raw materials leave the chain [9] and there are no closed cycles. New buildings are hardly ever made with recycled products, only 3% of the raw materials are used in their original function, so the influx of primary raw materials remains high [29]. The energy needed to produce building materials usually comes from fossil sources. The carbon footprint of these materials and the extraction of raw materials for construction lead to pressure on ecosystems [27].

The spatial sector is characterised by a complex system of different value chains. The transition to a circular economy within the construction and real estate sector requires optimising this chain from the source [30]. This not only concerns spatial and technical aspects, but mainly requires organisational and institutional changes and other processes in the design of the built environment. There are no new steps at the financial, administrative or organisational level to implement this structurally [31]. Circular construction starts with the design of a building, but also involves the associated collaboration and knowledge sharing. A subsequent life cycle of buildings, building elements, products and materials must be part of the design process [32]. This means that information must be made available in the long term and the working methods of the chain partners in the various stages of life must be coordinated. Making this information accessible to the actors involved plays an important role in this, so that sources can be used locally [33].

Existing instruments for assessing the environmental impact and sustainability aspects (such as Building Research Establishment Environmental Assessment Method (BREAAM), Life Cycle Analysis (LCA), ECO Cost) are partly in line with the principles of circularity and can be used as a basis for better specifying circularity requirements. However, these tools need to be further developed. These instruments can also be integrated with Building Information Management (BIM) [27]. 3D models of areas can serve as a framework for linking spatial information to data from a life cycle analysis or materials passport. In this way, data at different scale levels can be made transparent and can be related to each other—such as raw material flows at the area level but also within a building—and policy regarding the various raw material flows can be effectively coordinated [9].

Circularity not only has a physical side. Stakeholder interests and the way in which the actors involved make agreements with each other influence the overall process. Van Splunter [9] distinguishes between three groups of actors: Suppliers and producers influence the use and choice of raw materials. Designers and construction companies make product choices in the design process and determine which materials are added in the construction process. Clients, developers, investors and governments influence the first two groups through their commissioning, tender specifications and forms of contract, or through legislation.

Recent studies [20,34–36] by Wientjes, Potemans, Van Haagen and Castelein show that there are also various strategies in the spatial sector that are suitable for circular tendering or contracting. Pauliuk [16] criticises the fact that the monitoring of the implementation of circular strategies remains vague for the time being. Clients or organisations are responsible for choosing the right indicators and each determines their own standard for circularity. Companies are not structurally involved in circularity and governments, as clients do not take the lead enough to create professional preconditions and set circularity requirements [27,37]. The available instruments are insufficiently applied and, on the organisational side, instruments and processes are less developed [2].

2.4. Sustainability Visions in Campus Development

The subject of sustainability has received increasing attention in university research and educational institutions in recent years [38]. Sustainability aspects are becoming an important topic in many campus projects. Not only in terms of technical innovation [39], but also in terms of influencing behaviour, active sustainability policy on campus plays a special role in society. In the pursuit of a sustainable society, in the future many of the current students will also influence other people or organisations outside the campus through their decisions [40].

On the strategic, physical, financial and functional levels, campus management has increasingly changed into area development in recent years. However, the campus should not only be seen as a city, but also jointly with the city [41–43]. In terms of new strategies for sustainability, the campus offers itself as an ideal testing ground for the development and implementation of social and technological innovation, enabling universities to expand their innovation potential both inside and outside the campus walls [44]. The tasks of campus management have become increasingly complex over the years; changing structures in funding and rapidly changing themes in research require increasingly flexible housing [45], but university organisations structurally lack the money to invest in the development of their campuses [42]. Economical use of square metres contributes to sustainability goals and reduces the risk of future vacancy. Reducing the ecological footprint is also a strategic choice [46], but policy for more intensive use of space instead of building more calls for a different way of thinking. This requires sharing and multifunctional use of space on the campus and meeting peak demand through the use of temporary facilities. Relating the use of space to activities instead of allocating space to regular individual users can be a solution for making more efficient use of the available square metres [45].

More and more universities see a ‘green campus’ and achieving environmental objectives, such as reducing CO_2 emissions or limiting the ecological footprint, as important goals within campus management. Existing buildings are used in different ways [42]. Various European universities have now set up Green Offices or appointed a sustainability programme manager as a point of contact with expertise in the field of sustainability [40]. However, Ávila et al. [44] pointed out that changes in the organisation of a university are not easy. Previous research [38] has shown that sustainability objectives in campus policy in general are too fragmented and are not systematically integrated and coordinated within the organisation. Despite the increasing urgency to consider sustainable development as part of their activities, many university organisations remain reluctant in reviewing their own business models. In particular, the investments required are often regarded as a barrier, while the benefits in terms of both environmental and economic performance are not sufficiently recognised [44]. The lack of support from university management and willingness among policy makers prove to be among the main obstacles [44].

2.5. Knowledge Gap

Global population growth (The global population has quadrupled in the last 100 years and will cross the nine billion mark by 2050) [47] and increasing prosperity are leading to an increasing demand for raw materials worldwide [48]. The circular economy is seen as an economic system that strives to use resources in a smart way and to preserve their value as much as possible. Sustainable structuring of the built environment and limiting our ecological footprint are becoming increasingly important to enable us to live a prosperous life on a healthy planet in the future. The spatial sector can contribute to reducing ecological footprints, but the circular economy requires an integrated approach that goes beyond the level of a building. Spatial projects are characterised by a high degree of complexity. By making connections between the various spatial scale levels, this study is looking for a system at a higher abstraction level for a structural circular approach in area development.

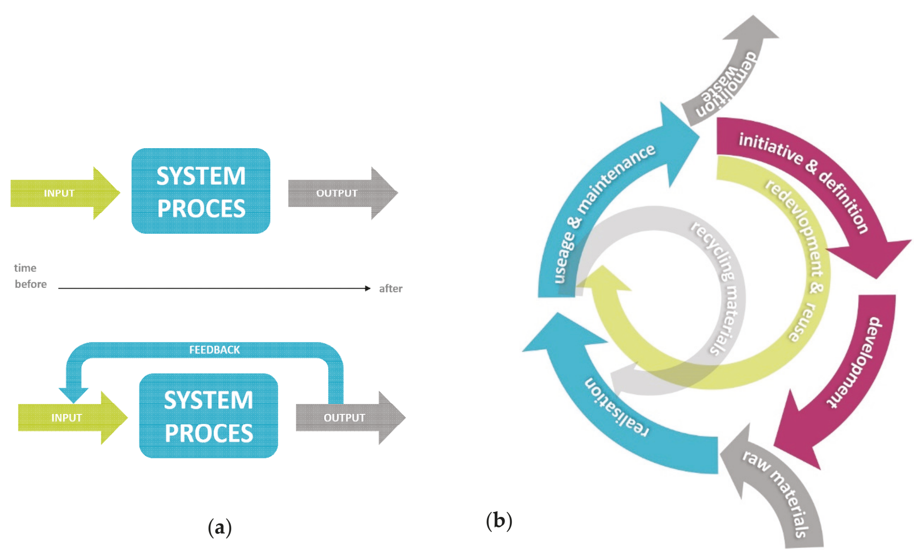
From the literature review, it is concluded that a gap exists in circularity in campus development. Universities and other educational institutions recognise the societal importance of sustainability issues and are increasingly focusing on them in their education and research programmes. This is often independent of the objectives for the development of their own campus [40,44]. Previous research shows that universities around the world, in different geographical regions, encounter similar obstacles to sustainable innovation on campus [44]. So far, few projects have been realised in campus or area development in which circularity is a determining factor. There is no systematic overview available of implementation strategies for the principles of a circular economy in area development or campus development. A framework that shows the connections between different dimensions and scale levels in the campus area is needed to provide CE implementation in campus development.

3. Circularity Strategies

3.1. Systems Thinking and Life Cycles

Systems thinking [16], synergy effects and closing cycles [15] involving the various life cycles in the area are important approaches to be able to apply the principles of circularity in area development processes. Since the 1950s, increasing interdependence in the world has led to new academic trends around complexity theories and systems thinking. It is recognised that new technologies alone will not solve our major sustainability issues. In systemic innovation, the social context changes simultaneously with the development of new knowledge and technology, and new ways of thinking, organising and acting arise in the context of the innovation [49]. Each system has a boundary and is characterised by a structure and a process, but also by the interaction between the system and the environment, the input and output. Systems thinking looks at both the bigger picture and the individual components [50]. In order to achieve synergistic effects, it is relevant to understand how components influence each other within the framework of the whole [12]. Involving the various life phases or life cycles and closing raw material chains are central strategies of the circular economy based on the principle of keeping a raw material in a cycle as long as possible, thereby limiting the loss of its value [5].

Whereas the initiatory and development phases of area development processes [51] (Figure 1) primarily involve intangible factors, such as policy and decision-making, more physical aspects, such as raw material flows, play a role during the implementation, use and management phases. At the end of a usage phase, it can be decided to redevelop and transform or reuse an area or building as a whole. This involves the process being restarted from the initiatory phase onwards [51]. Such choices affect the flows of raw materials and the input and output of the system. At the end of the life phase, these are extracted from the system, added as recycled materials or reused as building components.



(**a**) (**b**)

Figure 1. (**a**) System thinking; (**b**) life cycles in area and real estate development.

3.2. Dimensions in Campus Development

Circularity in campus development can be viewed from different angles. The campus is understood as a 'system' and seen as a suitable testing ground for the application of circular principles. By looking beyond the boundaries of a building and involving resources and flows at the area level, the extent to which transformation and development processes on the campus are in line with the principles of circularity can be mapped out. Campus development is regarded as a specific organisational form in area development. According to the Glaser, Karssenberg, Laven, Teeffelen and Hoff [52] model, area development is determined by three categories: use (software), built environment (hardware) and management (orgware). The urban metabolism establishes a close link between the quality of a specific area and the inflow and outflow of the system. According to Tjallingii [25], the management of flows depends on the actors involved, and the three elements 'areas', 'flows' and 'actors' cannot be seen in isolation [24]. A research model has been developed to analyse the applicability of the principles of circularity in the campus system, based on the different dimensions of campus development. The four dimensions of 'organisation', 'use & function', 'spatial scale levels' and 'flows & materials' were used (Figure 2) for the theoretical analysis.

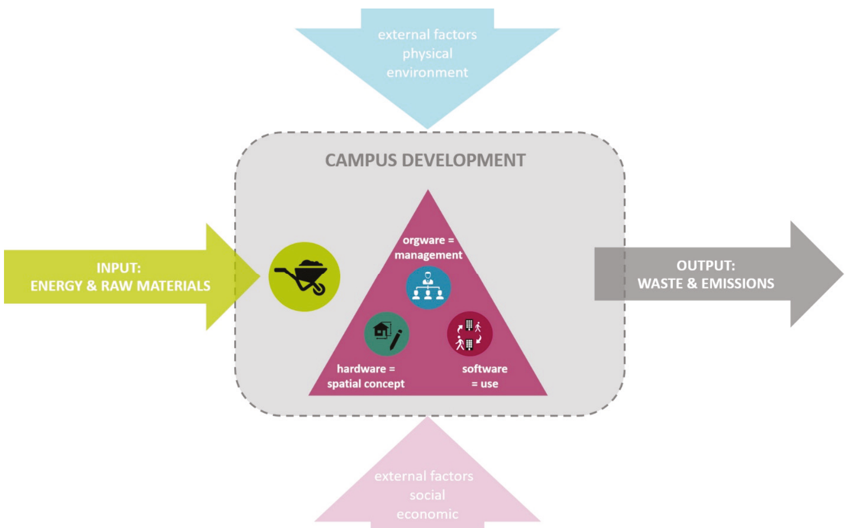


Figure 2. Research model with campus development as a system (own figure, based on various models from urban metabolism and area development).

Area development involves complex processes with a wide variety of stakeholders and actors. Area development processes are influenced by power relations, interaction and cooperation between the various actors [51]. Relationships between parties and actors are not only technological in nature, but also have a social character and are part of a complex network [2]. Ideally, an integrated area vision or real estate strategy should cover all phases and cycles of life. In the various life phases, different actors are again involved, which influence each other mutually through their decisions and actions (Figures 1 and 3). There is a complex network of parties and stakeholders involved in each phase of the development process. These have different goals and interests and each have their own strategies. Decision-making processes in networks are characterised by a system of mutual dependence and interdependence between the various actors [53]. Network management is a strategic tool to structure a complex field of action. The ability to link the various factors and elements is an influential factor for the success and task of process management [51,54]. The starting point is the interactions between parties, not the objectives of the individual actors [55]. Instead of a desire to achieve predefined results, adaptive capacity is the main requirement for managing the process [56,57].

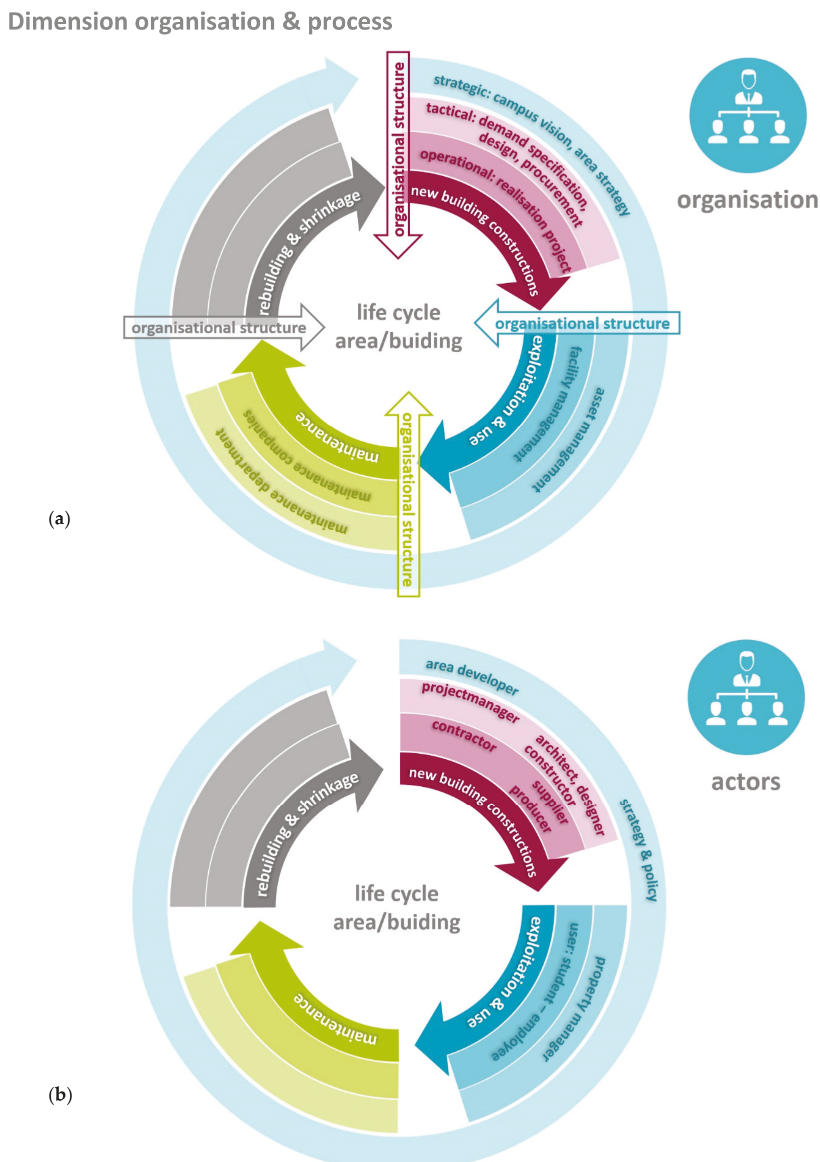


Figure 3. Dimension organisation & process: (**a**) Organisational structure and development processes: Campus organizations are usually hierarchically structured line organizations with different layers: The strategic level, which focuses on setting strategic goals and policies, the tactical level with the task of setting up processes and steering the realization of goals and the operational level, responsible for the execution of goals. (**b**) Actors: Within the organisation, different departments or sometimes external parties are involved in the different processes within the campus development for each life cycle phase.

Area development manifests itself through spatial changes in different areas, which are mutually correlated and are part of a city or region [51]. Apart from housing a university organisation, a campus also has a physical side. The spatial dimension is characterised by different levels of scale, which cannot be seen separately from one another. The spatial scale levels are often related to different functions such as the campus as a whole being a carrier for transport and underground infrastructure. In his approach, Brand [58] distinguished six different layers of a building, with a different life cycle each time for the area, the outer structure, the shell, the installation, the interior space and the layout. The separation of the various layers concerns not only the physical and technical components, but also the functional and economic interests and responsibilities [59]. By relating flows on campus to levels of scale and presenting them in cohesion, insights are sought for how chains can be closed (Figures 4–6). In some cases, local factors play an important role when it comes to closing cycles, while in other situations, optimisation can only be achieved on a larger scale [33].

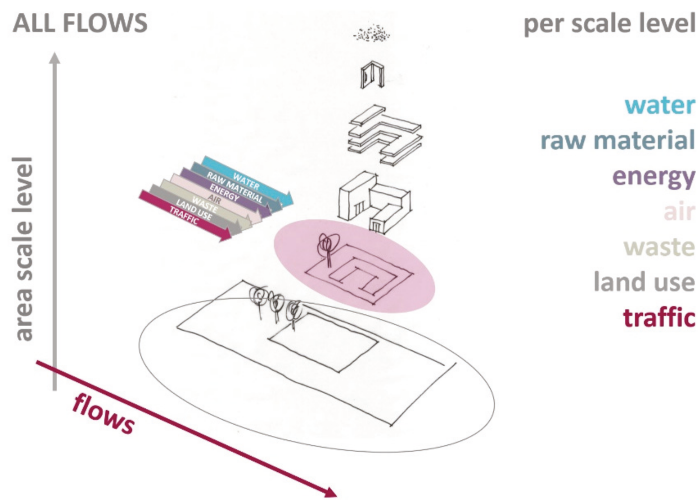


Figure 4. Relationship between all flows and one level of scale in the area.

In the theoretical framework, models from the area development are involved in order to be able to interpret circular principles in campus development. The research model (Figure 2) establishes connections between the different dimensions. The complex relationships between flows and levels of scale, principles of circularity, development processes and relevant actors are mapped out. The comparative analysis forms a theoretical approach to filtering factors and makes patterns visible: per scale level, different processes in campus development have an impact on the application of circular principles. The parties involved, such as the client, user, developer, manager, designer, contractor or producer, each have a different degree of influence by the choices they can make, depending on their role and the phase in the process (life cycle).

Depending on the scale level in the area, the strategies in the policy and system choices in the development process are decisive, or the choices of a producer in the production process of building materials have more influence on the degree of circularity. In order to apply circularity principles consistently, the different levels, phases and factors must be systematically linked to and weighed against each other for the whole life cycle.

Making the structures and connections transparent is an important condition in this respect. This applies not only to the construction chain, but the various actors within a campus organisation must also be involved. Intangible factors and processes at the organisational level, such as tendering policy and design choices, have a major influence on the applicability of circular principles. Requirements and criteria must be systematically specified and consistently applied in all development processes, especially at each level of scale and life phase, in order to achieve circularity in the spatial sector.

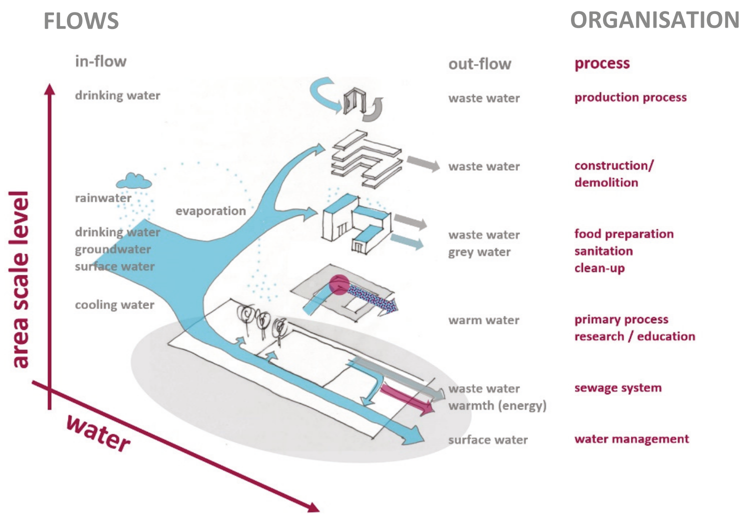


Figure 5. Example water—relationship between scale level of area, water flow and organisation (process).

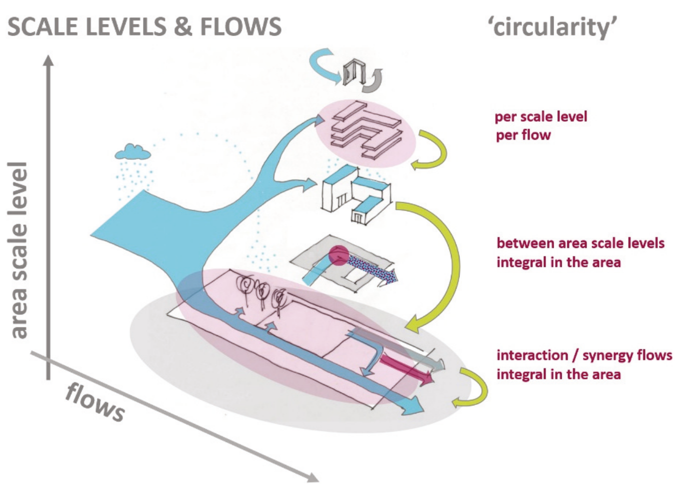


Figure 6. Closing cycles in relation to flows and scale areas: Cycles can be closed per flow or per scale level, but circularity can also be achieved between the different scale levels. In addition, an interaction can occur between different streams, per scale level or integrally in the area.

3.3. Practical Explorations on Campus

The subject of circularity is on the universities' agendas. The theoretical framework was verified and validated in 13 interviews with various stakeholder groups. Based on the theoretical analysis, interview questions were formulated to investigate how the circularity aspect is interpreted within the framework of the campus developments. The interviews were conducted among employees involved in sustainability, procurement and area development at six Dutch universities. Topics included circularity, sustainability and the four dimensions of campus development.

The first series of interviews with developers as a specific group of stakeholders led to new insights. These insights were used in the second series of interviews with different types of stakeholders. The second series of interviews was more broadly focused on achieving sustainability objectives, circular approach and policy on campus and was conducted with sustainability programme managers and procurement and external advisors. Questions asked are like: To what extent does sustainability or circularity play a role on the campus (vision) or in the specific project? What then is the focus—such as materials and flows, system choices, reuse? Where does the question of circularity come from—own initiative/management/designer/or? Where is the biggest challenge concerning circular projects? What are the issues? The questions were formulated and the interviews held in Dutch language. The original questionnaire can be found as an appendix (Figure S1).

The result is that circularity is mainly seen as a means to achieve sustainability objectives. However, in campus development, circularity is experienced as a complex theme. There is no common thread to translate the sustainability objectives into concrete requirements at the tactical and operational level. The ambitions differ; initiatives arise mainly at the project level and are supported by individuals. Because organisations are unable to define their sustainability ambitions and set priorities in terms of circularity, it is difficult for project managers to translate the objectives into concrete requirements. Despite the formulated sustainability ambitions, principles of circularity are not structurally applied by Dutch universities. There is no common thread in the complex subject: The policy for internal organisational processes is insufficiently coordinated by the various departments. No integral strategy is formulated for circularity. The aim is to retain existing policy frameworks, processes and instruments without investigating whether it is useful to maintain them. No conscious links are made between development projects at the area level; circular objectives focus mainly on the building level, energy or waste flows.

4. Results

4.1. Framework for a Circular Campus: Systems Thinking as a Starting Point

The research results confirm the need for more integrated policies for the various departments and processes in order to achieve circular objectives. The insights from the theoretical research and interviews have been translated into a more generic approach to campus development. It is remarkable that concepts for circularity focus mainly on technological questions. In order to be able to close cycles and use synergy effects, the various scales and layers within the (campus) organisation are just as important for circular area development. In a complex network with many actors, divergent interests and specialization of processes, the concept of circularity requires system thinking and network management. Making connections between the various spatial scales is another important aspect. Intangible factors and processes at the organisational level, such as procurement policy and design choices, also have a major influence on the applicability of circular principles. Circular economy in area development concerns a cultural change that cannot be achieved by systematically rolling out objectives from above.

The 'circular campus framework' shows the relevant process steps in order to apply the principles of circularity in a systematic way. By making the coherence transparent, the framework brings structure to a complex theme and offers the possibility to get a grip on the subject based on the four dimensions. The integration of the dimensions of organisation, spatial scale levels, flows and use is an important aspect of this. The research shows that these dimensions are closely interrelated and influence each other. Going through a linear step-by-step plan with a start and an end point seems insufficient to achieve the intended results. In the conceptual model, systems thinking is used as an essential approach to circularity and the campus is considered to be a system. The different dimensions affect this system and therefore also the application of circular principles. This makes systems thinking the logical starting point for the implementation of circular principles on campus.

The complexity and breadth of the concept of 'the circular economy' presents a major challenge for organisations to apply circular principles systematically as well, even though different methods and tools are available. Complexity occurs when a large number of actors or factors influence each other. 'Wicked problems' or unstructured problems are a recurring topic in area development [60,61]. Some concepts for network management in area development assume that increasing complexity can actually offer new perspectives. An overly sharp problem delineation in a process can then be dysfunctional, because the different actors have different perceptions of the problem. By formulating a problem broadly, different parties can contribute their interests [53,61–64].

Strategic innovation in the field of circularity requires continuous interaction in a complex network of internal and external actors. Changes take place at several points simultaneously in an iterative process, in which all relevant stakeholders must be involved. Depending on the perspective, there are different aspects and measures that influence each other. The dialogue between the parties concerned remains essential. By exchanging knowledge about issues and exploring new possibilities, the policy, work processes and responsibilities of departments are gradually developed.

4.2. Integral Policy at Strategic Level

On the one hand, the framework moves in the field of tension between integral policy at the strategic level (Figure 7) and, on the other hand, in translating objectives and making criteria specific at the tactical and operational level. Coordination of integral policy in the area of circularity is essential in order to prevent each department from formulating its own partial policy which is not consistent with the others'. Involving all departments in the development process and throughout the life cycle can create a consistent approach to circularity. This concerns the process side in the same way as the physical dimensions. Policy choices of the various departments affect the dimensions in different ways and need to be constantly adjusted in a dynamic process. A strategy for circular campus development must safeguard this coherence. The framework shows the mutual dependencies in a network system with different nodes (Figure 8). This not only concerns internal stakeholders within the campus organisation: A second axis in the field of tension concerns the relationship between internal and external parties and the method of working together. By asking clear questions, the client can stimulate the market without prescribing solutions. Being open to a different way of working and contractual arrangements are part of this. Methodologies for this already exist, but should be linked to circularity objectives.

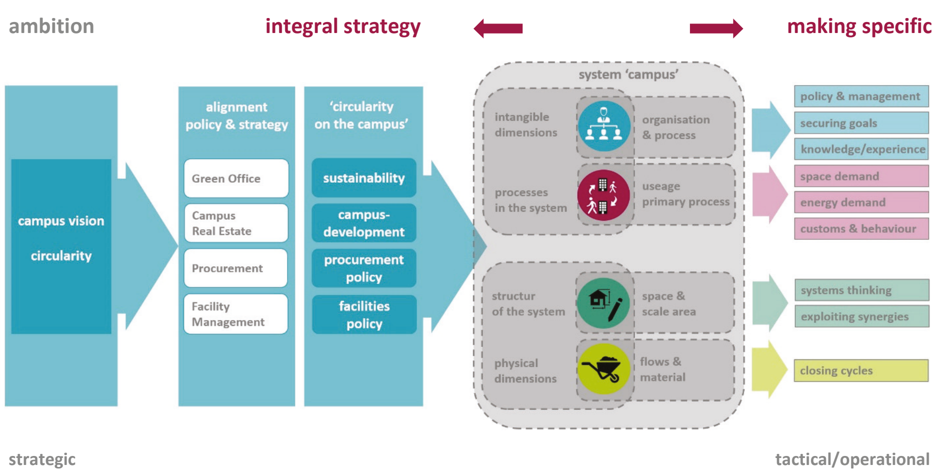


Figure 7. Field of tension between integral policy and making criteria specific for the tactical and operational level.

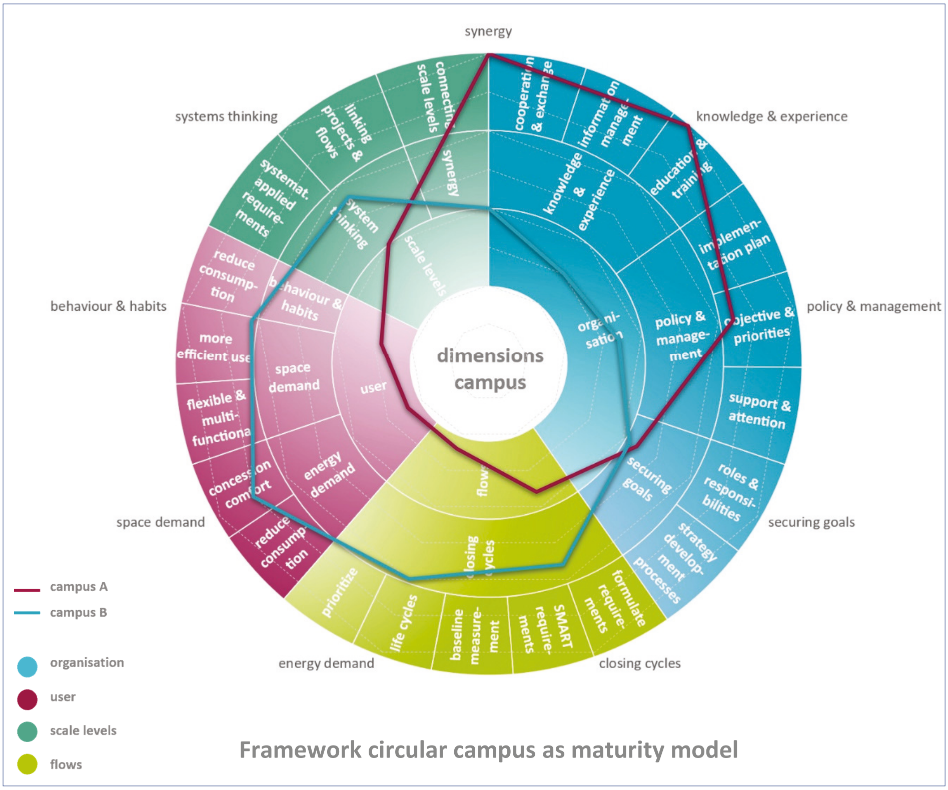


Figure 8. Framework for a circular campus as a maturity model with a fictitious example of two campuses. The framework cannot be seen as a blueprint. The starting point must be determined on the basis of a baseline measurement for the specific situation of a campus. Similar to a maturity model, the progress can be visualized in a coherent structure.

4.3. Tactical and Operational Level Specification

In addition to consistent policy at the strategic level, priorities and clear substantive objectives are required for the tactical and operational level. To this end, process agreements must be made at each scale level and concrete criteria must be determined for making the relevant flows circular (Figure 7). By defining a scope and gradually implementing it in terms of content, the complexity is reduced and the subject is clearer. For each dimension, various measures can contribute to putting circular ambitions into practice. Ensuring the coherence between the dimension is also essential at the tactical and operational level (Figure 8).

The systematics of the framework aim to make the underlying connections and structures visible. A clear scope can serve as a starting point for concrete substantive objectives and setting the necessary priorities. By linking thematic areas of attention on the campus to principles of circularity, a storyline is created and the subject becomes tangible for the various parties involved within the organisation. A pilot scheme on the campus such as a 'living lab circular campus' can play an important role in this if it goes beyond just a construction project and the various stakeholders are involved. Translating ambition into concrete content aspects makes the abstract subject of circularity more understandable and accessible.

5. Discussion and Conclusions

5.1. Discussion

Circular economy in area development is still in its infancy. In practice, those involved are confronted with the complexity of the theme. As the analysis showed, not only technical system choices but also the structure and processes within the organization influence the implementation of circular principles. The interviews confirm a number of assumptions from the theoretical analysis. As far as we know, practical research on circular economy on campus has focused on separate scale levels or, for example, facility services, food and waste flows or the energy theme. Campus organisations are working on the subject of circularity, but after the first experimental phase there is still a need for better structure and standardisation, particularly when it comes to an area-based approach. By establishing a link between circular principles and the various dimensions of campus development, the study contributes to the development of a new structure.

This research is based on the theoretical analysis and on the experiences of 13 interviews on six university campuses in the Netherlands with a similar structure. This concerns technical universities, but also campuses without a focus on technology. It is suspected that this group is representative. Other forms of organisation, such as colleges of higher education or universities in other (European) countries, were not investigated. The literature study shows that similar subjects also play a role in non-Dutch educational organisations.

This paper aims to provide a framework for CE implementation in campus development. In all cases, the campuses investigated are clearly demarcated areas that are part of a city. Campuses with other spatial typologies such as a greenfield campus outside the city or a university with separate buildings that are fully integrated into the urban fabric were not specifically investigated. The question of whether circular principles can also be applied to the development and transformation of other areas has thus not yet been answered. The system boundary plays a role in the application of circular principles. The results of this study suggest that full integration into the structures of a city increase the complexity and number of actors and that other processes influence the system. The design of business parks with clearly defined spatial and organisational boundaries, on the other hand, is comparable to the campuses studied. Additional research, in which more and different types of area typologies, organisational and administrative units are investigated, can contribute to broadening and deepening the knowledge about the application possibilities of circularity in area development processes.

5.2. Conclusions

Circularity is an organisational issue, but concepts for circularity focus mainly on technological questions. A framework for practical applications is lacking in campus development and there is a need for a better system that involves the various levels of scale of the area. In a complex network with many actors, divergent interests and specialisation of processes, circularity requires systems thinking and network management. Intangible factors and processes at the organisational level, such as tendering policy and design choices, also have a major influence on the applicability of circular principles. The circular economy in area development concerns a culture change that cannot be achieved by systematically rolling out objectives from above. Without an integrated policy, holding on to existing frameworks and instruments can be an obstacle if they do not sufficiently correspond to the approaches of circularity. As long as there is no meta-level vision, solutions will continue to focus on individual projects or technical details, without an integrated approach for the campus.

The complexity of the circular economy concept and the limited experience with it pose a major challenge to campus organisations. The subject must be made more comprehensible and accessible to the various parties involved, so that concrete steps can be taken. A clear system with a clear scope helps to make the underlying connections and structures visible and to set the necessary priorities for substantive objectives. One conclusion of this study is that the complexity must be reduced, especially in the initial phase, for the tactical and operational level.

Campus organisations want to get to work with circularity, but do not know exactly how to put it into practice. The expertise is limited and the substantive meaning of 'circular' is often not well thought-out. As a result, it remains unclear where the benefits lie and what the specific requirements should be. To ensure long-term circular objectives, integral policy and specific knowledge are required. Responsibilities and roles must be explicitly defined within the organisational structure. At the management level, the support base must be increased and the subject must structurally be given more priority in the various processes.

The universities have an important guiding role as a driver of circularity in the further development of instruments and processes. Although various instruments or certifications are available for sustainability aspects, they are not being applied sufficiently for circularity objectives. The circular development process requires a different way of thinking and working together in networks in the exchange of knowledge between client, designer, consultant, contractor and supplier. Exchange within an inter-university network could provide many valuable insights for implementation, but in practice, every campus reinvents the wheel.

5.3. Follow-Up Study

In all cases, the campuses studied are clearly demarcated areas that are part of a city. Additional research, in which more and different types of area typologies, organisational and administrative units are studied, can contribute to broadening and deepening the knowledge about the application possibilities of circularity in area development processes.

Existing methods for testing sustainability objectives or resource flows should be further developed into useful tools for testing circular aspects in area development. A combination of the resulting data with 3D building models and BIM can lead to new insights for the application of circular principles in area development and is a separate research theme in the field of information management. Measurement instruments and performance indicators which take circularity into account in an integral assessment of quality are lacking in campus development.

5.4. Recommendations for a Circular Campus

In order to be able to take steps towards an integrated strategy for circularity in campus development, the most important recommendations of the study are as follows:

1. Ensure a consistent policy and support from all departments by formulating an integral strategy for circularity. Make sure you also have an implementation plan.
2. Further develop the proposed system into a useful instrument by specifying substantive requirements and concrete objectives for the tactical and operational level.
3. Reduce complexity and make the subject of circularity accessible and understandable. Set clear priorities in the initial phase.
4. Let go of the automatism of existing frameworks and create space and flexibility for a different approach in the development process.
5. Think and work more in network contexts. To be able to close cycles at the local level, consciously establish links between development projects on campus at different scales and in different life cycles.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/3/627/s1, Figure S1: New dimensions for circularity on campus—appendix questionnaire 190112, Table S1: New dimensions for circularity on campus—appendix analysis 190112.

Author Contributions: Conceptualization, B.H., S.N. and L.V.; methodology, B.H., S.N. and L.V.; validation, B.H. and L.V.; formal analysis, B.H.; investigation, B.H.; resources, B.H.; writing—original draft preparation, B.H.; writing—review and editing, S.N and L.V.; visualization, B.H.; supervision, S.N and L.V.; project administration, B.H.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Geissdoerfer, M.; Savaget, P.; Bocken, N.M.P.; Hultink, E.J. The Circular Economy—A new sustainability paradigm? *J. Clean. Prod.* **2017**, *143*, 757–768. [CrossRef]
2. Leising, E.; Quist, J.; Bocken, N. Circular Economy in the building sector: Three cases and a collaboration tool. *J. Clean. Prod.* **2018**, *176*, 976–989. [CrossRef]
3. Kirchherr, J.; Reike, D.; Hekkert, M. Conceptualizing the circular economy: An analysis of 114 definitions. *Resour. Conserv. Recycl.* **2017**, *127*, 221–232. [CrossRef]
4. Ghisellini, P.; Cialani, C.; Ulgiati, S. A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *J. Clean. Prod.* **2016**, *114*, 11–32. [CrossRef]
5. Jonker, J.; Stegeman, H.; Faber, N. De Circulaire Economie—Denkbeelden, ontwikkelingen en business modellen. *Work. Pap.* **2018**. [CrossRef]
6. Pomponi, F.; Moncaster, A. Circular economy for the built environment: A research framework. *J. Clean. Prod.* **2017**, *143*, 710–718. [CrossRef]
7. Braungart, M.; McDonough, W. *Die Nächste Industrielle Revolution—Die Cradle to Cradle-Community*, 3rd ed.; Europäische Verlagsanstalt: Hamburg, Germany, 2011; ISBN 9783863930059.
8. Ganzevles, J.; Potting, J.; Hanemaaijer, A. *Evaluatie Green Deals Circulaire Economie*; PBL Planbureau voor de Leefomgeving: Den Haag, The Netherlands, 2016.
9. Van Splunter, M. *Circulair Bouwen Slopen: Ketenverkenning van de Bouw-En Sloopsector Cirkelregio Utrecht*; Utrecht Sustainability Institute: Utrecht, The Netherlands, 2016.
10. Meadows, D.H.M. *The Limits to Growth. A Report for the Club of Rome's Project on the Predicament of Mankind*; Universe Books: New York, NY, USA, 1972.
11. Braungart, M.; McDonough, W. *Cradle to Cradle: Remaking the Way We Make Things*; North Point Press: New York, NY, USA, 2002; ISBN 9780865475878.
12. Ellen MacArthur Foundation. *Towards the Circular Economy (Report)*; Ellen MacArthur Foundation: Cowes, UK, 2013; pp. 1–96.
13. Brundtland, G.H. Our Common Future: Report of the World Commission on Environment and Development. *Unit. Nations Comm.* **1987**, *4*, 300. [CrossRef]
14. Ruiz-Real, J.L.; Uribe-Toril, J.; De Pablo Valenciano, J.; Gázquez-Abad, J.C. Worldwide Research on Circular Economy and Environment: A Bibliometric Analysis. *Int. J. Environ. Res. Public Health* **2018**, *15*, 2699. [CrossRef] [PubMed]
15. Bocken, N.M.P.; de Pauw, I.; Bakker, C.; van der Grinten, B. Product design and business model strategies for a circular economy. *J. Ind. Prod. Eng.* **2016**, *33*, 308–320. [CrossRef]
16. Pauliuk, S. Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. *Resour. Conserv. Recycl.* **2018**, *129*, 81–92. [CrossRef]
17. Preston, F. A Global Redesign? Shaping the Circular Economy. *Energy Environ. Resour. Gov.* **2012**, 1–20. [CrossRef]
18. Von Bertalanffy, L. *General System Theory: Foundations, Development, Applications*; George Braziller: New York, NY, USA, 1968.
19. De Zeeuw, F. *Zo Werkt Gebiedsontwikkeling*; Delft University of Technology, Praktijkleerstoel Gebiedsontwikkeling: Delft, The Netherlands, 2017.
20. Wientjes, R. *Circulaire Economie Binnen de Ruimtelijke Ordening in Westas*; Saxion Hogeschool: Deventer, The Netherlands, 2015; Available online: http://www.kennislabvoorurbanisme.nl/wp-content/uploads/Circulaire-Stad.pdf (accessed on 10 December 2017).
21. Potting, J.; Hekkert, M.; Worrell, E.; Hanemaaijer, A. *Circular Economy: Measuring Innovation in the Product Chain—Policy Report (2544)*; PBL Netherlands Environmental Assessment Agency: The Hague, The Netherlands, 2017.
22. Kennedy, C.; Pincetl, S.; Bunje, P. The study of urban metabolism and its applications to urban planning and design. *Environ. Pollut.* **2011**, *159*, 1965–1973. [CrossRef] [PubMed]

23. Boomen, T.; van den Frijters, E.; van Assen, S.; Broekman, M. (Eds.) *Urban Challenges, Resilient Solutions. Design Thinking for the Future of Urban Regions*; Trancity—Valiz: Amersfoort, The Netherlands, 2017; ISBN 9789492095336.
24. Jelier, W.P.C. Het Concept Stedelijk Metabolisme: Verkenning van Het Concept 'Stedelijk Metabolisme' Met Het oog op de Bruikbaarheid ervan voor Duurzame Stedelijke Ontwikkeling. Master's Thesis, Delft University of Technology, Delft, The Netherlands, 2011.
25. Tjallingii, S.P. *Ecopolis: Strategies for Ecologically Sound Urban Development. Landscape and Urban Planning*; Backhuys Publishers: Leiden, The Netherlands, 1995.
26. Rijksoverheid. Nederland Circulair in 2050. Government of The Netherlands. 2017. Available online: https://circulaireeconomienederland.nl/rijksbreed+programma+circulaire+economie/default.aspx (accessed on 3 March 2018).
27. Schut, E.; Crielaard, M.; Mesman, M. Beleidsverkenning circulaire economie in de bouw. Rijkswaterstaat, Rijksinstituut voor Volksgezondheid en Milieu, The Netherlands. 2015. Available online: https://www.rivm.nl/bibliotheek/rapporten/2015-0197.pdf (accessed on 3 March 2018).
28. Nederland Circulair. Meer dan helft alle grondstoffen verbruikt in bouwsector: Kansen voor circulair?—Nederland circulair. The Netherlands. 2016. Available online: https://www.circulairondernemen.nl/uitdagingen/meer-dan-helft-alle-grondstoffen-verbruikt-in-bouwsector-kansen-voor-circulair (accessed on 28 April 2018).
29. Transitieteam Circulaire Bouweconomie. Transitie-Agenda Circulaire Bouweconomie. Government of The Netherlands, 2018. Available online: https://www.rijksoverheid.nl/documenten/rapporten/2018/01/15/bijlage-4-transitieagenda-bouw (accessed on 14 March 2018).
30. Bastein, T.; Roelofs, E.; Rietveld, E.; Hoogendoorn, A. *Kansen voor de Circulaire Economie in Nederland*; TNO: Delft, The Netherlands, 2013; pp. 1–93. Available online: https://www.rijksoverheid.nl/documenten/rapporten/2013/06/20/tno-rapport-kansen-voor-de-circulaire-economie-in-nederland (accessed on 3 March 2018).
31. Cramer, J. *Strategische Verkenning 'Op weg Naar Cirkelregio Utrecht'*; Utrecht Sustainability Institute: Utrecht, The Netherlands, 2015.
32. Bijleveld, M.M.; Bergsma, G.C.; Krutwagen, B.T.J.M.; Afman, M.A. *Meten is Weten in de Nederlandse Bouw Milieu-Impacts van de Nederlandse Bouw-En Sloopactiviteiten in 2010*; CE Delft/Bouwend Nederland: Delft, The Netherlands, 2015.
33. IABR. *Stedelijk Metabolisme, Duurzame Ontwikkeling van Rotterdam*; IABR: Rotterdam, The Netherlands, 2014.
34. Potemans, A. Modular Building in a Circular Economy. Master's Thesis, Delft University of Technology, Delft, The Netherlands, 2017.
35. Van Haagen, F.P.C. Circulair Aanbesteden—DNA-Match: Het Geheim Achter Een Spraakmakende Circulaire Aanbesteding. Master's Thesis, Delft University of Technology, Delft, The Netherlands, 2018.
36. Castelein, L. Circulair Contracteren: Een Onderzoek Naar De Huidige Mogelijkheden Voor Circulariteit in Bouwcontracten. Master's Thesis, Delft University of Technology, Delft, The Netherlands, 2018.
37. Ten Klooster, G. *Op Weg Naar Circulair Bouwen en Slopen in Amersfoort*; University of Twente: Enschede, The Netherlands, 2017; Volume 41, Available online: http://research.economicboardutrecht.nl/sites/nl.economicboardutrecht.research/files/OpwegnaarcirculairbouwenenslopeninAmersfoort.pdf (accessed on 24 January 2018).
38. Lozano, R.; Ceulemans, K.; Alonso-Almeida, M.; Huisingh, D.; Lozano, F.J.; Waas, T.; Hugé, J. A review of commitment and implementation of sustainable development in higher education: Results from a worldwide survey. *J. Clean. Prod.* **2014**, *108*, 1–18. [CrossRef]
39. De Vries, J. Presteren Door Vastgoed, Onderzoek Naar De Gevolgen Van Vastgoedingrepen Voor De Prestatie Van Hogescholen. Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands, 2007.
40. Verhoef, L.; Graamans, L.; Gioutsos, D.; Van Wijk, A.; Geraedts, J.; Hellinga, C. ShowHow: A Flexible, Structured Approach to Commit University Stakeholders to Sustainable Development. In *Handbook of Theory and Practice of Sustainable Development in Higher Education*; Filho, W.L., Azeiteiro, U.M., Molthan-Hill, F.A., Eds.; Springer: Berlin/Heidelberg, Germany, 2017; Volume 4, pp. 491–508. [CrossRef]
41. Den Heijer, A.C. Managing the University Campus: Information to Support Real Estate Decisions. Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands, 2011.

42. Curvelo Magdaniel, F. Technology Campuses and Cities: A Study on the Relation Between Innovation and the Built Environment at the Urban Area Level. Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands, 2016.
43. Den Heijer, A.C.; Curvelo Magdaniel, F.T.J.C. The university campus as a knowledge city: Exploring models and strategic choices. *Int. J. Knowl. Based Dev.* **2012**, *3*, 283–304. [CrossRef]
44. Ávila, L.V.; Leal Filho, W.; Brandli, L.; Macgregor, C.J.; Molthan-Hill, P.; Özuyar, P.G.; Moreira, R.M. Barriers to innovation and sustainability at universities around the world. *J. Clean. Prod.* **2017**, *164*, 1268–1278. [CrossRef]
45. Den Heijer, A.C.; Arkesteijn, M.; de Jong, P.; de Bruyne, E. *Campus NL—Investeren in de Toekomst (Report). Architecture, Management in the Built Environment*; Delft University of Technology: Delft, The Netherlands, 2016; Available online: http://www.vsnu.nl/files/documents/CampusNLdigitalversion(forwebsites).pdf (accessed on 4 January 2018).
46. Den Heijer, A.C. *Campus Wordt Duurzame Kennisstad: Het Delen van Ruimte als Positieve Keuze (Journal Article)*; Delft University of Technology: Delft, The Netherlands, 2011; Available online: https://repository.tudelft.nl/islandora/object/uuid%3Afb3b5dae-b452-4c37-8785-ca6fac75ee0b?collection=research (accessed on 21 February 2018).
47. Circulaireeconomienederland. Available online: https://www.circulaireeconomienederland.nl/default.aspx (accessed on 26 November 2018).
48. EEA. *SOER 2015—The European Environment—State and Outlook 2015*; European Environment Agency: Copenhagen, Denmark, 2015; Available online: https://www.eea.europa.eu/soer (accessed on 26 November 2018).
49. Loorbach, D.A. *To Transition! Governance Panarchy in the New Transformation*; Erasmus University Rotterdam: Rotterdam, The Netherlands, 2014; ISBN 978-90-822881-0-0.
50. De Graaf, R.S. *Basisboek Systems Engineering in de Bouw: Een Methodische Totaalaanpak van Het Bouwproces*; Brave New Books: Austin, TX, USA, 2014; Available online: https://research.utwente.nl/en/publications/basisboek-systems-engineering-in-de-bouw (accessed on 10 May 2018).
51. Franzen, A.; Hobma, F.; de Jonge, H.; Wigmans, G. *Management of Urban Development Processes. Governance, Design and Feasibility*; Techne Press: Amsterdam, The Netherlands; Delft, The Netherlands, 2010; ISBN 9789085940296.
52. Glaser, M.; Karssenberg, H.; Laven, J.; van Teeffelen, J.; van't Hoff, M. *The City at Eye Level. Lessons for Street Plinths*; Eburon Academic Publishers: Delft, The Netherlands, 2016.
53. Teisman, G.; Gerrits, L. The Emergence of Complexity in the Art and Science of Governance. *Complex. Gov. Netw.* **2014**, *1*, 7–28. [CrossRef]
54. Klijn, E.H.; Steijn, B.; Edelenbos, J. The Impact of Network Management on Outcomes. *Gov. Netw. Public Adm.* **2010**, *88*, 1063–1082. [CrossRef]
55. Nelissen, N.; de Goede, P.; van Twist, M. *Oog voor Openbaar Bestuur*; Elsevier Overheid: The Hague, The Netherlands, 2004; ISBN 9059014987.
56. Daamen, T.A.; Verheul, W.J. Stedelijke ontwikkeling als een emergente adaptieve strategie. *Bestuurswetenschappen* **2014**. [CrossRef]
57. Hopff, B. *De Stad en de Campus (Essay)*; MCD Erasmus University Rotterdam: Rotterdam, The Netherlands, 2017.
58. Brand, S. *How Buildings Learn: What Happens after They're Built*; Viking Press: New York, NY, USA, 1994.
59. Zuidema, R. *De Olifant Dendert Door de Circulaire Stad*, 2nd ed.; Stichting BRIQS: Amsterdam, The Netherlands, 2017; ISBN 978-94-92383-67-9.
60. Nijhuis, S.; de Vries, J.; Noortman, A. Ontwerpend onderzoek. In *Praktijkgericht Onderzoek in de Ruimtelijke Planvorming*; Simons, W., van Dorp, D., Eds.; Methoden voor analyse en visievorming; Uitgeverij Landwerk: Wageningen, The Netherlands, 2017; pp. 256–283.
61. De Bruijn, H.; Ten Heuvelhof, E.; in't Veld, R. *Een Nadere Positionering van de Procesbenadering. Procesmanagement. Over Procesontwerp en Besluitvorming*, 4th ed.; Boom Uitgevers: Amsterdam, The Netherlands, 2012; ISBN 978 90 5261 932 3.
62. Teisman, G. *Publiek Management op de Grens van Chaos en Orde (Public Management on the Border of Chaos and Order)*; Erasmus University Rotterdam: Rotterdam, The Netherlands, 2005.

63. Loorbach, D.A. Transition Management for Sustainable Development: A Prescriptive, Complexity-Based. *Governance* **2010**, *23*, 161–183. [CrossRef]
64. De Bruijn, J.A.; Ten Heuvelhof, E. Strategieën: Een vergelijking tussen projectmatige en procesmatige verandering. In *Management in Netwerken*; Boom Lemma Uitgevers: Utrecht, The Netherlands, 2007; pp. 75–109. ISBN 978 90 5931 013 1.

sustainability

MDPI

Article

How Water Bottle Refill Stations Contribute to Campus Sustainability: A Case Study in Japan

Takuro Uehara [1,*] and Alayna Ynacay-Nye [2]

1 College of Policy Science, Ritsumeikan University, 2-150 Iwakura-cho, Ibaraki City, Osaka 567-8570, Japan
2 Research Organization of Open Innovation and Collaboration, Ritsumeikan University, 2-150 Iwakura-cho, Ibaraki City, Osaka 567-8570, Japan; 18v00273@gst.ritsumei.ac.jp
* Correspondence: takuro@fc.ritsumei.ac.jp; Tel.: +81-726652020

Received: 24 July 2018; Accepted: 26 August 2018; Published: 29 August 2018

Abstract: The purpose of this study was to explore the feasibility of installing Water bottle Refill Stations (WRSs) and their contributions to campus sustainability by means of encouraging pro-environmental behavior in students. Plastic waste is one of the most critical environmental issues. Therefore, we investigated how WRS can deter students from using disposable plastic bottles. We conducted a survey at a Japanese university to address (1) students' Willingness To Pay (WTP) to install WRS, (2) their Willingness To Use (WTU) WRSs while acknowledging its environmental benefits, and (3) the impact of communicating information about points (1) and (2). We utilized Goal-Framing Theory (GFT) and the Integrated Framework for Encouraging Pro-Environmental Behavior (IFEP) as the theoretical background of our study. The results of our survey found that the mean WTP was 2211 JPY (1 JPY = 0.01 USD), an amount students would donate just once. This finding indicates students would be willing to pay to install a WRS at their university. The mean WTP students supported would be enough to cover the WRS installation and maintenance costs. According to our study, 58.82% of students stated that they would be willing to use WRS. In doing so, students would save 45,191 disposable plastic bottles and reduce 10,846 kg of related CO_2 emissions every year. Our study also showed a statistically significant increase in WTP and WTU WRS as we introduced more and more information about pro-environmental behaviors to students. This finding indicates the importance of information campaigning and learning how to encourage pro-environmental behavior.

Keywords: water bottle refill stations; campus sustainability; willingness to pay; contingent valuation method; willingness to use

1. Introduction

Campus sustainability as a discipline is of growing importance not only for university campuses, but also for its possible implications for society as a whole [1–3]; Universities have a social responsibility to address environmental issues, and they can play unique role in a sustainable society [1]. This role could include educating future leaders, researchers, consumers and entrepreneurs [1,4]. In other words, campus sustainability practices could make a long-term and wide contribution to society by educating students [4], in addition to direct and short-term contributions such as reducing waste and saving energy.

Among the various environmental issues universities need to address [5], plastic waste is one of the major issues in the era of "plasticene" [6] or "plastisphere" [7], therefore, its management becomes a critical issue [4]. It is estimated 8300 million metric tons of virgin plastic have been produced and 79% of it is accumulated in landfills or the natural environment [8]. A significant amount of plastic waste has also polluted the oceans [9–12]. Jambeck et al. [9] estimated 4.8–12.7 million metric tons of plastic waste was dumped into the ocean in 2010 because of insufficient plastic waste management. Due to this, there is a growing concern on how plastic waste could potentially impact human bodies, animals, plants, economies, and ecosystems [13,14]. By utilizing the natural capital valuation approach, the UNEP estimated that the natural capital cost of plastic in the consumer goods sector was 75 billion USD per year and the natural cost of plastic in marine ecosystems was 13 billion USD per year [13].

This paper intends to shed light on how Water bottle Refill Stations (WRSs) could potentially contribute to campus sustainability by reducing the amount of disposable plastic bottles with a device that utilizes refillable water bottles. A WRS is a device designed to provide drinkable tap water to users with a refillable water bottle. Users simply place a refillable bottle under the WRS's sensor and it dispenses water directly into the bottle. Universities in the United States have begun installing WRSs in an effort to reduce the number of plastic bottles used on campuses [15,16]. Installing WRSs is just one way universities can contribute to campus sustainably goals. While there is no agreed-upon definition of campus sustainability [17], it generally comprises of four main attributes; (1) ecological (e.g., food and recycling), (2) economic and financial (e.g., endowment transparency), (3) institutional (e.g., student involvement) and (4) energetic (e.g., climate change and energy) [5]. For example, Washington University in St. Louis, installed a WRS in order to meet one of their campus sustainability goals. In 2014–2015, due to the campus wide bottle water ban and the implementation of a WRS, the university saw a reduction of 567,000 plastic bottle purchases [18]. It also reduced the university's carbon footprint levels by decreasing the production and transportation of plastic bottles as well as limited the number of un-recyclable plastic bottles ending up in landfills [19].

While WRSs offer a number of promising contributions to campus sustainability, there seems to be a paucity of academic literature on the subject. Most information currently available can be found from campus reports (e.g., Reference [16]), online newspapers [20,21], and campus project proposals [22], though not rigorous scientific studies. In addition, most of the campus reports and studies have been conducted solely in the U.S. Our study intends to fill these gaps. Due to a number of universities banning the sale of plastic bottles [23–26], there have since been extensive studies on drinking water preferences (e.g., tap water vs bottled water) in the U.S. Our study has taken advantage of the information gathered from these related studies.

The purpose of this study was to investigate how WRSs could contribute to campus sustainability by students answering three Research Questions (RQs). First, we measured how many students would support a WRS by analyzing their Willingness To Pay (WTP) for WRS (RQ1). Second, we measured students' Willingness To Use (WTU) WRS and its impacts on the environment measured by avoiding disposable plastic bottle uses with related CO_2 emissions (RQ2). Third, we analyzed the impact of disseminating information about RQ1 and RQ2 (RQ3). We conducted a survey at a university in Japan to answer these research questions.

The remainder of the paper is organized as follows. Section 2 explains materials and methods, including the theoretical background of our study. Section 3 outlines the results. The last section discusses the implications of our findings regarding the three research questions, the limitation of our study, and the conclusion.

2. Materials and Methods

This section addresses the materials and methods used to answer our three research questions. After introducing our case study, we explain the theoretical background we based our questionnaire design on. Then, we explain the questionnaire design and assessment methods. Lastly, we explain how we analyzed the data obtained from the questionnaire survey.

2.1. Case Study

We conducted a survey in a class composed of first-year policy science students at Ritsumeikan University, located in Osaka, Japan. Ritsumeikan University strives to achieve campus sustainability. One way Ritsumeikan University has tried to enhance campus sustainability and contribute to a sustainable society is by creating a set of guidelines intended to encourage pro-environmental behavior in students and staff [27].

The survey was distributed to first-year students in an introduction to policy science research methods class, taught by one of the authors. Of the 410 students enrolled in the College of Policy Science, 362 participated in our survey. The remainder of the students are enrolled in the Community and Regional Policy Students (CRPS) degree program, and are not registered for this particular research methods class and therefore did not complete the survey. Since we did not have the opportunity to ask CRPS students to participate in the survey, they are excluded from our sample pool.

2.2. Theoretical Background

There have been a number of theories developed to understand pro-environmental behavior. For example, Theory of Planned Behavior (TPB), Value-Belief-Norm theory (VBN), and Goal-Framing Theory (GFT) are prediction models commonly used in environmental research [28,29]. Each theory has a different focus. While the TPB focuses on individual cost-benefit analysis [30–32], the VBN focuses on personal norm [33]. GFT is more comprehensive than TPB and VBN because it proposes three different goals (hedonic, gain, and normative) to encourage pro-environmental behavior [34]. Self-regulation models are another type of theory focusing on the dynamic psychological mechanisms explaining people's behavior, as opposed to predicting people's behavior [28].

Our research adopted the Integrated Framework for Encouraging Pro-Environmental Behavior (IFEP), which draws on GFT [29], for our theoretical background. There have been a number of studies conducted utilizing the IFEP and GFT. One example is its use to test the empirical validity of the IFEP in Sweden [35]. Another example is the work of Rezvani et al. [36], who applied GFT to try to explain consumer electric vehicle adoption. Pro-environmental behavior often involves a conflict between hedonic or gain goals with normative goals; therefore, strategies to encourage pro-environmental behavior should take into account the conflict or balance among them. The IFEP proposes two strategies to influence hedonic, gain and normative goals. The first strategy is to reduce the conflict between hedonic (e.g., enjoyable) or gain goals (e.g., cost saving) with normative goals (e.g., right thing to do). It is important to note there is some risk in encouraging hedonic and gain goals exclusively as it may push normative goals to the background and undermine sustainable pro-environmental behavior [29]. Therefore, the second strategy is critical to strengthen normative goals for substantial behavior change. If a person focuses on normative goals, it strengthens individual values which in turn can impact the way a person perceives the importance of a situation. If normative goals are linked to a person's values, the strength of those values can outweigh perceived costs of pro-environmental behavior.

There are two reasons we adopted the IFEP for our research. First, it includes more comprehensive goals than other theories and our case study utilizes these various goals. Other theories, such as the theory of planned behavior, focuses more on individual cost-benefit analyses [30], which is not the focus of our particular case study. Second, the IFEP emphasizes that situational factors play a prominent role [29]. The main intention behind installing WRS on campuses is to introduce a situational factor, which in this case, would be to deter students from using disposable plastic bottles.

2.3. Questionnaire Design and Asessment Methods

Based on the IFEP framework, we designed a survey to test how WRS could contribute to influencing students' pro-environmental behaviors. The target pro-environmental behavior was to encourage students not to use disposable plastic bottles, which would result in less plastic waste and CO_2 emissions. This behavioral change may create a conflict between hedonic or gain goals and normative goals; students would have to give up convenient and better tasting water (i.e., disposable plastic water bottles) in order to support a pro-environmental choice. Therefore, the IFEP may be effective in encouraging students to make the pro-environmental change by reducing the conflict between these goals.

Figure 1 describes the main components of the survey including their hypothetical relationships and expected attitudes, along with the two corresponding strategies proposed in the IFEP. The Type of

Strategies '1' label indicates the removal or reduction of the conflict between hedonic or gain goals and normative goals. The Type of Strategies '2' label indicates strengthening normative goals.

Approach		Attribute	Description of Attribute	Type of Strategy			Expected Attitude
Stage 1	WRS installation	WRS installation	Convenient, less effortful	1	Decrease gain costs		Support toward WRS Willingness to WRS
		No charge	Cheaper	1	Decrease gain costs		
	Assessment measure	Reasons to say yes to WTP and WTU of WRS					WTP, WTU, Bottles saved
Stage 2	Additional information	Importance of campus sustainability	Environmental impacts	2	Strengthen normative goals		More support toward WRS More will to use WRS
		Bottle counter	Fun	1	Make hedonic goals compatible with normative goals		
		Clean water	Health	1	Make hedonic goals compatible with normative goals		
		Cold water	Taste	1	Make hedonic goals compatible with normative goals		
		Plastic waste	Environmental impacts	2	Strengthen normative goals		
		CO_2 emissions	Environmental impacts	2	Strengthen normative goals		
		Common in USA	Role models	2	Strengthen normative goals		
	Assessment measure	Changes in reasons to saying yes to WTP and WTU of WRS					Changes in WTP, WTU, Bottles saved

Figure 1. Hypothetical relationships between the survey design and expected influences on students' attitudes toward pro-environmental behavior.

The survey was comprised of two stages. For Stage 1, we proposed the installation of WRS on campus without giving a lot of detailed information about WRS or its background, and then asked for their support and WTU. The installation is a so-called contextual factor (or situational cue) intended to make pro-environmental behaviors more accessible by reducing the cost of engaging in pro-environmental behaviors [29,37]. The students' support was measured by their WTP for the installation of WRS, and its environmental consequences were estimated by their WTU and changes to their plastic bottle usage. The students would donate an amount just once. While our study adopted a one-time donation method, there are other types of payment vehicles available such as paying higher prices, taxes, or a surcharge on utility bills [38]. Each payment vehicle has its own strengths and weaknesses. For example, while donation methods could yield an underestimate of value, taxes could lead to protest responses [39]. In other words, the specification of a payment vehicle could cause unintended effects or vehicle bias [38,39]. We confirmed the validity of a donation method as a payment vehicle in our pre-test prior to our main survey. We further questioned the students' reasons for their approval or disapproval of the WRS installation plan and their WTU WRS in order to test hypothetical relationships.

For WTP estimates, we adopted a double-bound dichotomous choice method, a type of Contingent Valuation Method (CVM), to elicit students' WTP for the WRS's installation because it is less susceptible to biases compared to other methods [40]. We proposed seven different bid amounts (250, 500, 1000, 2000, 4000, 8000, and 16,000 JPY) (see Supplementary Materials SI1 for the scenario for CVM). Five different combinations for bid values (in JPY) were used (Initial; Lower; Upper): (500; 250; 1000), (1000; 500; 2000), (2000; 1000; 4000), (4000; 2000; 8000) and (8000; 4000; 16,000). Selecting the bid amounts was critical [41,42] and a challenge for our study because, to our knowledge, there are not any similar studies in the literature we can refer to. A double-bound question (or one follow-up) is said to increase estimation efficiency when a priori knowledge is not available, as in our study, to guide bid design [42]. As a reference, we chose the combination of bids used by Sakurai and Uehara [43] from their survey with similar sample (i.e., students in the same department at the same university). However, since the topic is not germane to our study (to reduce smoking on campus), we carefully verified the validity of the combination from the smoking survey in 2017 in our pre-test prior to our main survey. Using a pre-test or a focus group is a common method used to choose bid amounts [44,45]. The combination was verified from the pre-test; it was neither too low nor too high [39]. A smaller number of bids (five to eight) is also considered to be an effective method to increase estimation efficiency [39,41].

At Stage 2, we provided further information about the WRS including the background of the device's installation to examine how additional information might change students' support and WTU. For Stage 2, Figure 1 describes the different kinds of additional information we provided and its hypothetical impact on students' attitudes toward a WRS. We explained how focusing on environmental issues and campus sustainability is not only important for the university but it is also a social responsibility [46]. We also reminded students that their university, Ritsumeikan University, had created a guideline to support pro-environmental behavior and which asks students and faculty members to contribute to the realization of a sustainable society [27]. We explained the severity of increasing plastic waste including related CO_2 emissions [8,47] and its potential impact on humans, animals, plants, and ecosystems [14]. We also explained additional characteristics of a WRS such as how it could be fun to see the counter counting the number of bottles saved and its water quality in comparison with bottled water. Lastly, we mentioned how WRS are common on U.S. campuses. To assess the impacts of the information as it was disseminated, we measured changes in WTP, WTU, and plastic bottle usage. We further investigated the student's reasons to approve and disapprove the bid amount to install the WRS and their WTU WRS to test hypothetical relationships.

In addition to questions directly related to WTP, WTU, and plastic bottle use calculations, we also asked students about their basic characteristics and daily habits (e.g., gender, frequency to campus, etc.), preference of drinking water [25], attitudes toward sustainability at school/community and their own personal responsibility [5], as well as educational background [3] in order to examine their potential relevance to WTP, WTU, and plastic bottle use. We adopted a best-worst scaling (BWS) [48] method in order to measure the students' priorities for their choice in drinking water (i.e., health, taste, convenience, costs, and environmental costs). BWS is easier to answer because it asks respondents to choose what they feel are least and most important, rather than having to individually rank a large number of possible options. By reiterating these possible options in a number of different sets, the ranking of all the possible choices were revealed. We used the counting approach [49] and adopted the following Standardized BW_i to measure how to present the relative importance of choice i.

$$\text{Standardized BW}_i = \frac{\sum_n B_{in} - \sum_n W_{in}}{Nr}, \tag{1}$$

B_{in} and W_{in} indicates the number of times choice i is selected as the best and the worst out of all the questions by respondent n respectively. r is the number of times item i appears in all the questions. N indicates the number of respondents. Standardized BW_i is zero when respondents select choice i as the best as frequent as they select it as the worst or, if they select it neither as the best nor the worst.

2.4. Survey Implementation and Data Analysis

On 24 May 2018, we tested the survey on six students from a different class than the one analyzed in this study in order to make sure it was designed as expected [39]. Given the students' feedback and our own findings, the survey was amended accordingly and the implementation the survey was reconsidered (e.g., speed of proceeding the questionnaire). The finalized survey, endorsed by the Human Research Ethics Review Committee at Ritsumeikan University (Kinugasa-Jin-2018–6), was conducted in class on 30 May 2018. To avoid potential student-teacher bias, we explained to students that their answers would not influence their grade for the course and they had the option to not participate.

We used R (Version 3.3.2 for Windows (64 bit)) by the R foundation [50] to compute WTP and BWS estimates, and a statistical analysis software STATA (Version 14.2) by StataCorp LP [51] for the rest of data analyses.

3. Results

This section explains our case study results including summary statistics, WTP for WRS, and the number of disposable plastic bottles with related CO_2 emissions saved if a WRS is installed.

3.1. Summary Statistics

Not all first-year students registered for the class completed the survey (268 out of 362, 74.03%) mainly because some of them did not attend class on the day the survey was conducted. Among the respondents, 59.55% were male, similar to the composition of all first-year students (62.15%); 51.54% of students were taking or had taken courses related to environmental issues; on average, the students surveyed came to campus 4.49 days out of 5 days per week (see Supplementary Materials SI3 for further detail of summary statistics).

Table 1 shows the students' attitudes toward sustainability in their school/community and how they feel about their own personal responsibilities. We adopted questions used by the authors of Reference [5] who had previously surveyed college students in Alabama and Hawaii. All of the questions used the same Likert scale (1. Strongly agree, 2. Agree, 3. Neutral, 4. Disagree, 5. Strongly disagree). In order to make our survey comparable to Reference [5], we calculated the sum of choices 'strongly agree' and 'agree' into one column, and the sum of choices 'strongly disagree' and 'disagree' into another. As Table 1 shows, both types of responsibility, school/community and personal, were strongly favored. In contrast to the findings in Alabama and Hawaii, our survey found that students felt more responsibility toward school/community than their own personal responsibility. In addition, the students in our survey tended to support school/community responsibility more than the findings in Reference [5] (69% (Hawaii) and 57% (Alabama) for the first question and 68% (Hawaii) and 56% (Alabama) for the second). Chronbach's α statistic, which measures the internal consistency or homogeneity of statements [52], was 0.7502. Since the value was higher than proposed threshold values (0.7 to 0.8) [53], we used the simple sum of these four values as a composite index for attitudes toward campus sustainability in WTP estimates.

Table 1. Students' attitudes toward sustainability in school/community and their own personal responsibility.

	Item	Strongly Agree or Agree (%)	Strongly Disagree or Disagree (%)	*N*
School/community responsibility	Do you think campus maintenance, development and management should prioritize sustainability?	80.83	3.39	266
	Do you think every member of the university should support sustainable solutions?	76.32	6.76	266
Personal responsibility	Do you want to be part of creating of a sustainable campus, community and/or world?	78.12	4.15	265
	Would you support and/or participate in environmental conservation activities put on by the university?	72.45	4.91	265

Figure 2 shows the students' preferences when choosing drinking water utilizing a standardized best-worst score (Equation (1)). While taste, health, and costs were considered priorities, convenience and environment were less of a priority when choosing drinking water.

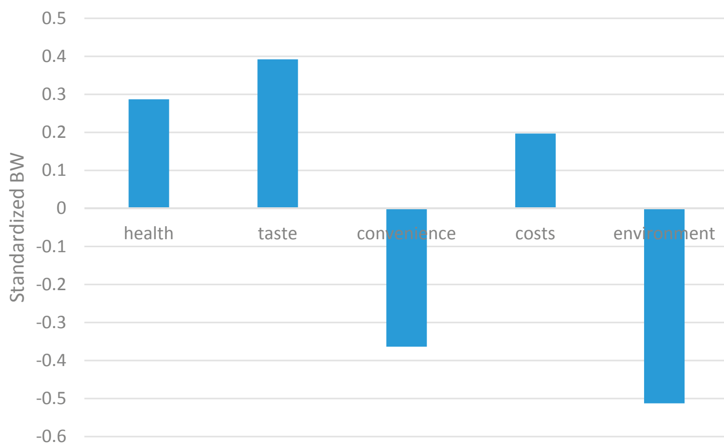


Figure 2. Priorities in choosing drinking water utilizing a standardized best-worst score (N = 255).

3.2. WTP for WRS

Table 2 shows how frequently participants responded to each of the five bid combinations. Table 3 is a logit model used to calculate WTP estimates. The responses before and after information about WRS provided were pooled. The logit model revealed a statistically significant increase in WTP (a 10% level) if more information was provided versus when it was not (Information dummy). While the mean WTP truncated at maximum bid without information provided was 1997 JPY per student, it was 2211 JPY per student after information was provided. Their 95% confidence intervals (Lower; Upper) were (1652; 2424) and (1932; 2589) respectively. Likewise, while the median WTP without information provided was 921 JPY per student, it was 1042 JPY after information was provided. Their 95% confidence intervals (Lower; Upper) were (749; 1128) and (901; 1216) respectively.

Table 2. Frequencies of responses to each of the five bid combinations.

First Bid	Second Bid If Yes to the First	Second Bid If No to the First	YY		YN		NY		NN		Total	
500	1000	250	13	(14%)	39	(43%)	16	(18%)	23	(25%)	91	(100%)
1000	2000	500	3	(5%)	21	(34%)	18	(29%)	20	(32%)	62	(100%)
2000	4000	1000	7	(9%)	16	(20%)	28	(35%)	30	(37%)	81	(100%)
4000	8000	2000	4	(5%)	8	(11%)	29	(38%)	35	(46%)	76	(100%)
8000	16,000	4000	4	(5%)	4	(5%)	28	(37%)	39	(52%)	75	(100%)

YY: yes to the first bid, yes to the second one; YN: yes to the first bid, no to the second one; NY: no to the first bid, yes to the second one; NN: no to the first bid, no to the second one.

To explore attributes that affect students' WTP, we also estimated a full model including attributes potentially relevant to their WTP as shown in Table 4. Table 5 describes the variables used in the full model. The number of students with prior knowledge of WRS was statistically significant, at a 10% level. Students who tended to answer affirmatively to "Attitudes toward campus sustainability" also raised their probability of saying yes to the bids. "Attitudes toward campus sustainability" is a composite index comprising of four questions regarding attitudes toward sustainability in their school/community and their own personal responsibility (Table 1). Students who tended to come to campus more frequently, also tended to support WRS more often. Lastly, female students tended to support WRS more than male students.

Table 3. A simple logit model for WTP estimates.

Variable	Coefficient	Std. Error	*p*-Value	
Constant	9.144	0.556	<0.001	****
Information dummy	0.333	0.195	0.088	*
log(Bid)	−1.340	0.076	<0.001	****
Log-likelihood	−545.256			
AIC	1096.512			
BIC	1108.372			
N	385			

**** $p < 0.001$, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table 4. A full logit model to explore the factors affecting WTP estimates.

Variable	Coefficient	Std. Error	*p*-Value	
Constant	10.326	1.352	<0.001	****
Information dummy	0.428	0.210	0.041	**
Environmental education	0.072	0.212	0.734	
Knew about WRS	−0.461	0.271	0.089	*
Attitudes toward campus sustainability	−0.149	0.045	<0.001	****
Frequency to campus	0.412	0.195	0.035	**
Gender	−0.379	0.216	0.079	*
Part-time Job	−0.113	0.238	0.636	
log(Bid)	−1.405	0.083	<0.001	****
Log-likelihood	−479.397			
AIC	976.7933			
BIC	1011.411			
N	346			

**** $p < 0.001$, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table 5. Description of variables used in the full logit model.

Variable	Description	Mean	Std. Dev.
Information dummy	0: Not informed, 1: Informed	0.496	0.501
Environmental education	1: Yes, 2: No	1.503	0.501
Knew about WRS	1: Yes, 2: No	1.833	0.374
Attitudes toward campus sustainability	The sum of four questions regarding attitudes toward campus sustainability (Q7, 8, 9, and 10). 4: Strongly agree with all four questions, . . . , 20: Strongly disagree with all four questions	7.958	2.393
Frequency to campus	1: Once a week, 2: Twice a week, 3: Three times a week, 4: Four times a week, 5: Every day (Five times a week)	4.491	0.630
Gender	1: Male, 2: Female	1.427	0.495
Part-time Job	1: Yes, 2: No	1.299	0.458

The primary reasons for students saying yes to the bid were answers "I want to drink water from a water bottle refill station.", "I can reduce the environmental impacts and/or because I can contribute to society through practices at a sustainable campus.", and "It seems like it would be fun to use a water bottle refill station." (Figure 3). Respondents who chose answer "I think it is good to give money to public schools, regardless of the benefits of water bottle refill stations." are not valid yes respondents [38], therefore they were excluded from WTP estimates. After comparing the first three reasons before and after information was provided, we found that their frequency had increased. Among which, answer "I can reduce the environmental impacts and/or because I can contribute to society through practices at a sustainable campus." increased the most.

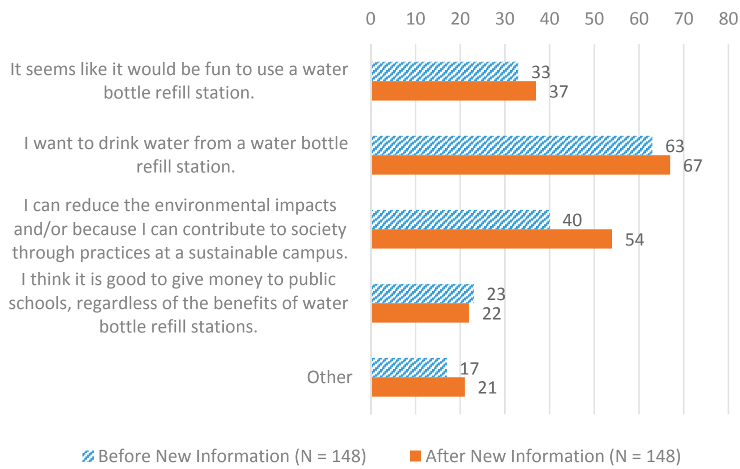


Figure 3. Reasons for saying yes to bid.

The primary reasons for students saying no to the bid were answers "This is not important to me.", "The contribution amount is too expensive.", and "I do not feel like it is my responsibility to have to pay." (Figure 4). Following Reference [38], answers "This is not important to me.", "I do not feel like it is my responsibility to have to pay.", and "It does not sound like a realistic plan." were considered to be protest responses therefore respondents who chose one of these answers were excluded from the WTP estimate. Protest responses occur when a respondent rejects paying for the bid offered for certain aspects of a scenario in CVM different from the amount of bid, though they may value the good benefited from the scenario. After comparing the answers from before and after information provided, there was a significant drop regarding the answer "This is not important to me."

3.3. WTU and Disposable Plastic Bottles with Related CO_2 Emissoins Saved

Table 6 compares the number of students who chose "Water from the water bottle refill station" from before and after information provided. After information was provided, the number of students who were willing to use WRS increased from 130 (54.62%) to 140 (58.82%). The difference was statistically significant (Paired t-test $p = 0.029$). However, WTU was lower than a previous survey conducted in the U.S. which had reported that 91% of students currently using disposable bottles would be willing to switch to a reusable water bottle if there were WRS in prominent locations on campus [54].

Figure 5 shows the reasons for WTU. Answer "I want to drink water from a water bottle refill station" was the main reason. After comparing before and after information was provided, there was a stark contrast regarding an environmental and sustainability concern ("I can reduce the environmental impacts and/or because I can contribute to society through practices at a sustainable campus."), more than doubling (from 24 to 51) after information was provided.

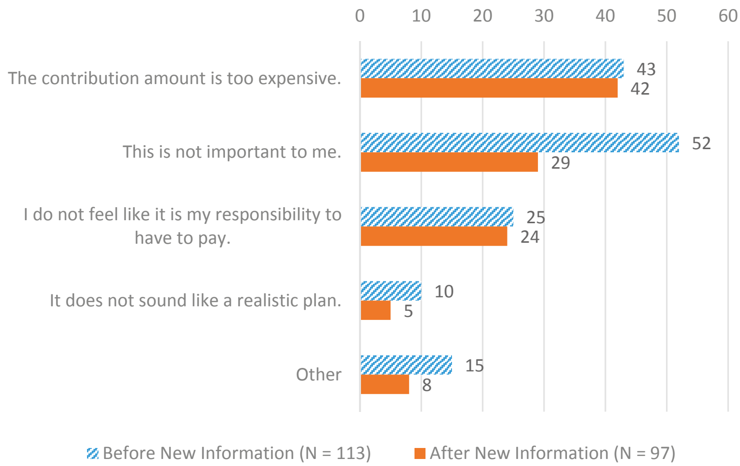


Figure 4. Reasons for saying no to bid.

Table 6. Students' WTU before and after new information.

WTU	New Information			
	Before		**After**	
	Freq.	**Percent**	**Freq.**	**Percent**
Yes	130	54.62%	140	58.82%
No	108	45.38%	98	41.18%
Total	238	100.00%	238	100.00%

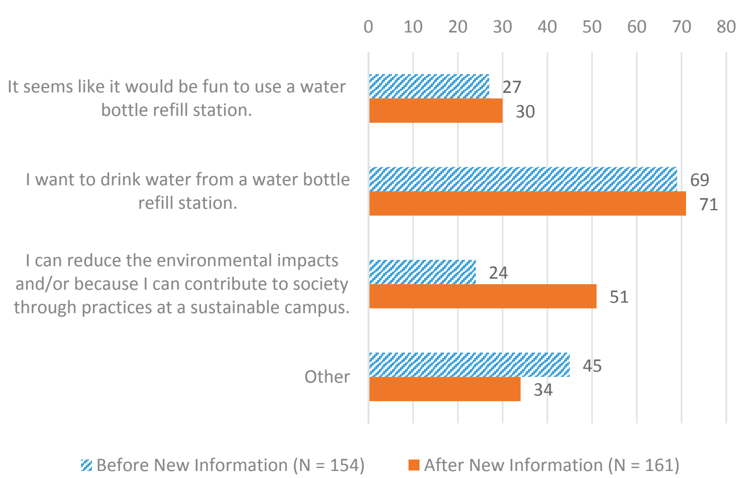


Figure 5. Reasons for WTU.

Figure 6 shows the reasons students chose not to use WRS. The main reason was because "It's annoying to bring a refillable water bottle around. I feel like I'm going to forget to bring it." However, after information was provided, this reason as well as the concern regarding taste and/or smell ("I'm concerned about taste and/or smell.") decreased. Students who chose they do not care about the environment ("I do not care about the environment.") also decreased. In contrast to our initial expectation, there was an increase in concern regarding water quality and/or health ("I'm concerned about water quality and/or the impact on my health.").

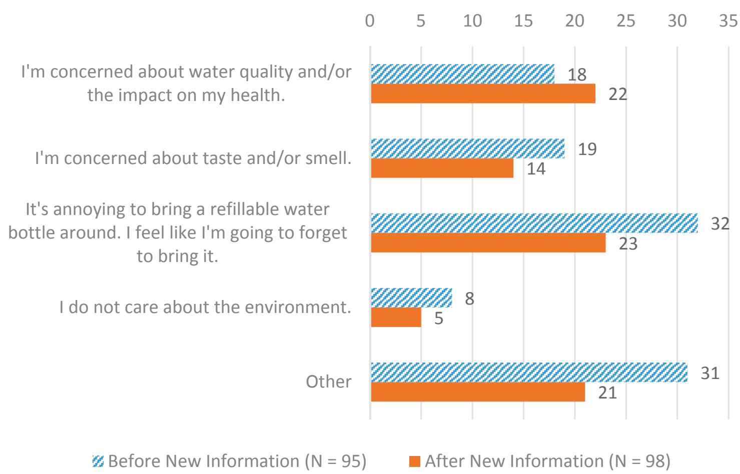


Figure 6. Reasons for students not wanting to use WRS.

We have to note that students' WTU does not necessarily reduce the number of plastic bottles used because some students might use both plastic bottles and get water from a WRS. As Table 7 shows, with WRS installed, all other types of beverage containers reduced. However, the total usage of beverage containers increased from 356 to 375. Plastic bottle use decreased by around half (from 135 without WRS to 74 respondents with WRS installed and information provided), though if we compare the responses before and after information provided, the reduction of plastic bottle usage did not change significantly.

Table 7. The types of beverage container students drink from (N = 237).

Item	Without WRS	WRS without Information	WRS with Information
(1) PET bottles or plastic bottles	135	76	74
(2) Paper cartons	35	22	26
(3) A reusable bottle with water or tea brought from home	117	99	97
(4) Water from the water bottle refill station	-	129	139
(5) Others (tea or water from the cafeteria, etc.)	69	34	39
Total	356	360	375

4. Discussion

Priorities for choosing drinking water differs from findings in the U.S. [23,25] and Southeastern Asian cities (Singapore, Hong Kong, and Macau) [32], highlighting the importance of contextual differences. Figure 2 shows that taste, health, and costs (related to gain goals) were focal, whereas convenience (related to gain goals) and environment (related to normative goals) were less of a concern. The reason for convenience being a higher priority than environmental reasons requires interpretation. The reason is probably because students in Japan have more access to drinking water and therefore convenience is not considered a priority. In Southeastern Asian cities, convenience and availability were rated highest on average, which is probably because it is more difficult for students to access drinking water than for those in Japan. When it comes to switching from disposable water bottles to refillable bottles, convenience would probably play a more important role. Without WRSs, students in Japan would have to fill their refillable water bottles at home and bring them to campus. Although there are water dispensers in the cafeterias on campus for students to refill the cafeteria cups, they are not allowed to fill up their own personal bottles. Hence, the installation of a WRS (i.e., contextual factor [37]) is appealing as a gain goal and the distribution of information about WRS (i.e., information campaign [29]) is strengthening a normative goal as well as appealing to a hedonic goal, all of which seem to be effective strategies to encourage students to give up disposable plastic bottles. These strategies also employ to the two strategies (i.e., reducing or removing a conflict and strengthening normative goals) proposed by the IFEP [29]. As discussed above, the information given to students regarding WRS installation and its background showed that installing the device would be a feasible and effective way to encourage students' pro-environmental behavior. This in turn, shows the validity of the IFEP in our context.

4.1. RQ1. Students' Support for WRS

The mean WTP (truncated at maximum bid) was 2211 JPY, indicating that WRS gained students' support after information was disseminated. The two mean WTP amounts (i.e., before and after information) were notably higher than the corresponding median WTP amounts, indicating the distribution of the WTP was skewed [55]. While the median WTP addresses what the majority of respondents are actually willing to pay, the mean WTP gives greater weight to a minority of respondents who have strong and positive preferences [55]. As shown in Table 2, a notable difference occurs when there is a large number of respondents bidding a small or zero value and a small number of respondents bidding large values. As the choice involves value judgment and is an ongoing debate [55,56], our study reported both measures. To our knowledge, there has been no similar estimate in order for us to make a comparison. The installation of a WRS on campus employs the first strategy of the IFEP; as the installation makes it convenient, less effortful, and free of charge to access water from a WRS rather than using disposable plastic bottles. It would result in reducing conflict between gain and hedonic values on one hand and strengthening normative values on the other. The students' reasons for saying yes to the bid (Figure 3) indicate that the motivations behind supporting WRS included all three gain goals. Students valued not only the water to drink (gain goal), but also how fun it would be to use a WRS (hedonic goal) as well as acknowledging the WRS's potential contribution to the environment and campus sustainability (normative goal). The full model (Table 3) revealed the types of respondents who would support installing a WRS. Similar to the findings from reasons for yes (Figure 3), environmental concern ("Attitudes toward campus sustainability") is statistically significant (i.e., more concern leads to more support). "Frequency to campus" (i.e., more opportunity to use WRS) is also statistically significant. Prior knowledge of WRS and gender (i.e., female students tend to support WRS more) are statistically significant. Although a previous study [25] also found that gender played a role in drinking water preferences, we do not have a good interpretation for the difference. The reasons for saying no to the bid (Figure 4) indicate that campuses should reconsider how they would pay for a WRS. For example, at Portland State University, the installation costs were paid by students' building fees [16]. Since some students felt WRS were not important to them, educating them more about the importance of campus sustainability could also be an effective way to gain support (Figure 4).

Students' support for WRS can be measured by an aggregate welfare estimate (aggWTP) using a mean WTP from the sample multiplied by the affected population N [39]. That is,

$$\text{agg}WTP = \overline{WTP} * N, \tag{2}$$

where $\overline{WTP}$ is the mean WTP truncated at maximum bid (2211 JPY). There are a total of 410 first-year students in the College of Policy Science (362 students taking courses in Japanese and the rest in English), and we adjusted N by multiplying it by 0.78 in order to exclude a proportion of students who chose protest responses or contributing to the school, irrespective of the benefits of WRS as a reason for saying yes to the bid. We assumed students taking courses in English hold the same preferences for WRS. Hence, we estimated every year, first-year students would be willing to pay 706,984 JPY (= 410 students × 0.78 × 2211 JPY). The cost of WRS varies, for example, purchase and installation costs of the three bottle refills stations could be 4000 USD to 7000 USD (≈700,000 JPY) [16,22]. In addition, WRS require subsequent maintenance costs ranging, for example, from 600–650 USD (≈60,000–65,000 JPY) per year at Pennsylvania State University [57]. Though, the cost of installing three WRS could be paid off in a few years.

We should note however, that the WTP estimates could be exaggerated because people tend to overstate how much they would actually pay in hypothetical situations as seen in CVM [58,59]. Calibration factors (mean hypothetical value/mean actual value) tend to exceed 1 [59]. Therefore, the actual payment for a WRS could be lower than the WTP estimates.

4.2. RQ2. Students' WTU and Its Environmental Impacts

WTP measures the benefits of using a WRS such as being able to drink water but also how much fun it could be to use WRS and, its contributions to the environment and campus sustainability. On the other hand, WTU directly measures how many students would want to use a WRS. It is interesting to note that out of 100 students who stated they were not willing to use the WRS, 44 of those students were still willing to pay for the WRS. This indicates that the WTP could include more than hedonic and gain values, but also, normative values.

After further information about WRS was provided, 58.82% of students said that they were willing to use the WRS. To calculate the number of plastic bottles saved with the installation of WRS, we compare Q6 with Q37, which asked students what kind of beverage containers they usually drink from (Supplementary Materials SI1). We assumed that a student would purchase one bottle per visit to campus if the student chooses "1. PET bottles or plastic bottles" in Q6 and/or Q37. There was a study done which calculated U.S. college students' average weekly use of disposable water bottles and found that approximately 40 percent of students purchase more than one bottle [54] a day. However, this data is not directly comparable to our study because it includes the use of plastic water bottles off campus. When installed, the use of plastic bottles would reduce from 135 to 74 (N = 237), or 61 bottles. Therefore, 0.26 plastic bottles (=61/237) could be saved for each student when they come to campus. Using this data, it is estimated all first-year students could save 474 plastic bottles and reduce 108.96 kg of CO_2 emissions per week (Table 8).

Table 8. Estimation of the number of plastic bottles saved and reduction of CO_2 emissions per week by all first-year students.

Number of First-Year Students	Number of Days per Week to Come to Campus	Plastic Bottles Saved per Student per Visit	Plastic Bottles Saved per Week	CO_2 Emissions per Bottle (g)	CO_2 Emissions Avoided (kg)
1	2	3	4 = 1 × 2 × 3	5	6 = 4 × 5/1000
410	4.49	0.26	473.76	240	113.70

CO_2 emissions per bottle represents the carbon footprint of a disposable plastic water bottle (Japan Environmental Management Association for Industry, 2012).

Assuming the students come to campus 30 weeks per year, they could save 14,213 plastic bottles and save 3411 kg of CO_2. Furthermore, if we assume the second and third year students come to campus at the same frequency as the first-year and if the fourth-year students come once a week, students enrolled in College of Policy Science could save 45,191 plastic bottles and 10,846 kg of CO_2 emissions every year. We should also note that since students buy plastic bottles not only on campus but also off campus, the environmental impacts are not only for campus sustainability but also for community sustainability [2] (i.e., bearing social responsibility [1]). One report in the U.S. (multiple-choice survey) showed that 48.84% of students and staff on campus purchase plastic bottles off campus [60].

The motivations behind students' WTU were in line with their reasons to support WRS and included all three gain goals. Answer "I want to drink water from a water bottle refill station" (gain goals) was the main reason (Figure 5). The main reason for not wanting to use a WRS was answer "It's annoying to bring a refillable water bottle around. I feel like I'm going to forget to bring it." To have students bring around a water bottle is a precondition, therefore this barrier could be difficult to overcome. However, we could still alleviate the difficulty by, for example, hanging eye-catching signs on doors such as "Don't forget your refillable water bottle" [26]. A report at University of the Sunshine Coast [60] showed that 60.46% of students and staff admitted that they chose to buy bottled water rather than using a WRS on campus because they forget to carry a refillable bottle with them. However, the other top two reasons for not wanting to support a WRS (i.e., concern about water quality, health impacts, taste, smells) can be overcome through education (or information campaigning) and further improvement of water quality. Saylor et al. [26] have proposed more comprehensive strategies to reduce the barriers of using tap water and to discourage buying bottled water.

4.3. RQ3. The Impacts of Information on Students' WTP, WTU, and the Environment

It has been well researched that information can influence people's preferences about environmental causes. For example, information can influence WTP for wetland protection [61], endangered species conservation [62], and willingness to accept genetically modified food [63]. Güngör-Demirci et al. [25] has revealed the type of information provided plays an important role in influencing how people choose between bottled and tap water. Although its mechanism and effectiveness are still controversial, information about the environment and environmental education seems to be key to influencing pro-environmental attitudes and behavior [4].

We hypothesized that information would influence WTP and WTU because the type of information we provided could appeal to three gain goals (i.e., environmental contributions of WRS, it would be fun to use because of the counter, and taste and health impacts). Our study revealed that both WTP and WTU increased at statistically significant levels after further information about WRS was provided. The students' reasons for WTP and WTU provided some clues as to how information affected their preferences. Their reasons for saying yes to the bid revealed the information seemed to appeal to all three goals ("It seems like it would be fun to use a water bottle refill station." (hedonic), "I want to drink water from a water bottle refill station." (gain), and "I can reduce the environmental impacts and/or because I can contribute to society through practices at a sustainable campus." (normative) (Figure 3). One reason for students saying no to the bid, answer "This is not important to me.", decreased from 52 to 29 (Figure 4). Students seem to become aware of its importance after the information was provided. We did not see the impact of how the information about the common usages of WRS in the U.S. might have influenced their choice. However, it might be hidden in answer "Other" as seen in Figure 3. In most cases, the students' reasons for saying yes or no to use the WRS (Figures 5 and 6) generally supported the same findings with the exception of the increase of answer "I'm concerned about water quality and/or the impact on my health." and a significant decrease in answer "Other" as a reason for not wanting to use the WRS. It is difficult to interpret the increase in answer "I'm concerned about water quality and/or the impact on my health." because that choice only includes positive information about water from WRS. The number of respondents who chose answer "Other" was quite significate compared to the other choices. Therefore, it is possible we missed some important reason for students not wanting to use a WRS. Although there were not many, some students wrote the reason for chose answer "Other" on the back of their surveys. Some students stated that they do not even like drinking water, or, some just prefer to drink tea rather than water.

5. Conclusions

Our study investigated the feasibility and potential contributions of WRSs to campus sustainability. Adopting GFT and the IFEP as theoretical frameworks, we hypothesized the installation of WRSs and dissemination of information about WRSs encourages students' pro-environmental behavior (using less disposable plastic bottles). We designed a questionnaire survey to test our hypotheses.

There were three major findings corresponding with our three research questions. First, our study revealed that amount students were WTP for a WRS was sufficient enough to cover the installation and maintenance costs of a WRS. To our knowledge, there had been no study regarding students' WTP for a WRS. Students' reasons for supporting a WRS were consistent with all three reasons proposed by the IFEP. Students' reasons for opposing a WRS and the predictors for the full model for WTP estimate provided important implications for gaining further support for a WRS. Second, utilizing their WTU, it was estimated that students in College of Policy Science, including CRPS students and all years, could save 45,191 plastic bottles and 10,846 kg of CO_2 emissions every year. While the WTP includes students who would support installing a WRS but not necessarily use it, the WTU tells us how many students would use a WRS and can be used measure its environmental impacts by the number of plastic bottles and CO_2 emissions saved. It was interesting to find that there were students who would be willing to support installing a WRS in WTP but were not willing to do use WRS measured in WTU. Lastly, as we hypothesized, disseminating information about WRSs positively influenced WTP and WTU.

There are several limitations of our study, which should be considered in future research. The main limitation of our study is that we used self-reports from our survey to analyze respondents' attitudes [37]. Empirical studies have revealed that the link between attitudes and environmental behavior is not always clear or contradictory [3,4,64]. In particular, there could have been a significant gap between attitudes and behavior if university students were asked to make radical changes, rather than light changes (called "light green") [65]. In our study, there are two primary gaps we should expect: WTP vs actual donation, and WTU vs actual use of WRS. As discussed in previous sections, WTP tends to be overstated. However, a smaller donation, such as a one-third donation as List and Gallet [59] discussed, may not be a serious issue if the university could pay the upfront costs until future first-year students could repay later. The gap between WTU and actual use of a WRS also may not be significant. While in general pro-environmental behaviors mostly appeal to normative goals and less so for hedonic and gain goals, WRS appeal to hedonic and gain goals as it is fun to use and students would at no cost receive clean and healthy drinking water. As our study revealed, the installation of a WRS corresponds with the strategies proposed in the IFEP. However, relying on self-reports about their attitudes is certainly the biggest limitation of our study and further studies on actual behavior should be looked into. The second limitation of our study is the representativeness of our sample. The estimated aggregated WTP and WTU and its environmental impacts may be biased because our sample did not include the CRPS students or students in upper-grades. We assumed that other students' WTP and WTU would be the same as the first-year students who participated in the survey. However, it is possible for CRPS students, mostly international students, to have different preferences. Upper-grade students could also have different preferences as they spent more time on campus. The third limitation of our study was that it was not entirely comprehensive in that it did not consider all the costs and benefits of a WRS. For example, there is a cost-benefit analysis of implementing a ban on the sale of plastic water bottles and introducing WRSs on campus in the U.S. [66]; the analysis showed that there is loss in revenue from sale of water bottles, while the environmental benefits measured in monetary value were limited. Therefore, when proposing the installation of a WRS, such possible positive and negative aspects should be carefully considered.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/10/9/3074/s1, SI1: Questionnaire, SI2: Summary statistics, SI3: Summary tables.

Author Contributions: Conceptualization, T.U.; Methodology, T.U.; Software, T.U.; Formal Analysis, T.U.; Data Curation, T.U. and A.Y.; Writing-Original Draft Preparation, T.U. and A.Y.; Writing-Review & Editing, A.Y.; Visualization, T.U.; Supervision, T.U.; Project Administration, T.U.; Funding Acquisition, T.U.

Funding: This research was funded by Ritsumeikan University.

Acknowledgments: We thank to College of Policy Science at Ritsumeikan University for providing us with an opportunity to conduct an in-class survey.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Amaral, L.P.; Martins, N.; Gouveia, J.B. Quest for a sustainable university: A review. *Int. J. Sustain. High. Educ.* **2015**, *16*, 155–172. [CrossRef]
2. Velazquez, L.; Munguia, N.; Platt, A.; Taddei, J. Sustainable university: What can be the matter? *J. Clean. Prod.* **2006**, *14*, 810–819. [CrossRef]
3. Zsóka, Á.; Szerényi, Z.M.; Széchy, A.; Kocsis, T. Greening due to environmental education? Environmental knowledge, attitudes, consumer behavior and everyday pro-environmental activities of Hungarian high school and university students. *J. Clean. Prod.* **2013**, *48*, 126–138. [CrossRef]
4. Vicente-Molina, M.A.; Fernández-Sáinz, A.; Izagirre-Olaizola, J. Environmental knowledge and other variables affecting pro-environmental behaviour: Comparison of university students from emerging and advanced countries. *J. Clean. Prod.* **2013**, *61*, 130–138. [CrossRef]
5. Emanuel, R.; Adams, J.N. College students' perceptions of campus sustainability. *Int. J. Sustain. High. Educ.* **2011**, *12*, 79–92. [CrossRef]
6. Ten Brink, P.; Schweitzer, J.-P.; Watkins, E.; De Smet, M.; Leslie, H.; Galgani, F. Circular economy measures to keep plastics and their value in the economy, avoid waste and reduce marine litter. *Econ. Discuss. Pap.* **2018**, *3*, 1–15. Available online: http://www.economics-ejournal.org/economics/discussionpapers/2018-3/file (accessed on 28 August 2018).
7. Zettler, E.R.; Mincer, T.J.; Amaral-Zettler, L.A. Life in the "Plastisphere": Microbial Communities on Plastic Marine Debris. *Environ. Sci. Technol.* **2013**, *47*, 7137–7146. [CrossRef] [PubMed]
8. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and fate of all plastics ever made. *Sci. Adv.* **2017**, *3*. [CrossRef] [PubMed]
9. Jambeck, J.R.; Geyer, R.; Wilcox, C.; Siegler, T.R.; Perryman, M.; Andrady, A.; Narayan, R.; Law, K.L. Plastic waste inputs from land into the ocean. *Science* **2015**, *347*, 768–771. [CrossRef] [PubMed]
10. Eriksen, M.; Lebreton, L.C.M.; Carson, H.S.; Thiel, M.; Moore, C.J.; Borerro, J.C.; Galgani, F.; Ryan, P.G.; Reisser, J. Plastic pollution in the world's oceans: More than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PLoS ONE* **2014**, *9*, e111913. [CrossRef] [PubMed]
11. do Sul, J.A.I.; Costa, M.F. The present and future of microplastic pollution in the marine environment. *Environ. Pollut.* **2014**, *185*, 352–364. [CrossRef] [PubMed]
12. Lebreton, L.; Slat, B.; Ferrari, F.; Sainte-Rose, B.; Aitken, J.; Marthouse, R.; Hajbane, S.; Cunsolo, S.; Schwarz, A.; Levivier, A. Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. *Sci. Rep.* **2018**, *8*, 4666. [CrossRef] [PubMed]
13. UNEP. *Valuing Plastics: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry*; UNEP: Nairobi, Kenya, 2014.
14. Vethaak, A.D.; Leslie, H.A. Plastic debris is a human health issue. *Environ. Sci. Technol.* **2016**, *50*, 6825–6826. [CrossRef] [PubMed]
15. Roth, B. Campus Water Stations Save 400,000 Plastic Bottles | Duke Today. *Duke Today*, 2015. Available online: https://today.duke.edu/2015/10/hydrationstations(accessed on 28 August 2018).
16. Zalkow, D.; Lieb, E. *Report of the PSU Sustainable Drinking Water Task Force*; Portland State University: Portland, OR, USA, 2012.

17. Moganadas, S.R.; Corral-Verdugo, V.; Ramanathan, S. Toward systemic campus sustainability: Gauging dimensions of sustainable development via a motivational and perception-based approach. *Environ. Dev. Sustain.* **2013**, *15*, 1443–1464. [CrossRef]
18. Vasquez, M.; Carter, J.; Valko, P. *Bottled Water Ban: Update 2015*; Washington University in St. Louis: St. Louis, MO, USA, 2015.
19. Thompson, R.C.; Moore, C.J.; vom Saal, F.S.; Swan, S.H. Plastics, the environment and human health: Current consensus and future trends. *Philos. Trans. R Soc. Lond. B Biol. Sci.* **2009**, *364*, 2153–2166. [CrossRef] [PubMed]
20. Cornell University Drinking Water. Available online: https://www.sustainablecampus.cornell.edu/initiatives/drinking-water (accessed on 7 July 2018).
21. Michigan State University Graduate Class Uncovers Key Campus Drinking Water Preferences. Available online: https://sustainability.msu.edu/get-involved/faculty-resources/get-involved-faculty-water-study.html (accessed on 7 July 2018).
22. The University of Arizona. *Reduce and Reuse: One UA Water Bottle Refill STATION at a Time*; The University of Arizona: Tucson, AZ, USA, 2016.
23. King, A.; Bjerregaard, Z.; Booth, M.; Clugston, S.; Dittmore, M.; Fossett, S.; Pilkington, D.; Sawatzki, P.; Trentelman, C.K. Behaviors, Motivations, Beliefs, and Attitudes Related to Bottled Water Usage at Weber State University. *J. Utah Acad. Sci. Arts Lett.* **2014**, 191–211. Available online: https://www.researchgate.net/publication/282735738_Behaviors_Motivations_Beliefs_and_Attitudes_Related_to_Bottled_Water_Usage_at_Weber_State_University (accessed on 28 August 2018).
24. Curtis, I.A. Valuing ecosystem goods and services: A new approach using a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to the attributes. *Ecol. Econ.* **2004**, *50*, 163–194. [CrossRef]
25. Güngör-Demirci, G.; Lee, J.; Mirzaei, M.; Younos, T. How do people make a decision on bottled or tap water? Preference elicitation with nonparametric bootstrap simulations. *Water Environ. J.* **2016**, *30*, 243–252. [CrossRef]
26. Saylor, A.; Prokopy, L.S.; Amberg, S. What's wrong with the tap? Examining perceptions of tap water and bottled water at Purdue University. *Environ. Manag.* **2011**, *48*, 588–601. [CrossRef] [PubMed]
27. The Ritsumeikan Trust Environmental Action Guideline. Available online: http://www.ritsumei.ac.jp/rs/eco/guideline/ (accessed on 24 July 2018).
28. Nielsen, K.S. From prediction to process: A self-regulation account of environmental behavior change. *J. Environ. Psychol.* **2017**, *51*, 189–198. [CrossRef]
29. Steg, L.; Bolderdijk, J.W.; Keizer, K.; Perlaviciute, G. An Integrated Framework for Encouraging Pro-environmental Behaviour: The role of values, situational factors and goals. *J. Environ. Psychol.* **2014**, *38*, 104–115. [CrossRef]
30. Ajzen, I. The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.* **1991**, *50*, 179–211. [CrossRef]
31. De Leeuw, A.; Valois, P.; Ajzen, I.; Schmidt, P. Using the theory of planned behavior to identify key beliefs underlying pro-environmental behavior in high-school students: Implications for educational interventions. *J. Environ. Psychol.* **2015**, *42*, 128–138. [CrossRef]
32. Qian, N. Bottled Water or Tap Water? A Comparative Study of Drinking Water Choices on University Campuses. *Water* **2018**, *10*, 59. [CrossRef]
33. Hiratsuka, J.; Perlaviciute, G.; Steg, L. Testing VBN theory in Japan: Relationships between values, beliefs, norms, and acceptability and expected effects of a car pricing policy. *Transp. Res. Part F Traffic Psychol. Behav.* **2018**, *53*, 74–83. [CrossRef]
34. Lindenberg, S.; Steg, L. Normative, gain and hedonic goal frames guiding environmental behavior. *J. Soc. Issues* **2007**, *63*, 117–137. [CrossRef]
35. Ruepert, A.M.; Keizer, K.; Steg, L. The relationship between Corporate Environmental Responsibility, employees' biospheric values and pro-environmental behaviour at work. *J. Environ. Psychol.* **2017**, *54*, 65–78. [CrossRef]
36. Rezvani, Z.; Jansson, J.; Bengtsson, M. Consumer motivations for sustainable consumption: The interaction of gain, normative and hedonic motivations on electric vehicle adoption. *Bus. Strategy Environ.* **2018**, 1–12. [CrossRef]

37. Steg, L.; Vlek, C. Encouraging pro-environmental behaviour: An integrative review and research agenda. *J. Environ. Psychol.* **2009**, *29*, 309–317. [CrossRef]
38. Freeman, A.M., III; Herriges, J.A.; Kling, C.L. *The Measurement of Environmental and Resource Values: Theory and Methods*; Routledge: Oxon, UK, 2014; ISBN 1317703936.
39. Boyle, K.J. Contingent valuation in ractice. In *A Primer on Nonmarket Valuation*; Champ, P.A., Boyle, K.J., Brown, T.C., Eds.; Springer: Dordrecht, The Netherlands, 2017; pp. 81–131.
40. Mitchell, R.C.; Carson, R.T. *Using Surveys to Value Public Goods: The Contingent Valuation Method*; Resources for the Future: Washington, DC, USA, 1989; ISBN 0915707322.
41. Boyle, K.J.; MacDonald, H.F.; Cheng, H.; McCollum, D.W. Bid design and yea saying in single-bounded, dichotomous-choice questions. *Land Econ.* **1998**, *74*, 49–64. [CrossRef]
42. Scarpa, R.; Bateman, I. Efficiency gains afforded by improved bid design versus follow-up valuation questions in discrete-choice CV studies. *Land Econ.* **2000**, *76*, 299–311. [CrossRef]
43. Sakurai, R.; Uehara, T. Contingent Valuation Study regarding Placing Campus Patrol for Reducing Smoking at a University: Applying Inferred Valuation Approach. *Int. J. Ecol. Econ. Stat.* **2017**, *38*, 124–140.
44. Seroa da Motta, R.; Ortiz, R.A. Costs and Perceptions Conditioning Willingness to Accept Payments for Ecosystem Services in a Brazilian Case. *Ecol. Econ.* **2018**, *147*, 333–342. [CrossRef]
45. Subroy, V.; Rogers, A.A.; Kragt, M.E. To Bait or Not to Bait: A Discrete Choice Experiment on Public Preferences for Native Wildlife and Conservation Management in Western Australia. *Ecol. Econ.* **2018**, *147*, 114–122. [CrossRef]
46. Department of Facilities Planning and Administration, Minister's Secretariat. *Guidelines for Planning National University Campuses*; Department of Facilities Planning and Administration: Tokyo, Japan, 2013.
47. The Council for PET Bottle Recycling. *Annual Report for PET Bottle Recycling 2017*; The Council for PET Bottle Recycling: Tokyo, Japan, 2017.
48. Louviere, J.J.; Flynn, T.N.; Marley, A.A.J. *Best-Worst Scaling: Theory, Methods and Applications*; Cambridge University Press: Cambridge, UK, 2015; ISBN 1107043158.
49. Aizaki, H.; Nakatani, T.; Sato, K. *Stated Preference Methods Using R*; Chapman & Hall/CRC The R Series; CRC Press: Boca Raton, FL, USA, 2015; ISBN 9781439890479.
50. The R Foundation R. Available online: https://www.r-project.org/ (accessed on 6 August 2018).
51. StataCorp LP STATA. Available online: http://www.stata.com (accessed on 6 August 2018).
52. Cronbach, L.J. Coefficient alpha and the internal structure of tests. *Psychometrika* **1951**, *16*, 297–334. [CrossRef]
53. Field, A.; Miles, J.; Field, Z. *Discovering Statistics Using R*; SAGE Publications: London, UK, 2012; ISBN 9781446289136.
54. Chudwick, E.; Salvemini, M.; Welker, A. *Implementing Water Refill Stations across Campus to Promote Reusable Water Bottle Use*; Villanova University: Pennsylvania, PA, USA, 2013.
55. Pearce, D.; Atkinson, G.; Mourato, S. *Cost-Benefit Analysis and the Environment: Recent Developments*; OECD: Paris, France, 2006; ISBN 9264010041.
56. Hanemann, W.M. Welfare Evaluations in Contingent Valuation Experiments with Discrete Responses. *Am. J. Agric. Econ.* **1984**, *66*, 332–341. [CrossRef]
57. The Pennsylvania State University Water Bottle Refill Stations. Available online: http://sustainability.psu.edu/waterbottles (accessed on 24 July 2018).
58. Bohm, P. Estimating demand for public goods: An experiment. *Eur. Econ. Rev.* **1972**, *3*, 111–130. [CrossRef]
59. List, J.A.; Gallet, C.A. What experimental protocol influence disparities between actual and hypothetical stated values? *Environ. Resour. Econ.* **2001**, *20*, 241–254. [CrossRef]
60. University of the Sunset Coast. *Reuse Refill and Reduce: The Eco-Logical Way to Drink Water*; University of the Sunshine Coast: Queensland, Australia, 2014.
61. Bergstrom, J.C.; Stoll, J.R. The impact of information on environmental commodity valuation decisions. *Am. J. Agric. Econ.* **1990**, *72*, 614–621. [CrossRef]
62. Tkac, J. The Effects of Information on Willingness-to-Pay Values of Endangered Species. *Am. J. Agric. Econ.* **1998**, *80*, 1214–1220. [CrossRef]
63. Lusk, J.L.; House, L.O.; Valli, C.; Jaeger, S.R.; Moore, M.; Morrow, J.L.; Traill, W.B. Effect of information about benefits of biotechnology on consumer acceptance of genetically modified food: Evidence from experimental auctions in the United States, England, and France. *Eur. Rev. Agric. Econ.* **2004**, *31*, 179–204. [CrossRef]

64. Scott, D.; Willits, F.K. Environmental attitudes and behavior: A Pennsylvania survey. *Environ. Behav.* **1994**, *26*, 239–260. [CrossRef]
65. Kagawa, F. Dissonance in students' perceptions of sustainable development and sustainability: Implications for curriculum change. *Int. J. Sustain. High. Educ.* **2007**, *8*, 317–338. [CrossRef]
66. Curtis-Murphy, M.; Sessions, C. Ban the Bottle: Implementing a Ban on the Sale of Plastic Water Bottles. *Evans Law Sch. Rev.* **2014**, *4*, 44–58.

sustainability

MDPI

Article

Delta Project: Towards a Sustainable Campus

Héctor Hugo [1,*], Felipe Espinoza [1], Ivetheyamel Morales [1], Elías Ortiz [2], Saúl Pérez [3] and Galo Salcedo [4]

1 School of Architecture and Urbanism, University of Guayaquil, Cdla. Universitaria "Salvador Allende", Guayaquil 090510, Ecuador; felipe.espinozao@ug.edu.ec (F.E.); ivetheyamel.moralesv@ug.edu.ec (I.M.)

2 School of Administrative Sciences, University of Guayaquil, Cdla. Universitaria "Salvador Allende", Guayaquil 090510, Ecuador; elias.ortizmor@ug.edu.ec

3 Department of University Works, University of Guayaquil, Cdla. Universitaria "Salvador Allende", Guayaquil 090510, Ecuador; saullgcurve@gmail.com

4 School of Sciences for Development, University of Guayaquil, Cdla. Universitaria "Salvador Allende", Guayaquil 090510, Ecuador; galo.salcedor@ug.edu.ec

* Correspondence: hector.hugou@ug.edu.ec; Tel.: +593-988912004

Received: 23 June 2018; Accepted: 16 September 2018; Published: 15 October 2018

Abstract: The University of Guayaquil, which shares the same name as the city where it is located, faces the challenge of its image transformation for the 21st century. It was deemed necessary to identify details about the urban evolution of the city over time, in relation to the changes produced by the project's site and its direct area of influence. The goal is to integrate the main university campus within a framework which guarantees sustainability and allows innovation in the living lab. To achieve this, the action research method was applied, focused on the community participation and the logic framework. The proposal, the management model, and the integrated working groups were organized with internal users such as professors, students, and university authorities, and external actors such as residents, local business communities, Guayaquil city council, and its local mayor and governor. As result of the diagnosis, six different analysis dimensions were established which correspond to the new urban agenda for the future campus: compactness, inclusiveness, resilience, sustainability, safety, and participation. As a proposal, the urban design integrates the analysis of the dimensions whose financial support and execution are given by the municipality authorities that integrates the campus with its network of community police headquarters.

Keywords: sustainability; university living lab; management model

1. Introduction

Urbanization and its areas belong to a set of worldwide, multiscale phenomena that are profoundly altering the relationship between society and the environment, affecting green areas, sustainability, and resilience in complex ways at alarming rates. In recent decades, sustainability, resilience, and transformation have become key concepts aimed to answer an array of looming challenges posed by urbanization and environmental change [1].

Guayaquil University (See Figure 1), is located in the city of Guayaquil in the Republic of Ecuador, is the country's biggest and oldest University. It is located in the north of the city in the Tarqui parish inside Salvador Allende citadel, Malecon del Salado waterfront, and Delta and Kennedy Avenue.

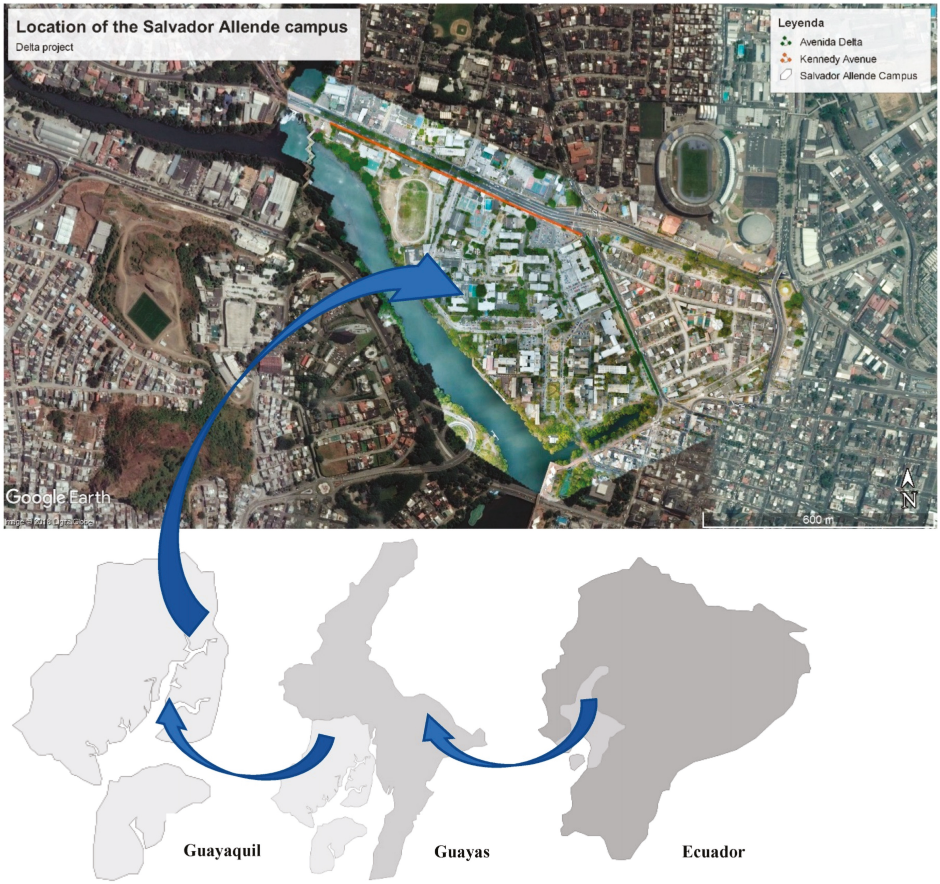
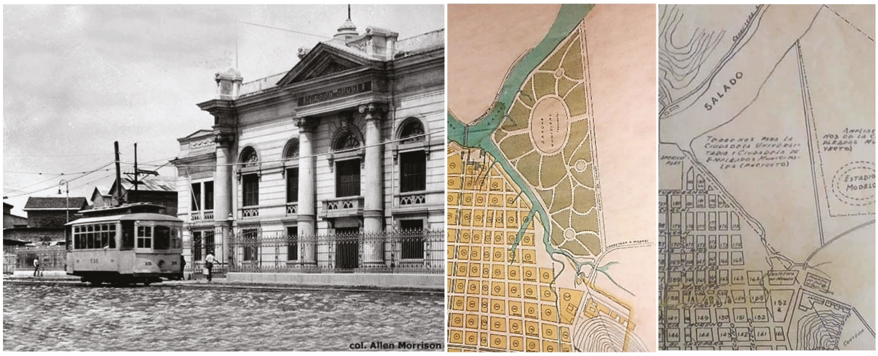


Figure 1. Location of the Salvador Allende campus.

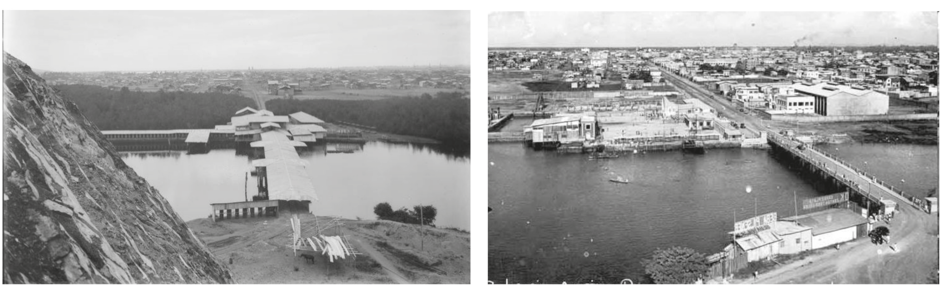
This university had passed through a foundational process that began in 1843, driven by the aspiration of the residents to receive professional training in their hometown. After several attempts to establish the university, the educative entity was finally defined in 1897. It was the first university in Ecuador to welcome a new reform, initiated in 1918 at the National University of Córdoba (Argentina), that first promoted undergraduate students, cogovernment, and the freedom of professorship. At the end of the 19th century, it occupied an empty lot placed on Pedro Carbo Street (See Figure 2a), but it moved to its current principal campus between 1949 and 1954 (See Figure 2b).

During its history, many characters of great transcendence in the political field and other areas have been part of the university student body, as well as its teachers and governing body. Throughout its existence, and as result of a misunderstood autonomy and the background of political instability in the country, urban limitations were established; enclosures were built, causing a serious fragmentation to the public university space and a detriment of the university community. An urban integration proposal between Salvador Allende citadel and the rest of the city through the Delta Project, which consists of a pedestrian circuit incorporating the public and natural spaces, recalls the pattern of integration of the natural ecologic corridor which existed in Guayaquil in the 18th century, but which gradually disappeared during the 19th century (See Figure 3a,b).



(**a**) (**b**)

Figure 2. Chronological data collection of Guayaquil [2]. (**a**) First university house of Guayaquil University. Built during the period of Doctor Julian Coronel's directorship. The workmanship was charged to the architect Rocco Queirolo and was concluded in 1906. The property was declared to be under Cultural National Patrimony on 26 February 1988; (**b**) The land was originally projected as a Municipal Park in 1944. On the right, in 1946, it can be seen how the land use was changed for the university citadel and municipality employees.



(**a**) (**b**)

Figure 3. Chronological data collection of Guayaquil [2]. (**a**) View towards the downtown: old baths of the estuary between 1862 and 1876, divided into two sections, the left one for women and the right one for men; (**b**) View towards the downtown in 1935: Cinco de Junio Bridge and the American Park Spa are highlighted.

The first phase of the project widens the sidewalk that borders the university campus, turning it into a continuous corridor with green urban infrastructure connecting it with its adjacent spaces, a series of sidewalks, and waterfront parks (Malecón del Salado waterfront park of Guayaquil University, Guayarte Project, and the waterfront park of Catholic University Santiago de Guayaquil). Historically, they have been kept disconnected (See Figure 4). In this way, the current perception of scattered university buildings will shift to one of a unique and broad "integrated campus", which is sustainable, resilient, inclusive, safe, and participatory in consonance with the urban area of the city that shelters it.

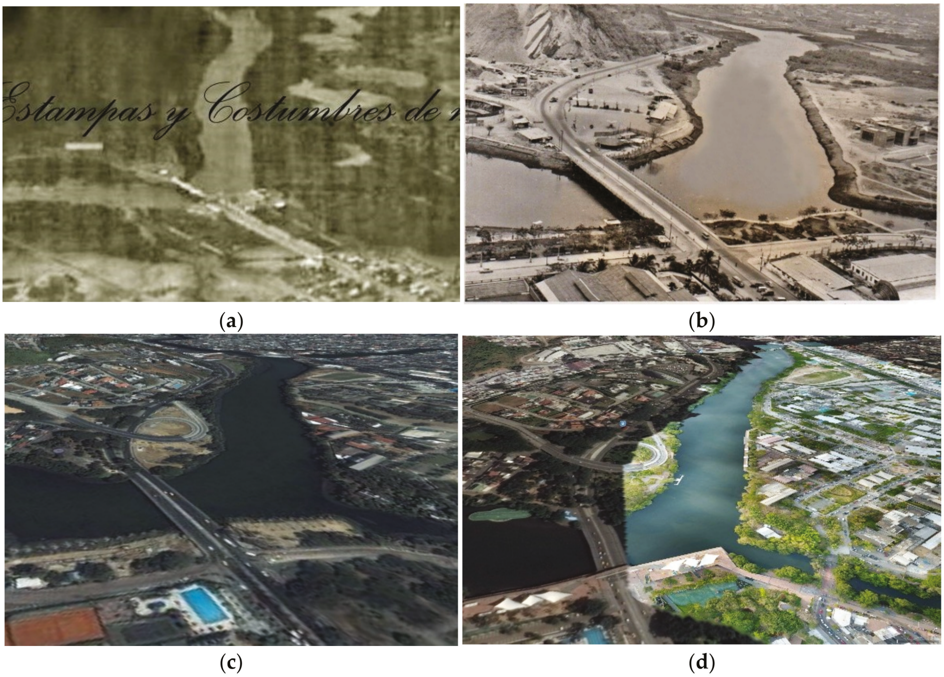


Figure 4. Chronological data collection of Guayaquil [2]. (**a**) Campus Salvador Allende, 1922; (**b**) Campus Salvador Allende, 1958; (**c**) Campus Salvador Allende, 1979; (**d**) Authors' elaboration of the current situation of the Campus Salvador Allende, 2018.

According to the National Institute of Statistics and Census report (INEC), until 2012, Ecuador had an average of 4.69 m^2 of green area per inhabitant; the recommended minimum is 9 m^2 per inhabitant, up to an ideal of 15 m^2 of green area per inhabitant. The city of Guayaquil is part of the 95% of Ecuadorian municipalities with a shortfall in green areas. The INEC, in its May 2012 report of the VII population census and VI of housing, points out that Guayaquil has 1.12 m^2 of green area per inhabitant, far below the level recommended by the World Health Organization.

Green infrastructure is a unique combination of economic, social, and environmental goals and benefits that requires an adaptable framework for planning, implementation, and evaluation [3] (See Table 1).

Table 1. Green infrastructure types vary widely based on system goals and motivation [3].

Green Infrastructure Types and Goals					
Infiltration	**Transportation**	**Natural Systems**	**Stormwater Reuse**	**Buildings**	**Other**
Permeable pavements	Street bumpouts	Increased tree canopy	Cisterns	Green roofs	Nonstructural measures (policy)
Infiltration planters/planter boxes	Permeable pavements	Constructed wetlands	Rainwater harvesting	Blue roofs	Solar panels
Bioretention areas	Traffic calming Bioretention	Restoration of wetlands		Cisterns	
Bioswales		River estuary			
Vegetated detention strips		Planting in abandoned lots			

Most cities recognize that operations and maintenance are important steps in the accomplishing of their green infrastructure goals. Twenty-four cities have put in place a green infrastructure plan; nineteen of them included specific measures for maintenance. These measures include: providing resources for private landowners to maintain their green infrastructure, creating maintenance teams, and forging agreements with local businesses and homeowners to keep green infrastructure. Additionally, several cities require municipal agencies to inspect these green infrastructure projects on private land [3].

The Salvador Allende campus of the university has parks and gardens where a great variety of flora (fruit and timber trees, bushes, climbing plants, and palm and ornamental trees) are conserved and maintained; these make the campus more attractive, although it does not have an integral plan or management model of green areas that allows efficient planning and management for its maintenance and conservation (See Table 2).

As a consequence of the segmentation of the public space and an evident nonplanned intervention of the natural area and urban landscape limitations (See Figure 5), the idea emerged from the forums and interinstitutional liaison required to present the project to the Town Hall for financial support and execution.

(**a**) (**b**)

Figure 5. Current situation. Copyright the authors. (**a**) The metal fence can be observed in the central parterre; (**b**) Destruction of the trees to place a metallic post with a traffic light at the entry to the University of Guayaquil is observable in the background.

A city system's resilience in this sense is determined by its ability to persist and adapt to a new environment; a city's resilience reflects its ability to remain within given ecological thresholds, either in the existing environment or in the new environment. Here, changes in resilience reflect the evolution of a city system [4].

Table 2. Green areas inventory of the Salvador Allende campus, University of Guayaquil.

Faculty/Dependency	#	Total (m^2) Green Areas	Timber Trees	Fruit Trees	Ornamental Plants	Palm Trees	Medicinal Plants	Grass (m^2)	Cane Plants
Architecture	22	4392	32	53	505	30	5	650	0
Administration & Management Sciences	10	0	8	30	232	6	1	0	0
Economic Sciences	13	1340	29	19	532	23	10	467	0
Mathematics	4	504	0	18	214	0	0	235	0
Main Administration	8	700	0	6	157	25	23	565	0
Main Administration Front Park	2	505	14	7	457	19	0	20	0
Medicine Auditorium	6	796	5	11	92	2	0	0	0
Medicine—Obstetrics	7	324	0	10	114	2	0	15	0
Medicine	24	3880	14	84	865	26	1	406	0
Odontology	12	805	7	8	52	15	0	0	0
Psychology	6	2561	8	30	473	11	1	80	0
Law	15	1254	10	14	581	23	4	221	0
Philosophy	16	700	18	5	254	107	5	0	0
Professor's Association	4	348	5	6	294	13	0	275	0
Agricultural Sciences	10	557	12	16	207	32	0	0	50
Chemical Engineering	20	2025	38	69	418	26	0	670	0
Chemical Sciences	12	1608	10	26	614	72	1	1298	0
University Works	4	405	2	5	90	0	0	140	0
Fixed Assets and Maintenance	4	272	4	23	64	2	4	200	0
Physical Education	12	8873	15	41	266	5	2	6602	0
Student Welfare	9	240	3	11	278	2	8	27	0
Rufilli Lab	7	1045	1	25	164	0	2	0	0
Central Small Square	10	570	14	0	41	19	0	500	0
Park and Roundabout	3	2233	20	7	2068	32	35	1359	0
Ecological Park	1	1038	12	23	100	26	0	0	1200
Ecological Student Park	1	1510	36	0	29	12	0	0	0
Associations	6	1183	19	38	27	2	0	0	0
TOTAL	248	39,667	336	585	9188	532	102	13,729	1250

The Delta Project was formulated as an applied research project and approved by the University Council in 2017. It is integrated by research professors and students that belong to different academic faculties, whose main objective is to carry out the urban architectonic study of a sustainable campus for the University of Guayaquil; a living lab integrated with the public space, to be developed in two phases (See Figure 6).

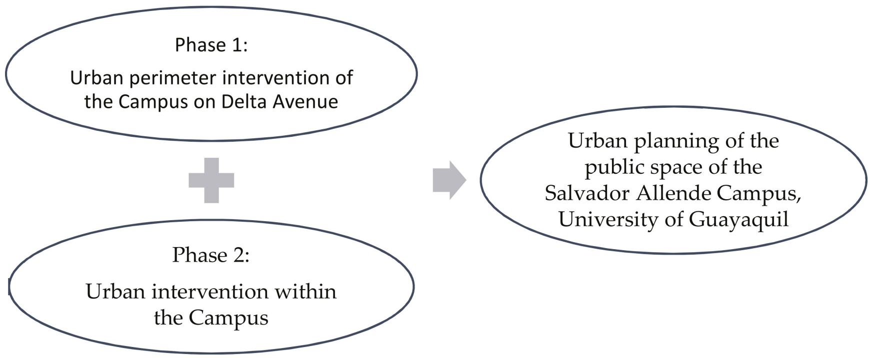


Figure 6. The first stage of the project is presented in this paper. See Appendix Figure A9.

2. Materials and Methods

The issues of sustainable resource management have been addressed in several international forums, from the report on growth limits developed by the Rome Clubto the update of the same report in 2012 [5], which in general terms, address the optimal management of resources in an environment of finite resources of the planet, considering the correct administration and use of technology as part of the way that could help humanity to survive in it.

2.1. General Sustainability Guide

2.1.1. Sustainable Development (SD) in University Education

Higher education is fundamentally key to a sustainable future; it has the necessary tools to develop new ideas and an active society that participates in experimentation for sustainable living. Universities have a moral obligation to work towards sustainable societies, focused on environmental degradation, threats to society, production, and sustainable consumption for them and for future generations. Leaders have the opportunity and responsibility to prepare professionals focused on interdisciplinary collaboration and cooperation, with high values of conscience, knowledge, skills, and values, that help to transform their places of work, society, and the place where they live, becoming responsible global citizens. Higher Education Institutions (HEIs) [6] must work as a fully integrated community (See Figure 7) that models social and biological sustainability in itself and in its interdependence with local, regional, and global communities, where students learn from everything that surrounds them.

University communitive initiatives to promote SD, such as statements, letters, associations, conferences, and so forth, could provide guidelines on how to integrate sustainability into the university system. Collaboration with other universities, making SD an integral part of the institutional framework, life experiences on campus, and “educating educators” are key elements that must be systematically integrated into HEIs to provide learning and educational value, as well as a race of the participants in the transition to the SD, thus guaranteeing the SD as the “gold thread” throughout the university system [5].

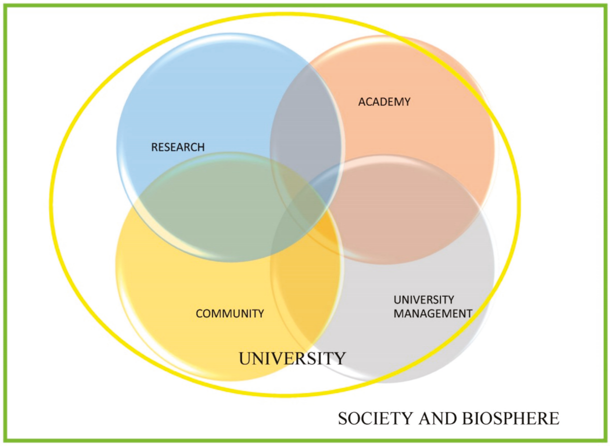


Figure 7. Higher education modeling sustainability as a fully integrated system [6].

2.1.2. How Can Universities Achieve Sustainable Development?

According to some authors [7], the sustainable universities should have the following characteristics: a bidirectional, interactive, and student-centered learning process, with a strong emphasis on critical thinking skills; a high degree of importance in conducting interdisciplinary and scientific research; social orientation of problem solving in education and research, where students are able to deal with the real problems and uncertainties associated with the future; creation of networks that can take advantage of the varied experience throughout the campus to share resources efficiently and meaningfully; and leadership vision responsibilities and rewards that promote the change necessary for the long-term transformation of the university by responding to the changing needs of society.

The strategies of seven universities around the world were compared [7] to identify the key aspects of its transformation towards sustainability, the ideal characteristics of the sustainable university, and the promoters and barriers in the transformation (See Table 3).

Three interactive dimensions (framework, level, and actors) were distinguished in this process of change. The framework dimension (F) is related to intensive interactive changes in culture, institutional structure, and technology (the means to meet the needs). The level dimension (L) describes the change that is required. Finally, the dimension of actors (A) refers to people involved in the transformation process. The lack of an incentive structure to promote changes at the individual level is mentioned as the main barrier to overcome, and the presence of "connectors" with society, the existence of agencies and coordination projects, and the availability of funds are presented as keys to the progress of sustainability. A common feature is the declaration of transdisciplinary and interdisciplinary strategic objectives (See Figure 8).

As a strategic objective, as well as establishing and supporting networks of experience within universities, the establishment of connections with society is presented as a growing trend.

Table 3. Internal and external barriers and promoters in the universities for the change towards sustainability.

Barriers	**Internal**	Academic freedom: Individual decisions about the best way to achieve research and education objectives; it is difficult for an administrator to propose changes and achieve consensus among groups of teachers at any level.
		Incentive structure: Lack of recognition and compensation to teachers and staff involved in the transformation of the university.
		Conservative administration. Lack of desire to change.
	External	Pressure of the society: Lack of demand on the part of society, of the desired characteristics of graduates, and research for their development.
Promoters	**Internal**	Champions: They are the innovators or defenders of sustainability, who can be important agents for change. By failing to provide them with institutional support to fuel continuous work, universities run the risk of losing their most valuable supporters.
		Visionary Leadership: Leaders with appropriate assignments and responsibilities, who promote cooperation and collaborative efforts instead of interunit competition.
		Connectors: These are the networks or groups of interdisciplinary research people that come through the university to include a critical mass of actors on the campus, who can interact between departments or with society in general.
		Size: The complexity of the organization (more than 10,000–12,000 students) can reduce the possibility of rapid transformation.
		Sustainability Coordination Unit: Its creation is important to keep the process of change alive and distribute responsibility.
	External	Pressure from similar institutions: Pressure from peer institutions or top-level universities can serve as examples to promote change.
		Sources of financing and availability of employment: External financing through corporations or government agencies willing to pay for sustainability-oriented research, and employers that require graduates with sustainability strengths.

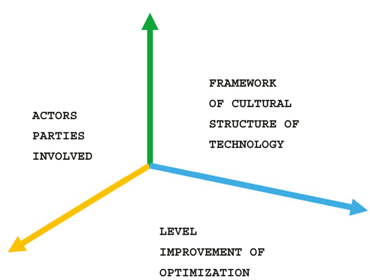


Figure 8. Framework, level, and actors (FLA) approach: three dimensions of change interaction to achieve sustainable development [8]. This figure shows the important interaction among the actors or participants involved, the framework structure of the living lab, and the optimization of the project.

Interconnecting sustainable development as a concept, within and between different disciplines and schools, adapted to its specific nature, could help universities move towards a more balanced, synergistic, transdisciplinary, and holistic academic system, thus helping graduates contribute in better ways to the development of more sustainable societies [9].

The School of Architecture has not been left out of the evolution towards a dependence on nonrenewable energy resources; it has had a limited evolution due to not only the restrictive framework of the survival of the traditional city, but also the technical elements that sustained it. The set of elements that connects architecture to the territory, and especially with the city, have hindered its articulation in the new productive system [10]. The material which the visible city is formed with has endowed this transformation with inertia, but at the same time, as it has been continuously stressed to adapt. The new city, the new buildings, the new forms of production of materials, the changes in the organization, and the end of the production process of architecture are decisively altering the traditional technical systems to start a different architectural technology with an absolute redefinition of its conception. At present, traditional materials such as stone, wood, or earth, which were examples of closed material cycles, have altered their production systems. The traditional technical system [10] in architectural technology is affected mainly by the transfer of production materials to the industry, aligning with the work and fighting against the physical location of the architecture that limits this transfer.

Sustainability in the environmental building design is a key factor to address in response to the limited availability of resources, ecological deterioration, and climate alteration. In order to respond to the demands of the current market, a pedagogical methodology must be developed to overcome existing educational and professional barriers and act as a communication platform that facilitates the transfer of knowledge between the construction science related to sustainability and creative design in the architectural curriculum [11].

Students should be encouraged to emphasize reflection and critical self-assessment and should be able to balance the integrity of design and environmental responsibility, considering environmental design as a basic, essential, and integrated requirement of the design exercise itself. A good theoretical base is essential in teaching; however, it has to be supported by empirical knowledge and evidence-based learning to understand how different principles can be applied in practice and by analytical tools and simulation techniques that can facilitate the testing and comparison of different hypotheses and make performance forecasts from the early stages of design. Skills such as concrete experience, reflexive observation, abstract conceptualization, and active experimentation could help the development of critical thinking, which together with interdisciplinary paradigms, are the basis of education for sustainability [11].

The achievement of a "sustainable" curriculum truly oriented to design is still difficult to achieve, due to the nature of the theme itself. Most of the time, design study projects are complex and time-consuming such that students are not able to do it in a semester while reaching a level of mature and deep analysis that includes awareness and integral implementation in the design of technical and environmental mandates [12].

Cognitive discrepancies are not only related to students, but also to their study tutors, who rarely master the technical aspects of environmental design, while academic staff teaching technical subjects are often not associated with the study team design [13]. Architects generally employ a solution-centered teaching strategy rather than a problem-centered design development approach, where students focus more on achieving a desired result than on a critical investigation of the complexity of the problem they face, favoring the acquisition of information and hindering the development of critical thinking.

2.2. Living Labs as a New Method of Scientific Production in Higher Education

According to [13], the proposed framework is used to lead the development of a database in order to collect key data about a Living Lab. It is designed to be a supportive instrument over the whole lifetime of a Living Lab—from initial planning stages, through monitoring phases, through to its final closure and reflection on the lessons learned. The seven categories for data collection cover all of the different stages of the Living Lab and allow monitoring on whether outcomes and impacts set out in the initial stages have been met, and how partnerships, participants, cocreators, and organizational structures have evolved. The seven data collection categories are (See Figure 9):

- General: a summary of the Living Lab location, key contacts, status, timelines, and budget
- Scope: the problem being addressed, historical details to the problem, the context, and the key sustainability 'theme' being addressed
- Participants and cocreators: different stakeholders and ways in which they are engaged
- Organization: leading organizations, partnerships, potential risks

- Outcomes: anticipated (and actual) sustainability outcomes in relation to the problem being addressed, as well as anticipated (and actual) educational, research, and engagement outcomes
- Impact: wider impacts outside of the Living Lab boundaries
- Reflection and review: evaluation of the living labs' products and processes

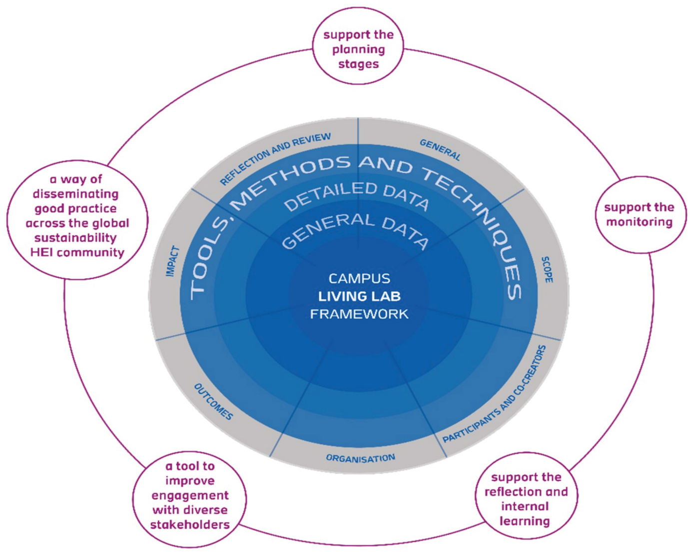


Figure 9. Campus as a Living Lab Framework design with its seven categories, five potential values, and three levels of detailing and application [13].

In this sense, we must promote horizontal systems to create a collective based on collaboration, so that we must learn to collaborate, to promote the collective versus the individual, and to achieve shared success and distributed merit. The development of transdisciplinary strategies is not only of undoubted interest for contemporaneity, but also brings very interesting values to collective work. When an excessively homogeneous community is created, it produces flat ideas. The article "Teaching Sustainability through Living Labs in Architecture: The case study of the UPC-LOW3 prototype solar house" bases its content on the LOW3 Living Lab, defining it as a project in execution, which aims to innovate in education for sustainability through user-centered research and collaborative learning within the university campus. The author indicates that specific disciplinary knowledge should be taught by adopting a holistic, transdisciplinary approach to the environmental, economic, and social aspects of sustainability. The analysis aims to leave its results and lessons learned as examples for similar activities in other universities [14].

Dynamic networks could generate laboratories that investigate in a distributed and connected way, going beyond the communication that technology facilitates. Not only should it be an organism with different coordinated devices, but also we must reinvent the way we investigate, overcoming separation and individualized concentration in order to seek unique and innovative results that exceed the sum of the parts [15].

Collaboration is more beneficial and difficult to handle, since the speed at which it occurs makes it impossible to control all the necessary dimensions. However, it is not enough to manage teams that sectionalize information too much, but rather, it is necessary that the components work together as a single body, so that the results benefit from an authentically collaborative process.

According to [16], "Innovative Models of Administration and Public Management: Towards the Emergency of New Paradigms", three basic characteristics of managerial processes are proposed.

> *(....). Innovation in Public Administration is characterized by the publication of numerous works in recent years (Maddock, 2009, Mulgan, 2009, Potts, 2009, Kohli and Mulgan, 2010, Moore and Hartley, 2010). This is reflected in the concept of innovation in the public sector as well as the plurality of existing "dispersed" approaches and the "polysemic and elusive" character (Ramírez-Alujas, 2012: 7), although it also notes a lack of empirical studies, such as consequence of "disciplinary myopia" (Windrum, 2008). Other authors add elements related to the practices carried out by the organizations in order to improve the product or service they provide, characterized by the ideas of Change (radical change and impact), New (something new for the organization in question; it is not only a "good idea") (Audit Commission, 2007), but also refers to the introduction of a social dimension, adding that innovation in the public sector and new ideas should be able to improve the operability of institutions and raise the standard of living of a society. Transformational and direct innovation is linked to changes in the structures of public management adding new ideas and practice of transparency, accountability, citizen participation and optimal use of resources. Its empirical observation is a complex task given the intermingled link between the values and their connection with the options of a political nature (external order), as well as the existing power relations within the public administration (internal order). In the external order, it manifests itself its relationship with the citizens in the process of co-creation, co-formulation, co-evaluation of public policies being the central element that distinguishes innovation from change in the impact of its process with the predominant paradigm of the organization. Nowadays, a large part of these new ways of public management involves the idea of Open Government. (Ramírez-Alujas, 2010, 2011)*

Innovation in administrative processes (incremental innovation) usually originates in practice; the implementation of the so-called "Best Practices 12" is not a new phenomenon, but has its origin in two assumptions: on one hand, due to the innovative processes introduced in business management and in organizations (models of motivation, personal development, achievement of objectives), and on the other, as a consequence of citizens' demands and the consequent crisis of legitimacy of the public administration that manifested itself in and since the decade of the 1990s. Public administration suffered a constant deterioration, in which the need to introduce good practices became an urgent task. The proposals derived from the good practice have served to apply management proposals in an experimental way, as has happened in various municipalities and higher education institutions in Latin America.

Not all "new" approaches and trends are truly new or innovative. Some are merely applied practice to solve very specific problems in the short term, derived from broader frameworks for reformulating public management, such as adaptations of the New Public Management. These are specific actions adapted to information and communication technologies (ICTs) and can support the initiation of new models and forms of public and social management, whose possibilities and doubts have already been exposed [17]. Mention must be made of the planning and management actions and strategies aimed at the economic sphere, which, although they are not new models for reformulating public administration in its entirety in a broad sense, are more practical, or less successful and innovative, and that have been applied for some time successfully and that are limited to different levels or specific fields of general and local public administration, such as the case of the Common Assistancy Framework (cAF).

2.3. Operational Sustainability Guide

The complexity of the problems meant fac an enormous effort to redesign the existing processes, discarding old methodologies and creating new systems that will make it possible to attain the new objectives demanded for a contemporary environment. Therefore, new structures must be built so the research can continue and be able to bring the future closer.

In this sense, the standardized and enclosed structures should be substituted for others which are more flexible and open, favoring the evolution of individual work towards a collective effort. The Delta

Project does not respond to classic research standards since the campus is a model of cumulative results; there is no evidence of integral planning processes.

The inductive research process began by defining the pedestrian road system, with the collection of traffic accident records along the Kennedy and Delta Avenues. It was necessary to know the streets' geometric characteristics and the volume of the vehicular and pedestrian traffic that circulated along Delta Avenue. Pedestrian traffic is distributed on both sidewalks, one of them adjacent to the university and the other adjacent to the Bolivariana district, where most of the complementary services which are required by the students, such as restaurants or stores selling stationary, are located. It is therefore necessary to raise the activities' plan and citadel's soil usage in order to integrate it to the zone's functional dynamics.

On the other sides of the campus, the Guayaquil University is surrounded by a system of spaces and natural estuaries with low or null accessibility. Even though the municipality has control over the riversides, the works that have been implemented were not integrated into the students' lives. Pedestrian systems are not connected to the natural systems, which requires research to identify the species that configure these natural and green areas of the campus and to know the projection for pedestrian movement within a growth plan.

As indicated at the beginning, the physical planning process has been incremental and slow, requiring an upgrade infrastructure which has taken more than 60 years. It was indispensable to know or to evidence the planning system and the actions within the campus by various departments in areas such as road tracing, soil usage, grouping of buildings parking lots, development areas, existent necessities, future necessities, and so forth.

Another guiding aspect in the research process was the city's planning system, adopted by the local Town Hall. The municipal projects in the study zones were studied, especially the impacts of Project Delta connected to the rest of the city, emphasizing the urban infrastructure such as roads, parks, and others that are close to the university.

In order to address these tasks, it was necessary to connect these four big systems in a dynamic way, requiring the adoption of a methodology that allows building fast and integrated knowledge, (See Figure 10). Using research and formulating a collaborative investigation system in a living-lab environment, thus granting a higher student participation as well as teacher participation. This lab was shaped by students of different semesters, from the beginning to the tenth, whilst the professoriate was comprised of the project director, general adviser, and some other experts.

The main concept was focused on the users (the students) emphasizing the thought of design where the students learn and exchange their knowledge, developing new ways of working. They develop new designs and new work mechanics, and they work together for the development of their territory.

The interest which the project generated in the university allowed this methodology to be adopted, with the selection of students with some expertise, as well as the configuration of expert groups of teaching staff or external professionals that would communicate with each other during the dynamic interdisciplinary forums.

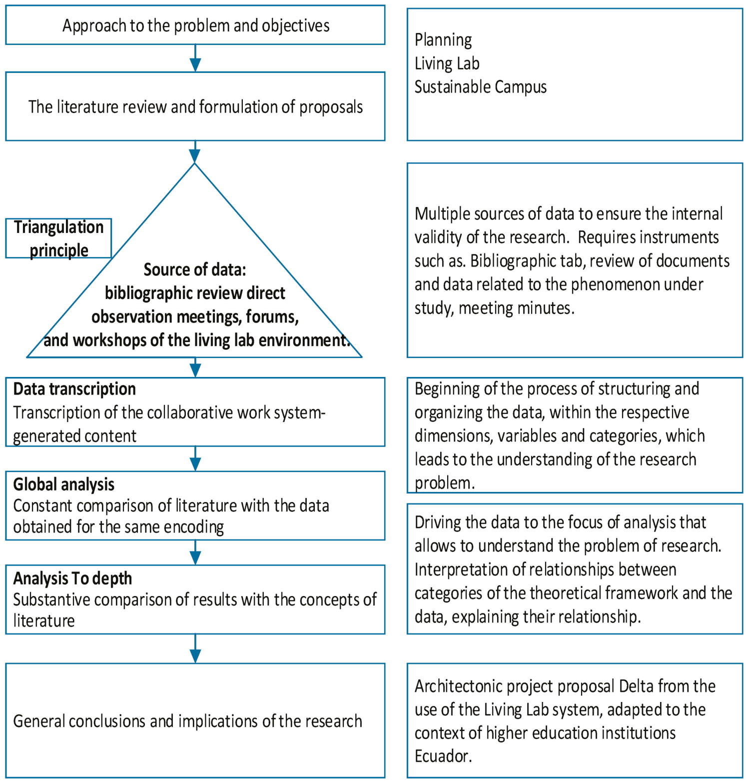


Figure 10. Applied methodological structure.

2.4. The Collaborative Research System in a Living-Lab Environment Needs to Be Developed in Four Well-Defined Process Protocols

The Standardized Physical Planning Protocols, The knowledge integration protocols, The Professionalization and the management of the project (See Figure 11).

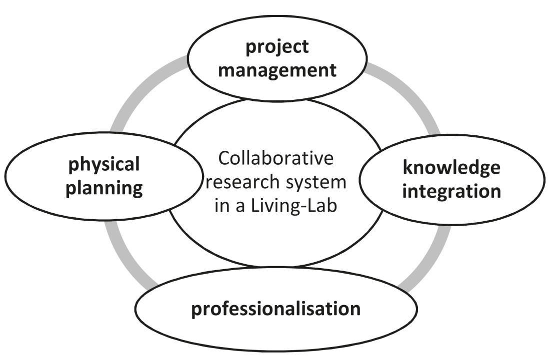


Figure 11. The collaborative research system in a living lab. Copyright the authors.

2.4.1. The Standardized Physical Planning Protocols

The Standardized Physical Planning Protocols must be addressed to a big number of simultaneous processes, unlike the approach of Delta Project, that emphasizes an inductive system, beginning from the flow system (or, rather, the pedestrian-road system), then a system of natural spaces and estuary, so they could finally mix together with the physical planning system and the city's planning system.

The most general tools for this kind of project were the Urban Regulations of Public Spaces (which were developed by Jan Gehl), the Municipal Urban Regulations, the Ordinance of the Land Use Plan, the Traffic Rules, the Territorial Arrangement Planning's annexes 5a and 5b, and the AASHTO standards; there were even reviewed pedestrian simulators such as SIMULEX, PED go, Legion, Exodos, Gridflow, but in the end, it was concluded to use the VISSIM Simulator, polls, ecosystem nomenclature, especially the link between social and natural sciences of Eugene P. Odum, and the EPA's Handbook of Urban Runoff Pollution Prevention and Control Planning.

In the physical planning area, the project had several technological tools that allowed researchers to obtain first-hand onsite information using a drone.

2.4.2. The Knowledge Integration Protocols

The knowledge integration protocols allowed students in the lab to integrate different types of knowledge simultaneously in one place, while the professors' forums enabled the students to integrate this knowledge while they worked, differentiating from the academic speech which usually proposes a pyramidal classes' system in the different classrooms.

The protocols used required a mapping of possible knowledge blocks that the project should support, from the blocks of STEM (Science, Technology, Engineering, and Mathematics) to the blocks of Humanities. This combination would allow a quick resolution of problems.

The first protocol defines the modality of student participation. The time used in the project was considered as part of the preprofessional work experience which all undergraduate students must complete. The student tasks were divided into different activities, which allowed the project to be divided into parts, from the identification of the problem, the establishment of solution paradigms, the formulation of concepts to solve the problem, and the updating of knowledge about the project, to the implementation of a work method for the coupling of the software that the project would use; then, each student was responsible for a development block, which was then submitted to the integral refining committee. The participation of the students in the project was from different faculties.

2.4.3. Professionalization

Professionalization is another essential protocol which enables a person to become sufficiently academically knowledgeable, practical, skillful, and competent to be able to perform a paid job (self-employed or employed by others). These protocols will allow the design standards demanded by the professors to be comparable to those required in the professional market. The professors who joined the laboratory had extensive professional training, having carried out many professional projects, and this would guarantee that the students would integrate high design standards in the proposal, which would make a big difference with teachers who did not have professional experience.

The most relevant protocols were created by professionals in specialized forums and interdisciplinary forums. Counting with the participation of students, the key forums considered software, public space, ecology, green areas, transit and transport, art, budget, infrastructure, networks, and facilities. The practical action of the professionals in the design allowed the students to find answers with high standards. The forums could be done inside or outside the university; for instance, the Faculties of Mathematics and Agricultural Sciences, botanical garden, the planning department of the university, the paving stone companies, and so forth have created and participated actively in different forums, getting great results.

2.4.4. The Management of the Project

The management of the project is the last protocol proposed, that began with discussions in the different governmental levels of the university: the students, the community, the press, the city, the region, and the country. Through that management, principal agents were identified that would achieve the required level of feasibility for the project's execution; the project was never considered as an academic project from the outset, as its main objective was to be deemed sufficiently viable to be implemented.

The main proposed tools included:

- The consultation and student community agreements process with local residents and businesses
- Press briefings
- Presentation of the project to several authorities, especially to those of the Town Hall
- Presentation of the project in international conferences and workshops to coordinate collaboration with universities and other partners.

3. Results

3.1. Physical Planning

The project was concluded with the urban proposal, the road proposal, the pedestrian proposal, the proposal of the taxonomy of the trees, the proposal of lights, and the proposal of higher steps and level (See Table 4). These proposals were based on multipurpose surveys, vehicular and pedestrian traffic counts, national and international technical standards, INEN, American Association of State Highway and Transportation Officials, streets and roads manual of the public works ministry, and the Ecuadorian construction code.

Table 4. Contribution of public space for the Delta Project at Salvador Allende campus, University of Guayaquil.

Items	Faculty of Architecture	Faculties of Administration and Medicine	Faculty of Dentistry	Total	Measure
Existing trees	26	22	8	56	Units
Proposed trees	27	61	12	100	Units
Green area proposal	1460.10 m^2	990.87 m^2	294.15 m^2	2735.12 m^2	m^2
Paving stones	4565.73 m^2	4137.37 m^2	1152 m^2	9855.10 m^2	m^2
Individual Park Furniture	-	9 × (module of 4 U)	-	36	Units
Multiple Park Furniture	-	8 × (module of 12 U)	-	96	Units
Bus furniture	-	6	-	6	Units
Bikeway	-	-	-	555.23 m	meters
Current enclosing meters	180.24 m	272.57 m	134.50 m	587.31 m	meters
Reform of the closing meters with the Delta Project	88.48 m	149.47 m	20.39 m	258.84 m	meters

A sample of the relevant section of the results is provided in Appendix Figure A1.

3.2. Integration of Knowledge

The preprofessional work experience played an important role; it is a binary indicator because it allows to measure the degree of effectiveness and participation of the students in the project; besides, it measures the collective participation in the resolution of the problems. Last reports or records of group and individual tasks were used to conclude that they were fulfilled to a level of 80%.

Participants reached 80% of the learning goal, mainly through simultaneous knowledge (learning from different fields simultaneously). This analysis considers the teaching staff who formed part of the study, working in the multiple fields previously identified.

A sample of the relevant section of the results is provided in Appendix Figure A2.

3.3. Professionalisation

Twenty-five forums were organized with the participation of 32 professionals from 7 specialized fields: technological, agricultural, ecological, urban, road, transit and transport, and pedestrian. Twelve interdisciplinary forums were completed. A sample of the relevant section of the results is provided in Appendix Figure A3.

3.4. Project Management

In this field, the participation with different parties was carried out through meetings with local business community and students, calls, and surveys, which were evidenced by photos and videos (see Appendix Figure A4).

The project "Think & Eat Green @ School" is an example of participative management, involving schools and educational institutions, and by extension, the food system of the City of Vancouver. The project creates an experience of collaborative learning amongst stakeholders, university students and scholars, and health and educational institutions to a network of community-based and community-supported nonprofit organizations working on food and environment, linking farms to schools, city dwellers with farmers, and school cooks with successful green chefs, as well as creating links between restauranteurs, restaurant designers, gardeners, school authorities, teachers, and students [18].

The meetings with the university authorities were evidenced by photos and videos, concluding in the approval of the project by the University Council, having held meetings with the rector of the University of Guayaquil and deanships of each faculty regarding financial management, management of university works, direction of art and culture, and direction of green areas (see Appendix Figure A5).

The meetings with the Guayas Government were evidenced by photos and videos; the Project and the security problems were presented and exposed to its community, along with the need to create a sustainable campus, concluding in the assignment of a mobile community police unit. Now, the police elements are transported by bicycle inside the university campus (see Appendix Figure A6).

The meetings with the municipality were also evidenced by photos and videos, concluding in the allocation of the budget for the work, having held meetings with the local mayor, "Malecón 2000" and "Siglo 21" foundations, and the municipal transit authority (ATM) (see Appendix Figure A7).

The socialization and validation of the project in international events was undertaken to collect feedback and establish joint collaborations. In this case, the Delta Project was taken into account for the main conference in the workstation modality, also including the presentation of the poster on a technological park for the University of Guayaquil. A sample of the relevant section of the results is provided in Appendix Figure A8.

The press plays an important role, starting from an independent management and leading to the dissemination of the project in a massive way to public opinion that allows the empowerment and commitment of the actors involved in the project: the ones that finance, the ones that propose, the ones that study, and the users to whom the project was destined.

The press agents are the external equivalents who share and contrast information by taking statements from those involved, thus being an important link in interinstitutional coordination. At the same time, the population becomes aware of the results and benefits provided by the project.

4. Discussion

The broad objective of this project is to show that the School of Architecture aims to implement a strategy for the management of public space based on the use of four dynamic systems that interact, evaluate, minimize, project, and make feasible urban solutions. These are the physical planning system, knowledge integration system, professionalization system, and management system.

From the field of urban design, its response has been achieved to overcome the difficulties posed by traditional urban design standards, in terms of the revitalization of deteriorated urban areas, which has overcome the way of addressing the issues of urban revitalization. In the past, this was always oriented to physical planning from an academic dimension, and away from the profession. It can be said that public space was elusive for university pedestrians; existing pedestrian areas represented environmental risks, which were evaluated and minimized by implementing the strategy [19].

In general, the strategy consists of using new tools, which allows them to be joined, since in the academic field, they are used in an isolated and dispersed way. The only way to connect them was to use a new tool called the "living lab", a live operations laboratory, configured for students in different stages of their degree program who require professional internships. The production achieved in record time would not have been possible without the design of this living lab concept developed for the Delta Project.

The physical planning system, in general terms, is responsible for the design as well as the financial and regulatory variables. The system of integration of knowledge was responsible for adopting a scheme of knowledge clusters in situ; a different environment to that promulgated by the routine academic meshes. The variables of this system were shaped by the variables of fields of knowledge that were taught through of instructions of blocks of tasks. The professionalization system had an important impact, so much that it was introduced to the professionals and specialists in the evaluation processes, to minimize, project, and make the solutions viable. The variables of this system were established to implement the highest standards used in the professional market, suggested by the specialists, and configured by the variables of fields of knowledge with standards of design, programming, and costs. Many of the specialists who were part of the project were not necessarily academics. The management system was required for the implementation of actions for the resolution of the components, the processes, the availability of resources, the coordination of activities, the project to materialize, and the configuration of the variables of the student component, professionals, managers of the university, executives of the municipality, the community, the press, etc.

Other ways can be indicated to show that the systems adopted have allowed the necessary results to be achieved and the four levels of the process to be integrated: the associations of the affected or public actors for the public sector for public spaces, the integration of knowledge for professional practices, and the design strategies that are applied in the Delta Project area. All measures include aspects of the development and implementation of a sustainable approach.

The general approach that was adopted began with the integration of four key priority evaluations:

- Establishment of priorities based on the current risks presented by the current pedestrian conditions of university students;
- The natural conditions of public spaces;
- The direct participation of the actors;
- The design of the solution: to comply with all requirements in a sustainable manner, including environmental effects, space and available facilities, local perceptions, and other problems.

Subsequently, the second phase of the project will be implemented within the campus. Given that the river estuary (the Estero Salado) borders the campus to the west, a susceptibility analysis must be carried out.

Assessment of landslide susceptibility in urban areas could provide an important contribution to minimizing damage from natural disasters; it could be also used for planning and multiple hazard assessment [20].

It is therefore advisable, within the studies to be carried out in the field, to collect data on geological antecedents of the region. In the knowledge of the types of soil in the study sector, a thorough investigation should be organized to verify the incidence of this phenomenon in the premises where it will be built.

The karst collapse susceptibility map provides valuable information for land use planning at a regional scale, leading to the recognition and determination of the safe and nonsafe areas for urban development [21].

The susceptibility map can be used by the local authorities to guide the adoption of policies and strategies aiming towards sustainable urban development [21].

This work can contribute enormously to five essential aspects:

a. Increasing the public spaces of the city [22], since the local municipality lacks a policy of public spaces [23], a situation that is not foreseen in the land use plans, nor is it a component articulated in the Organic Code of Land Use.
b. Public spaces such as pedestrian areas are not registered in the Organic Law of Land Transport, Traffic and Road Safety, and are only in a very indirect way mentioned in articles 4 and 9 of the said law, when there must be a whole chapter dedicated to pedestrian areas and their relationship with the road system [24].
c. According to the results achieved, presenting a new way of teaching architecture and urban design [25], which goes beyond the traditional and routine education of the current mesh of subjects [26], so it would be advisable to reform the academic regime regulations established by the Council of Higher Education (CES), allowing an education of blocks of subjects in a design laboratory, which must be discussed in the Organic Law of Higher Education [27].
d. From the environmental point of view, urban ecological corridors are not part of the classification system for a healthy environment; regulations such as Book IX of the Unified Text of Secondary Legislation and other standards are only devoted to quality control of the resource, so that urban ecological corridors can be part of the environmental planning system, as elements that improve the life and health of people in cities, and these planning systems can be included in the environmental planning of cities [28].
e. It is necessary to emphasize that the sustainable development of the work was only reached when two institutions were intercepted to optimize the resources in the same project that benefits both the municipality and University of Guayaquil.

5. Conclusions

Creating sustainable and resilient urban relationships with the environment will entail a reimagining of those relationships. That reimagining will require that we improve our understanding of the dynamics of urban relationships with the environment across space and time. However, just as importantly, we must better understand our relationships with each other within and across domains of time, space, economics, and human organization [1].

The ecological corridor of the Delta Project is an urban rehabilitation project and its adequacy has depended on three key factors: the academic approach, the professional approach, and with a significant amount of urban management. The proposal consisted in proposing a corridor of public space for pedestrians, imitating the ecological corridors of the adjoining estuary with a participative environmental management. Agreements and alliances have been relevant to sustain conservation actions. The meetings and negotiations with public and private organizations, local communities, students, residents, merchants, research centers, botanical centers, universities, schools, owners, and authorities allowed to generate consensus about the importance of imitating the ecological corridor of the estuary around all the university campus, forming a circuit in the manner of a linear park endowed with walkways, native wooded areas, squares, bus stations, cycle tracks, and so forth.

The interactive work with the municipality, with the students, and with the local business community deepened the relationship needed to develop a pedestrian corridor that the university does not have, guaranteeing the right to public spaces and serving for the distribution of the student population to the internal and external areas of the university, in addition to ensuring the protection of biodiversity. For this purpose, surveys and technical and administrative consultations were carried out.

The limitations of the participatory approach were given as follows: Sporadic student attendance due to the time limit: this could be solved by the implementation of 240 h of preprofessional practice that must be approved to obtain the title of "professional"; Limited attendance of the investigators attached to the project, due to the absence of common schedules and the time allocated for investigation, which could not be greater than 7 h per week in the case of the director and a maximum of 5 h for the other members of the Project. To resolve the situation, the administrative and financial management was requested to support a full-time researcher for the purpose of coordinating progress with the students and consolidating the information that is produced daily in the space destined as a workshop. As a project whose financing and construction is provided by the Municipality of Guayaquil, it was presented for the second time to the higher academic college for approval of the initiation of the interinstitutional agreement with the municipality. Although there were no criteria against the project, a political variable appeared in this space, resulting in the voting support of the members who support the current administration and the abstention of the other members. As for the coordination with the Municipality of Guayaquil, since it was presented, the project was approved and supported by the mayor, who ordered the coordination of the project with the foundations 21st century, Malecón 2000, the Director of Public Works, and the Municipal Transit Authority. On the way, there were found different viewpoints with the Municipal Transit Authority; in our case, the project focused on pedestrians, and sustainable mobility had to be supported by a mobility policy that favors the vehicle. In this case, the mayor and the foundations were supported by the benefits of the project to generate a sustainable development model, and it was finally approved.

The results obtained pointed to several fronts:

On the academic front, a different approach to the teaching of urbanism is proposed through the living labs, which integrate knowledge in a group of subjects and not in isolation, as stated in the current curricular meshes of Ecuador; in the same way, this form of teaching and learning could well be applied to research and degree projects; such a recommendation affects the reform of the Academic Regime Regulation (RRA) proposed by the Council of Higher Education of Ecuador. This would imply a substantial reform in the form and substance of the presentation of the curricular meshes. Clusters of comprehensive knowledge fields were included, from the use of basic software to draw and make vehicle traffic counts, to the use of specialized software for the simulation of pedestrian and vehicular traffic, as well as climate simulators, the use of drones for planning and photography in real time, plant taxonomy, reforestation practices, artistic guidelines, budgets, soil studies, site visits, population needs, and so forth.

From the urbanistic point of view, it is concluded that the municipality could adopt a second front. In a systematic way, the criteria of an integral pedestrian corridor for the development of public spaces in the form of an ordinance will be considered strategic within the units of the land use plan, given that it corresponds to existing facilities at the time of execution—in particular, the characterization of the nearby natural resources—and therefore, is considered as a component of the landscape of the project area. These resources should be promoted and connected throughout the city, thus revitalizing and integrating the urban landscape, rather than simply paving cobblestones without providing space for the flourishing of life, as has occurred in the past [29].

Such policy takes advantage of the existing infrastructure invested in the city, raising the quality of public spaces and the surplus value of urban sectors. The characteristics of the urban perspective incorporate with great relevance the zones of reforestation and conservation; these enabled researchers to determine that the passive techniques of recovery are the best alternatives for the increase of the biomass and the conservation of the environments influenced by mangroves or mountain ranges. The area of study is very close to the mangrove and mountain areas that were exploited as quarries in the past. The zoning merits a special emphasis to be placed on the management of soil, planting of native species, erosion control (trenches), and monitoring of plantations. The infrastructure for conservation stands out. Support infrastructure was implemented, such as a network of trails, recreational sectors, overnight accommodation, recreational activities, cycling trails, tourist trails, and educational and research areas, in this environment of mangrove ecological corridors.

From the relationship point of view, the Town Hall must perform the intervention for the recovery of public spaces, a policy that cannot be explicitly seen in municipal policies, nor in land use plans or in the partial plans, to such an extent that the public spaces in the city of Guayaquil are meagre; they do not reach 3000 m^2, and neither the sidewalks nor the parks are included here. In this regard, it should be noted that the Delta Project contributes 22,754.54 m^2, seven times more than that contributed by the local municipality [30].

Finally, this methodology should be incorporated into territorial planning plans and into other planning instruments, especially the management and participation system. The city of Guayaquil requires an administrative mechanism that takes charge of the planning, organization, direction, and control of the area, and that includes political support, interinstitutional and intersectoral coordination, and the participation of owners and the community in the integral corridor projects [31].

Many of the urban interventions, such as Puerto Liza, Estero Mogollón, and Estero Salado, were not conceived for the continuity of the concept of the ecological corridor, which could well serve as forms of education and preservation of natural resources; on the contrary, they covered them with fillers.

The project took eleven months to be developed; 30% of the time was used for the initial phase: that of preparation and forums. The project was developed in a short time using this collaborative system; in this sense, the living lab methodology fulfilled its mission: to achieve academic and professional results with a large input of management.

The vision described in this paper was presented to the International Sustainable Campus Network in Stockholm and the discussions conducted there with experts from different universities and associated fields generated the determination of the University of Guayaquil to establish a model of development and gain accreditation as a living lab, setting an example for other cities in the world with similar aspirations. The full implementation of this project will enhance the experience of many different users who study, work, visit, or reside and work within the area of influence of this urban campus of the largest public university in Ecuador.

Author Contributions: Conceptualization and project administration, H.H.; Methodology and formal analysis, F.E., H.H. and S.P.; Software and visualization, S.P., with the support of students in the living lab; Validation, H.H., F.E., I.M. and G.S.; Investigation, F.E. and H.H.; Resources and funding acquisition, E.O. and H.H.; Writing—original draft preparation, H.H.; Writing—review & editing, I.M. and H.H.; Supervision, H.H.

Funding: This research was funded by the Municipality of Guayaquil (2019 budget) and University of Guayaquil Competitive Research Funding.

Acknowledgments: Administrative support: Ab. Jaime Nebot Saadi, Phd. Gulnara Borja Cevallos, Ing. Wilfrido Matamoros, Ab. Andrés Roche, Dra. Nathalie Marzo, Lcdo. Klever Loor, Arq. Freddy Olmedo, M. Sc Rosy Mendoza. Technical support: Ing. Eduardo Santos Baquerizo, Ing. Stalin Márquez, Ing. Víctor Hugo Verdezoto, Ing. Ramos, Eco. Fabián Vilema, Ing. Victor Párraga, Arq. Brick Reyes, Arq. Aurora Guaranda, Arq. Juan Carlos Torres, Arq. Luis Sagubay, Arq. Santiago Dick, Ing. Malena Marín, Arq. Marcela Blacio, Arq. Pamela Bermeo, Biologist Ph.D. Maritza Cárdenas, Biologist James Pepín Pérez, Biologist Luis Caicho, Graham Stagg, M. Sc Antonieta Morales, Arq. Luis Zuloaga, Arq. Cesar Antonio Knezevich, Ph. D Iván Paredes, Arq. Martha Donoso. Living Lab students: Verónica Rivadeneira, Steven Santistevan, Susana Peña, María Conchita, Paul Tinoco, Vincent Nader, Darwin Alcívar, Gabrielle Espinoza, Victor Moscoso, Gabriel Córdova, José Valdiviezo, and about 40 students of different faculties. Press: Blanca Moncada (Expreso Journal), Antonio Ruiz. Teleamazonas channel, and university press. Community leaders: Ana Herrera, Marcelo Santillán, Manuel Mera, bishop Miguel Matilla.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Figure A1. First stage of the Delta Project and its context area. Proposed situation: Copyright the authors.

Figure A2. Working process. Own elaboration. Students participating in the project; faculty of architecture and urbanism, August 2017.

Figure A3. Working process. Own elaboration. Participation of authorities and technicians of the Municipal Transit Authority (ATM).

(**a**)

(**b**)

Figure A4. Working process. Own elaboration. (**a**) Participation of the leaders of residents of the Bolivarian district in the construction of public space. Faculty of architecture and urbanism, August 2017; (**b**) Participation of students and professors from various faculties, as well as external building experts for the Delta Project.

(**a**)

(**b**)

Figure A5. Working process. Own elaboration. (**a**) Construction and briefing of the Delta Project with the Vice-Rector for Research; (**b**) construction and briefing of the Delta Project with the members of the university council.

(**a**)

(**b**)

Figure A6. Working process. Own elaboration. (**a**) Delivery of urban and architectural studies of the Delta Project by the rector of the University of Guayaquil to the governor of Guayas, Francisco Cevallos. Governorate of Guayas, August 2017; (**b**) April, 2018: Inauguration of the Security Plan in the Salvador Allende Campus.

(**a**)

(**b**)

Figure A7. Working process. Own elaboration. (**a**) Delivery of the urban and architectural studies of the Delta Project by the rector of the University of Guayaquil to the city mayor, Jaime Nebot Saadi; Guayaquil Town Hall, August 2017; (**b**) Definition of commitments and sharing by the project director, the architect Héctor Hugo, to the mayor of the city of Guayaquil and the managers of the municipal foundations.

(**a**)

(**b**)

Figure A8. Working process. Own elaboration. (**a**) Guayaquil University, speaker at workstations; (**b**) participation of the Delta Project at a workshop about living labs, led by Julie Newman, Ph.D. of MIT.

Schedule of activities Phase I ¨Delta Project¨		
Protocols	**Activities**	**DATE**
project management	Identification of the problem. Awareness and preparation of strategies. 4 Forums with students of different levels. 1st socialization and working tables with students from the University of Guayaquil	31 July 2017
	One Interdisciplinary Forum. First socialization of the conceptual proposal of urban solution and tables of work with the authorities of the University of Guayaquil 4 forums with students	31 August 2017
	One Interdisciplinary Forum, lay University Vicente Rocafuerte. 1st socialization of the proposal with neighbors, traders and residents (12 September 2017 to 18 September 2017) 4 Forums with students	30 September 2017
knowledge integration	Assignment of a researcher of university works, full-time in the project.	1 October 2017
	Approval of the project in the upper Academic College of the University of Guayaquil 4 forums with students	27 October 2017
	Programming: Needs program, function analysis, criteria to be used, context analysis	16 November 2017
	Elaboration of the urban plans. 4 Interdisciplinary Forums 3 Forums with students of preprofessional practices	15 December 2017
professionalisation	Elaboration of the architectural plans 4 Interdisciplinary Forums 3 Forums with students of preprofessional practices	23 February 2018
	Trade N. 0056 DEC-ARQ-2018, formal delivery to Ab. Jaime Nebot Saadi, mayor of the City of Guayaquil, studies corresponding to the first phase.	9 February 2018
physical planning	Elaboration of architectural and urbanistic details of the project. 2 Interdisciplinary Forums 1 forum with students of preprofessional practices	31 March 2018
	Resolution RCU-SE-09-069-03-2018, the Honorable University Council decided to approve the initiation of the process for the subscription of interinstitutional agreements to develop the Delta project.	14 March 2018
	Adjustments to the observations given by the municipality of Guayaquil Two forums with students of preprofessional practices	31 May 2018
	Presentation of the project at the 12th World Conference of the International Sustainable Campus network	09 June 2018-15 June 2018
	Completion of the 1st stage of the project. Delivery of the details to the foundation Siglo XXI allocation of funds by the municipality to the project, for its construction in the first semester of 2019	29 June 2018

Stage 1: diagnosis monthly advance July to October (weeks 1–4). Stage 2: proposed weekly advance (November, December, January, February, March, April, May, June; weeks 1–4 each).

Figure A9. Schedule of activities developed in Phase 1 of the Delta Project.

References

1. Romero-Lankao, P.; Gnatz, D.; Wilhelmi, O.; Hayden, M. Urban Sustainability and Resilience: From Theory to Practice. *Sustainability* **2016**, *8*, 1224. [CrossRef]
2. Los planos de Guayaquil: Dos Siglos de Evolución Urbana. Available online: http://biblioteca.culturaypatrimonio.gob.ec/cgi-bin/koha/opac-detail.pl?biblionumber=14153 (accessed on 9 August 2018).
3. Chini, C.; Canning, J.; Schreiber, K.; Peschel, J.; Stillwell, A. The Green Experiment: Cities, Green Stormwater Infrastructure, and Sustainability. *Sustainability* **2017**, *9*, 105. [CrossRef]
4. Zhao, P.; Chapman, R.; Randal, E.; Howden-Chapman, P. Understanding resilient urban futures: A systemic modelling approach. *Sustainability* **2013**, *5*, 3202–3223. [CrossRef]
5. Lozano, R.; Lukman, R.; Lozano, F.J.; Huisingh, D.; Lambrechts, W. Declarations for sustainability in higher education: Becoming better leaders, through addressing the university system. *J. Clean. Prod.* **2013**, *48*, 10–19. [CrossRef]
6. Cortese, A.D. The Critical Role of Higher Education in Creating a Sustainable Future. *Plan. High. Educ.* **2003**, *31*, 15–22.
7. Ferrer-Balas, D.; Adachi, J.; Banas, S.; Davidson, C.I.; Hoshikoshi, A.; Mishra, A.; Motodoa, Y.; Onga, M.; Ostwald, M. An international comparative analysis of sustainability transformation across seven universities. *Int. J. Sustain. High. Educ.* **2008**, *9*, 295–316. [CrossRef]
8. Jansen, L. The challenge of sustainable development. *J. Clean. Prod.* **2003**, *11*, 231–245. [CrossRef]
9. Lozano, R. Diffusion of sustainable development in universities' curricula: An empirical example from Cardiff University. *J. Clean. Prod.* **2010**, *18*, 637–644. [CrossRef]
10. Arquitectura i Sostenibilitat. Available online: www.mendeley.com/research-papers/arquitectura-i-sostenibilitat/ (accessed on 22 September 2018).
11. Altomonte, S. Environmental Education for Sustainable Architecture. *Rev. Eur. Stud.* **2004**, *3*, 12–21. [CrossRef]
12. Koch, A.; Schwennsen, K.; Dutton, T.A.; Smith, D. The Redesign of Studio Culture: A Report of the AIAS Studio Culture Task Force. 2002. Available online: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:The+Redesign+of+Studio+Culture:+A+Report+of+the+AIAS+Studio+Culture+Task+Force#0 (accessed on 22 September 2018).
13. Verhoef, L.A.; Bossert, M.; Newman, J.; Ferraz, F.; Robinson, Z.P.; Agarwala, Y.; Wolff, P., III; Jiranek, P.; Hellinga, C. Towards a learning system for University Campuses as Living Labs for sustainability. In *Universities as Living Labs for Sustainable Development: Supporting the Implementation of the Sustainable Development Goals*; Springer: Stockholm, Sweden, 2018; Volume 2, pp. 1–14. (in press)
14. Masseck, T. Living Labs in Architecture as Innovation Arenas within Higher Education Institutions. *Energy Procedia* **2017**, *115*, 383–389. [CrossRef]
15. La Investigación Colaborativa. Procesos Colectivos de Creatividad. Available online: https://idus.us.es/xmlui/handle//11441/78489 (accessed on 22 September 2018).
16. Pont Vidal, J. Modelos Innovadores de Administración y Gestión Pública: Hacia la Emergencia de Nuevos Paradigmas. Gestión y Análisis de Políticas Públicas, 2016; pp. 6–26. Available online: http://revistasonline.inap.es/index.php?journal=GAPP&page=article&op=view&path[]=10364 (accessed on 22 September 2018).
17. ¿Qué Democracia y qué Administración para la Nueva Época? Internet y la Gestión Pública. Available online: https://dialnet.unirioja.es/servlet/articulo?codigo=3966781 (accessed on 22 September 2018).
18. Rojas, A.; Valley, W.; Mansfield, B.; Orrego, E.; Chapman, G.E.; Harlap, Y. Toward Food System Sustainability through School Food System Change: Think&EatGreen@School and the Making of a Community-University Research Alliance. *Sustainability* **2011**, *3*, 763–788.
19. Gehl, J. *Cities for People*; Island Press: Washington, DC, USA, 2010; Volume 16, p. 269. Available online: http://books.google.pt/books?id=lBNJoNILqQcC (accessed on 22 September 2018).
20. Bathrellos, G.D.; Skilodimou, H.D.; Chousianitis, K.; Youssef, A.M.; Pradhan, B. Suitability estimation for urban development using multi-hazard assessment map. *Sci. Total Environ.* **2017**, *575*, 119–134. [CrossRef] [PubMed]
21. Papadopoulou-Vrynioti, K.; Bathrellos, G.D.; Skilodimou, H.D.; Kaviris, G.; Makropoulos, K. Karst collapse susceptibility mapping considering peak ground acceleration in a rapidly growing urban area. *Eng. Geol.* **2013**, *158*, 77–88. [CrossRef]

22. Armando, A.; Rosero, A. Espacio Público y Legislación. Discursos de Base en la Transformación de Ciudades en Colombia. 2013. Available online: http://hdl.handle.net/2099/14173 (accessed on 22 September 2018).
23. Armando, A.R. *La Transformación del Espacio Público; Entre Téoria Legislación y Practica: Estudio de Caso: La Ciudad de Villamaría*; Universidad Católica de Manizales: Manizales, Colombia, 2007; Available online: http://repositorio.ucm.edu.co:8080/jspui/handle/10839/367 (accessed on 22 June 2018).
24. El derecho al Espacio Público (The Right to Public Space). Available online: http://search.ebscohost.com/login.aspx?direct=true&db=fua&AN=97322675&lang=es&site=ehost-live (accessed on 22 September 2018).
25. Garrett, R.M. Issues in science education: problem solving, creativity and originality. *Int. J. Sci. Educ.* **1987**, *9*, 125–137. [CrossRef]
26. Sosa, M.; Zarco, R.; Postiglioni, A. Modelando aspectos de grupo en entornos colaborativos para proyectos de investigación. *Rev. Inf. Educ. Medios Audiov.* **2006**, *3*, 22–31.
27. Sancén Contreras, F. La universidad del futuro. Red de Revistas Científicas de América Latina, el Caribe, España y Portugal, 2013; p. 17. Available online: http://www.redalyc.org/pdf/340/34030524002.pdf (accessed on 22 September 2018).
28. Del Medio Ambiente Al Espacio Público. Precisiones Conceptuales. From the Environment To Public Space. Available online: http://www.redalyc.org/articulo.oa?id=29916108 (accessed on 22 September 2018).
29. Camargo, F.M. The Right to the City: From Henri Lefebvre to the Analysis about the Contemporary Capitalist City. *Folios* **2016**, *2*. Available online: http://libezproxy.iyte.edu.tr:81/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edsdoj&AN=edsdoj.49a31ac27cb242da97731f3703a1af3e&site=eds-live (accessed on 22 September 2018).
30. Urban Configuration, Habitat and Appropiation of the Space. Available online: https://www.researchgate.net/publication/298486016_Urban_configuration_habitat_and_appropriation_of_the_space (accessed on 22 September 2018).
31. Driscoll Derickson, K. Seeking spatial justice. soja, edward w. *Geogr. Ann. Ser. B Hum. Geogr.* **2012**, *94*, 203–205. [CrossRef]

sustainability

MDPI

Article

Prefiguring Sustainability through Participatory Action Research Experiences for Undergraduates: Reflections and Recommendations for Student Development

Carlie D. Trott [1,*], Andrea E. Weinberg [2] and Laura B. Sample McMeeking [3]

1 Department of Psychology, University of Cincinnati, Cincinnati, OH 45221, USA
2 Mary Lou Fulton Teachers College, Arizona State University, Tempe, AZ 85287, USA; andrea.weinberg@asu.edu
3 STEM Center, Colorado State University, Fort Collins, CO 80523, USA; lbsm@mail.colostate.edu
* Correspondence: carlie.trott@uc.edu; Tel.: +1-440-476-3885

Received: 26 July 2018; Accepted: 15 September 2018; Published: 18 September 2018

Abstract: *PAR-based UREs* are undergraduate research experiences (UREs)—built into university-community partnerships—that apply principles of participatory action research (PAR) towards addressing community-defined challenges. In this paper, we advance PAR-based UREs as an action-oriented framework through which higher education institutions can simultaneously enact and advance the United Nations sustainable development agenda, while cultivating student development. We draw upon interdisciplinary scholarship on sustainable development and PAR, as well as empirical findings from a pilot program, to accomplish dual goals. First, through the lens of six Sustainable Development Goal (SDG) clusters, we explore the synergies between undergraduate PAR engagement and sustainable development, explaining how PAR-based UREs can prefigure and facilitate SDG achievement by promoting cross-sector collaboration and supporting diverse stakeholder engagement through community-driven research and action. Second, within each SDG cluster, we offer complementary reflections and recommendations around the design and implementation of PAR-based UREs towards advancing students' skills and abilities as: (1) Community Collaborators (and Learners); (2) Community-Engaged Researchers; (3) (Interdisciplinary) Scholars; (4) Agents of Change; (5) (Sustainable) Co-Innovators; and (6) Institutional Representatives. Finally, we discuss the critical role of higher education institutions in minimizing structural barriers to PAR-based URE implementation, given their prefigurative and practical potential for both SDG achievement and student development.

Keywords: community partnership; higher education; participatory action research; prefigurative politics; sustainability; undergraduate

1. Introduction

In 2015, the United Nations (UN) General Assembly unanimously adopted a resolution outlining 17 Sustainable Development Goals (SDGs), which together set an ambitious, fifteen-year agenda to mobilize countries around the globe to promote human flourishing, while "protecting the planet" [1,2]. Encompassing social, environmental, and economic dimensions, the SDGs envision a world that is "free from hunger, injustice and absolute poverty", offers "universal education, health and employment", and fosters "inclusive economic growth, based on transparency, dignity and equity" [3] (p. 1)—all within fixed and finite planetary boundaries—by 2030 [4,5]. Given the breadth of the issues addressed by the SDGs, combined with its urgent timeframe, there exists a critical need for concrete, actionable ways to realize the vision of this transformative agenda.

In this manuscript, we emphasize the role of higher education institutions (HEIs) in simultaneously prefiguring sustainability—or modeling its conditions in the present—while facilitating SDG achievement and key forms of student development through community-engaged research practices [6,7]. Not only are HEIs hubs for innovation, creativity, and collaboration towards addressing the world's most pressing challenges, they are embedded within communities whose diverse histories, geographies, and members offer infinite opportunities for partnership, research, and action towards improving the well-being of people and planet [8]. Scholars across disciplines agree that achieving the SDGs will require moving beyond 'business as usual' (i.e., routine) procedures, and they emphasize the transformative potential of strategic partnerships across sectors [9,10]. Indeed, prioritizing partnerships is itself written into the SDGs as the final and only goal dedicated entirely to means of SDG implementation [1]. Energized by this bridge-building momentum, this paper examines the prefigurative and practical dimensions of PAR-based UREs, which are undergraduate research experiences (UREs)—built into university-community partnerships—that apply the principles of participatory action research (PAR) towards addressing community-defined challenges. In particular, we explore PAR-based UREs as a vehicle for SDG implementation through HEIs and offer recommendations for student development based on our own past findings related to the PAR-based URE framework [11].

Participatory action research is a collaborative approach to research, education, and action [12] that brings researchers and participants together to identify, examine, and address problems in community settings [13]. PAR challenges traditional hierarchies between researchers and participants by engaging participants as full collaborators in all aspects of the process—from defining the scope and design of the research to implementing solutions [14,15]. As such, PAR emphasizes democratic engagement, full-cycle collaboration, and social justice [16]. The goal of PAR is to "mobilize everyday people for change" through collaborative research and action [16] (p. 172).

The omnibus term "undergraduate research experiences" refers to varied high-impact models that engage students in authentic research with the goal of enhancing learning. Most UREs also aim to: (1) Assimilate students into science, technology, engineering and mathematics (STEM) cultures; (2) increase and diversify participation in STEM fields; and (3) enhance interdisciplinary knowledge and practice [17]. URE models range from year-long apprenticeships to summer internships and more recently have come to include course-based authentic research [17]. Traditionally, most UREs have been laboratory- or field-based, with a focus primarily on STEM topics; others have included interdisciplinary research that bridges STEM and the social sciences. Although the particulars of URE programs and their impacts may vary, extensive evidence suggests that UREs often serve to strengthen student outcomes such as knowledge and skills acquisition [18,19], communication abilities [20–22], and persistence in STEM [18,23,24]. As such, UREs are an established and highly-regarded mechanism for supporting the development of undergraduate students in STEM fields. However, programmatic UREs remain far less established in interdisciplinary contexts and among community-engaged researchers.

In this paper, we describe the integration of these frameworks (i.e., PAR and UREs) through the concept and practice PAR-based UREs, which apply PAR methods in collaboration with communities, while deliberately and meaningfully involving undergraduate students in authentic research. We argue that PAR-based UREs hold great promise as an action-oriented framework for enacting and advancing the SDG agenda by promoting cross-sector collaboration, developing interdisciplinary scholars and engaged citizens, and supporting diverse stakeholder engagement through community-driven research and action.

In the sections that follow, we explore PAR-based UREs through the lens of prefiguration. Specifically, we describe how PAR-based UREs may advance the role of HEIs in contributing to the SDG agenda through prefigurative research practices. Prefiguration is a term increasingly prevalent in social movements scholarship that refers to imagining and enacting alternative modes of being and interacting in the world that reflect—and, in so doing, bring into being—the desired social transformations of a group [6]. Prefigurative action is guided by the principle of 'means-ends consistency,' which emphasizes that the ultimate goals of a group must fundamentally shape the methods it employs (e.g., peace through nonviolence). Prefiguration further refers to exemplifying change in the 'here and now,' towards gradually building a "new world in the shell of the old" [25] (p. 108). As such, prefigurative research methodologies seek to collaboratively facilitate the design and implementation of viable alternatives to the unjust and unsustainable status quo [6] through ongoing research practices "concerned with the enacting of hope and desire in the present moment, rather than with the establishment of ideal future blueprints" [7] (p. 38). Just as the SDG agenda is aspirational—or future-oriented—yet demands action in the present, so too is the nature of prefiguration in PAR. Through non-hierarchical research relationships and democratic engagement, PAR simultaneously envisions and enacts counter-hegemonic modes of inquiry and community-driven action that blur the boundaries between process and goal [26]. Put simply, prefiguring sustainability through PAR-based UREs means instantiating a sustainable future now.

This is the third and final paper in a series exploring the concept, theory, and practice of PAR-based UREs. The first was an empirical research article, introducing the PAR-based URE approach and exploring its transformative impact on students and communities [11]. The second was a theoretical article reviewing 'typical' PAR and URE approaches, exploring the synergies and opportunities of their integration, and advocating a coordinated approach to accommodate their divergent dimensions [27] (under review). Having laid the groundwork for the present discussion, here we discuss the prefigurative and practical dimensions of PAR-based UREs in the context of the SDG agenda. Additionally, drawing on analyses of a PAR-based URE pilot program (described below), we offer a related set of reflections and recommendations for HEIs around the design and implementation of PAR-based UREs for key student development outcomes. In this, we respond to Newman's call for broader examination and exchange of "applicable lessons learned and models of service learning pedagogy" [28] (p. 18) in the area of student education and engagement in sustainability.

2. Pilot PAR-Based URE Study

The first published manuscript in this series was an empirical study [11] exploring students' experiences (i.e., perceived impacts) of a PAR-based URE pilot program that was developed as a voluntary second-year experience augmenting a traditional STEM lab-based URE. In this section, we briefly describe the pilot program (i.e., design, implementation, impacts) in order to provide adequate context for our subsequent discussion situating PAR-based UREs within the context of the SDG agenda. A more in-depth description and discussion of these aspects can be found in the first published manuscript in this series [11].

2.1. PAR-Based URE Program

The pilot PAR-based URE program took place over a nine-week summer period in 2012 with two historically marginalized, indigenous Southern Louisiana communities. Students were selected based on their prior participation in the lab-based URE associated with this pilot program, as well as an expressed interest in community-based research. During the PAR-based URE, two female, African American undergraduate students—one with a background in Meteorology and the other in Sociology and Anthropology—lived, socialized, and worked in these communities as they collaborated with community members on designing and implementing action-oriented research projects identified by the community as important (e.g., the creation of a land loss awareness mobile phone application).

The two communities were identified through an existing partnership between a community-based social scientist in the region and a climate scientist in the Mountain West U.S., as both communities were experiencing dramatic geomorphologic changes due to industrialization and urbanization that were then (as today) devastating the land-based livelihoods of local indigenous populations [29]. Members of these communities expressed a desire to enhance their own ability to advocate for state and local services by conducting research. The PAR-based URE developed organically around this identified need, as well as existing relationships between the community members and the local social scientist, the social scientist and the climate scientist, and the climate scientist and a qualitative research methodologist. All these partners served as mentors to the two undergraduate students throughout the nine-week PAR-based URE, although each had a unique role as content expert or community liaison, and sometimes both.

With support from their mentors, students spent the first two weeks of the program in the communities: (1) Establishing relationships with key community members (who held traditional ecological knowledge of the region); (2) meeting with local scientists (who held Western science knowledge on the climate change-fueled land loss experienced in the region); and (3) studying PAR methodology. The level of dedication to the program required for, and displayed by, the students during this time cannot be overstated; they spent a great deal of time traveling within the communities, participating in social events (e.g., community members' family dinners), learning about the communities' histories and cultures, and getting to know more about different community members as individuals. During the third week of the program, after students had begun to build relationships and establish trust within each community, research questions and approaches were co-developed by the community members and the students. The remaining weeks of the PAR-based URE were spent collaboratively conducting the planned research.

2.2. Study Methods

To examine the impacts of the PAR-based URE, our data collection and analysis methods closely followed the interpretive phenomenological analysis process, which seeks to explore a phenomenon both ideographically, as well as collectively [30]. We conducted three (i.e., prior to, immediately following, and six months after the experience) in-depth, semi-structured interviews with each of the two students. The specific focus of each interview varied based on its timing, but each explored the perceptions and experiences of the students in relation to their academic, professional, and personal development. General interview questions within these categories were predetermined, but the interview process was kept flexible and open to further follow-up and exploration of previously unidentified avenues of discussion. For example, students were asked, "How have you used what you've learned from the [URE]?" but because each student answered this question differently, follow-up questions and specific interview topics were unique to each interviewee, while remaining tied to the program.

Each author read and reread the interview transcripts, making notes about interesting or significant statements and discourse structure. From these notes, we developed inductive first-order labels and then second-order categories capturing patterns we each observed in the data. After analyzing the interviews individually, all authors met to compare our independent interpretations with the intent of establishing a stable set of emergent themes. We then engaged in an iterative process with the two undergraduate students, during which they reviewed our written interpretations for accuracy and provided clarity. In response, and in conversation with the students, we reconciled areas where our interpretations and the students' perceptions diverged. Once emergent themes were agreed upon, we identified connections between themes as well as convergences and divergences in the participants' experiences. We draw upon these analyses as we describe PAR-based UREs in relation to the UN sustainable development agenda.

3. Sustainable Development Goals and PAR-Based UREs

Given the immense—and some would say contradictory—mission of sustainable development, definitions of the term are inevitably varied and contested [31,32]. However, an often quoted definition of sustainable development has its origins in the Brundtland Report, also known as "Our Common Future", which describes sustainable development as that which "meets the needs of the present generation without compromising the ability of future generations to meet their own needs" [33] (p. 8). The 17 SDGs are therefore a patchwork of interdependent, variously overlapping—and frequently controversial—aims that together offer a future-oriented vision of human and environmental flourishing intended to inform present priorities and paths forward [4,34]. Ultimately, the SDG agenda is meant to mobilize global action towards "building an inclusive, sustainable and resilient future for people and planet" [2].

As written, the SDGs and associated targets provide greater detail in terms of *content* (i.e., the "what" of sustainable development) compared to *methods* of goal attainment (i.e., the "how" of sustainable development) [9]. In response to the need for developing pathways to SDG achievement, "The World in 2050" (TWI2050) [35]—a global research initiative launched by the International Institute for Applied Systems Analysis (IIASA), the Sustainable Development Solutions Network (SDSN), and the Stockholm Resilience Center (SRC)—brought together scientists, policymakers, analysts, and multi-sector organizations to identify means of SDG implementation. To aid in the identification of pathways to transformational change, and recognizing the interlinkages and interdependence across goals, collaborators classified and arranged the SDGs into various thematic groupings [35].

In the below sections, we describe how PAR-based UREs may simultaneously advance the role of HEIs in contributing to SDG achievement and student development. Although at first glance PAR-based UREs may appear to align most objectively with SDG Target 4.7 (i.e., education for sustainable development), this paper describes the broad implications of PAR-based UREs for all 17 SDGs, which are, in turn, buttressed by 169 individual targets. To streamline our discussion, we apply one of the frameworks proposed by TWI2050, which organized the 17 SDGs into six thematic clusters: (1) Basic Human Needs, (2) Universal Values, (3) Earth Preconditions, (4) Sustainable Resource Use, (5) Social and Economic Development, and (6) Governance and Partnerships [35]. We agree with TWI2050 that the SDGs are "universal, holistic and inter-dependent, thereby indivisible" [36]. As such, the six clusters are in no way meant to divide SDGs into competing categories, as progress within one SDG inevitably advances others, within and across clusters. Further, the order of the SDG clusters as presented in this paper does not imply priority or precedence but was determined to be most conducive to introducing PAR-based UREs, their prefigurative potential, and key practical considerations in a logical and meaningful way. Below, these six clusters, along with findings from our previous empirical study [11], frame our discussion of PAR-based UREs in relationship to the SDG agenda. Additionally, within each SDG cluster, we offer complementary reflections and recommendations around the design and implementation of PAR-based UREs relative to important dimensions of undergraduate student development. In particular, we focus on the capacity of PAR-based UREs to advance students' skills and abilities as: (1) Community Collaborators (and Learners); (2) Community-Engaged Researchers; (3) (Interdisciplinary) Scholars; (4) Agents of Change; (5) (Sustainable) Co-Innovators; and (6) Institutional Representatives.

3.1. Basic Human Needs

Robust and productive societies are created and maintained by healthy individuals whose basic biological needs are met. The first cluster, "Basic Human Needs", includes three SDGs [3]. First, *No Poverty* is a commitment to end poverty in "all its forms everywhere" (SDG 1) [1]. The aims and scope of this goal go beyond a singular conceptualization of poverty as a lack of income to broadly include hunger, malnutrition, access to education and basic services, discrimination, and opportunities to participate in decision-making. The closely-related *Zero Hunger* (SDG 2) aims to advance food security, improved nutrition, and sustainable agriculture [1]. The third and final SDG in this cluster, *Good Health and Well-Being* (SDG 3), is focused on promoting health and well-being for all people by eradicating diseases and addressing sanitation and health issues around the globe [1].

3.1.1. Basic Human Needs and PAR-Based UREs

As an innovative avenue towards advancing the SDG agenda, PAR-based UREs combine two approaches—PAR and UREs—already practiced within HEIs, but which are rarely combined. Whereas PAR is grounded in critical and constructivist paradigms, and most often involves collaboration between university faculty and community partners [37–39], UREs are most often oriented towards providing STEM undergraduates with traditional, campus-based (e.g., basic, laboratory) research experiences where positivist approaches dominate [40]. By integrating these approaches through PAR-based UREs, undergraduates within and beyond STEM are able to gain valuable experience with critical, community-engaged research under the mentorship of faculty, while contributing to the improvement of communities [11]. Moreover, PAR-based UREs have the potential to confer similar benefits as more typical UREs (e.g., increased student engagement, expanded understandings of disciplinary knowledge and practice, integration into cultures of research).

A foundational organizing principle of PAR-based UREs is the notion that those who will be most affected by a research project should be involved throughout the process—not just as participants (i.e., data units), but as collaborators who are "experts in their own lives" and who may substantially contribute to the scope and design of the research [41] (p. 390). As such, PAR-based UREs bring HEIs (e.g., university faculty; undergraduate students) and community partners (e.g., organizations; residents) together through prefigurative research that: (1) Employs methods—for data collection, dissemination, and action—that are community-driven; and (2) aims to address community-defined challenges in the present, rather than merely identifying avenues for future community improvement [11]. With problem identification, priorities, and process emerging through university-community collaboration, PAR-based UREs serve to address immediate issues that are most important to community members (e.g., basic necessities). The PAR literature documents numerous examples of universities and communities coming together to advance goals related to the "Basic Human Needs" SDG cluster, including poverty, hunger, health, and well-being [42–45].

3.1.2. Reflections and Recommendations for Student Development: Student as Collaborator and Learner

In the PAR-based URE pilot program described earlier, undergraduates facilitated the PAR process with majority-Indigenous Southern Louisiana communities experiencing saltwater intrusion and land loss due to climate change, as well as environmental degradation and pollution caused by the oil and gas industry. Through relationship-building and collaborative decision-making with key community members, their projects came to focus on: (1) Plant species of cultural and medicinal significance that are vulnerable to environmental degradation; and (2) the place attachment, risk perceptions, and adaptation preferences of Indigenous residents. As both projects centered on ecological threats to community members' livelihoods, health, and well-being, these student-facilitated PAR initiatives were relevant to communities' "Basic Human Needs".

A key strength of this PAR-based URE pilot was its capacity to address community-defined challenges through university-community collaboration, while simultaneously developing the community-engaged research capacities of undergraduates through authentic research and multidisciplinary mentorship [11]. In brief, students, as well as communities, were beneficiaries of the process. This occurred despite the seemingly divergent nature of PAR and UREs, in which the former is primarily a community-centered approach, and the latter is a primarily student-centered approach. However, a closer look at PAR process illuminates its potential to confer multifaceted benefits. According to Fals-Borda and Rahman, PAR is "not only as a means of creating knowledge; it is simultaneously a tool for the education and development of consciousness as well as mobilization for action" [46] (pp. 121–122). In PAR, they continue:

> ... both researcher and researched recognize that despite their otherness they seek the mutual goal of advancing knowledge in search of greater justice. They interact, collaborate, discuss, reflect and report in collectivities on an equal footing, each one offering in the relationship what [they] know best. ... It is in this space of a truly participatory activity that the actual meeting of diverse scientific traditions takes place, resulting in an enriched overall knowledge, which in addition is more effective in the struggle for justice and the achievement of social progress and peace. [46] (p. 152)

The PAR process is characterized by multiple cycles of research, reflection, and action through which all participants—students, researchers, and community partners alike—are likely to benefit through learning and transformation [46,47]. As such, in our view, the positive outcomes of PAR-based UREs are not a finite resource that require zero-sum calculations regarding "who benefits?" Rather, PAR maintains a focus on the questions "knowledge for what?" and "knowledge for whom?" towards the collective empowerment of marginalized groups [46] (p. 152). In order to uphold these potentialities of PAR, and to support students' development as *community collaborators and learners*, we recommend flexibly integrating student participation into the community-driven process. This means that students' roles will evolve and change in accordance with the PAR process, rather than adhere to a strict or pre-determined definition of what students' URE participation will entail. With communities setting the agenda for meeting their own needs through PAR-based UREs, HEIs can play an important role in prefiguring sustainability, while promoting the SDG-oriented civic engagement of undergraduates. Figure 1 illustrates the relationships between PAR-based UREs, the SDG framework, and student development outcomes.

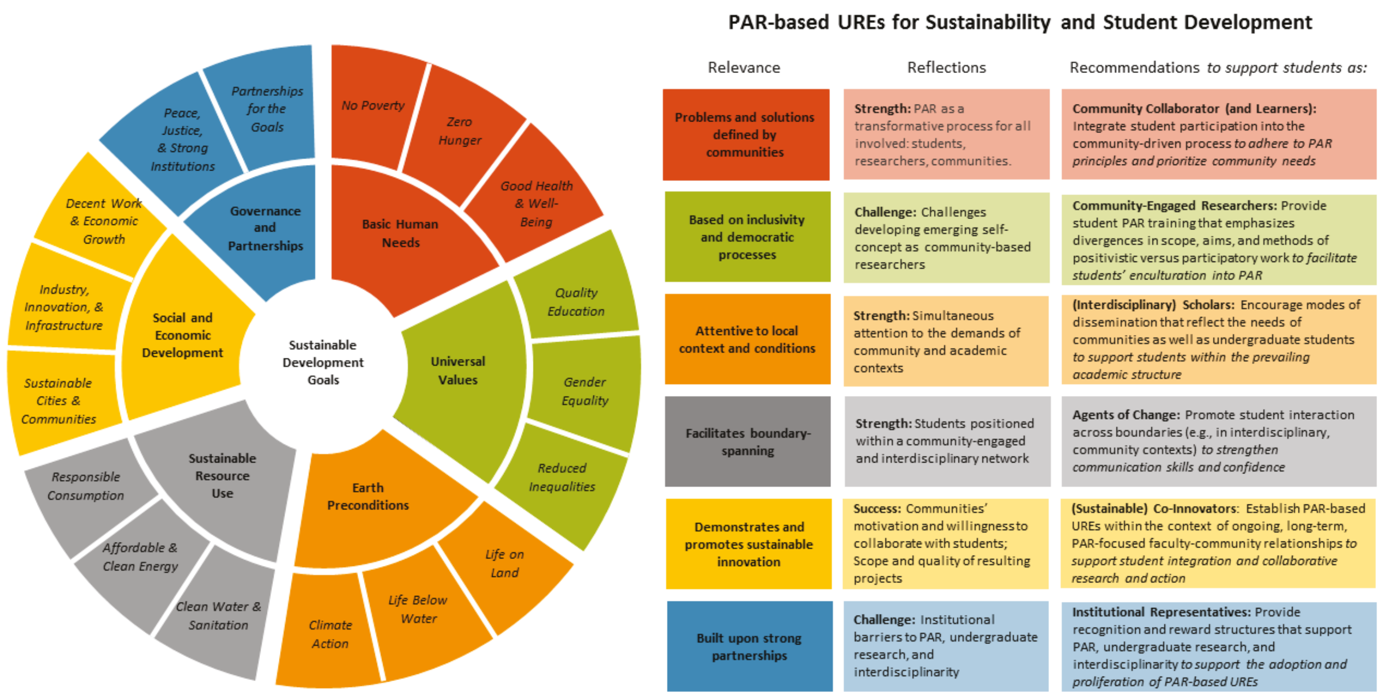
3.2. Universal Values

A second cluster of SDGs centers on "Universal Values" for fundamental human rights that provide a foundation for a peaceful, prosperous, and sustainable future [3]. *Quality Education* (SDG 4) is the achievement of universal educational goals for all people, across the lifespan [1]. *Gender Equality* (SDG 5) includes universal provisions for "equal access to education, services, decent work" as well as "equal representation in political and economic decision-making processes" [1]. Finally, *Reduced Inequalities* (SDG 10) is broad to include the reduction of inequality both within, and also across all countries across the world [1].

3.2.1. Universal Values and PAR-Based UREs

PAR initiatives, though diverse, are united by a shared set of values around the conduct and purposes of research. Central principles of PAR include broad inclusivity, democratic process, and reflexive practice. Respectively, in PAR practice, these value orientations translate into goals of diverse research participation, equal distribution of power and decision-making ability, and learning and transformation for all involved [13,46]. Together these process-oriented goals provide the basis for strengthening community agency and empowerment, where agency is defined as "the capacity of individuals to act independently to make their own free choices" [48] (p. 322), and empowerment refers to "the process by which people gain control over their lives, democratic participation in the life of their community . . . , and a critical understanding of their environment" [49] (p. 570). Towards these ends, PAR collaborations often involve work with marginalized groups, such as women, racialized and ethnic minorities, young people, and refugee and immigrant populations [14]. Ultimately, the PAR process is oriented towards improving quality of life and advancing the "collective situation" of community partners through collaborative research and action [7,15] (p. 10).

In these ways, through embodied practice, PAR-based UREs prefigure the aims of SDGs related to "Universal Values". For example, the educational dimension of PAR-based UREs aspires to engage and transform undergraduate students as well as community members from diverse walks of life and across the lifespan (SDG 4), while the non-hierarchical dimension of PAR practice is explicitly directed at reducing inequalities, both through the practice of collaborative research and by achieving equity and human flourishing within communities as the ultimate goal (SDG 5; SDG 10). In the PAR literature, there are numerous examples of collaborative research partnerships—bringing HEIs and communities together—focused on improving quality education [50], promoting gender equality [51–53], and reducing inequalities more generally [54–56].



(a) (b)

Figure 1. This figure illustrates how PAR-based UREs serve to advance sustainability and student development. (**a**) The left-hand portion of the figure depicts six clusters [36] that encompass the 17 UN Sustainable Development Goals (SDGs) [1]. (**b**) Using corresponding colors, the right-hand portion of the figure illustrates the relevance of PAR-based UREs for addressing the SDGs, and includes both reflections as well as recommendations for the design and implementation of PAR-based UREs.

3.2.2. Reflections and Recommendations for Student Development: Student as Community-Engaged Researcher

During the summer prior to their participation in the PAR-based URE pilot, undergraduate students completed a more typical lab-based URE in which the procedures, methods, and modes of inquiry were situated squarely, and solely, within the realm of atmospheric science. Like in most STEM UREs, the research questions addressed by students were predominantly faculty-driven and pre-determined. In the second-year PAR-based URE, all aspects of the projects were guided by and co-constructed with community members, with limited, if any, direct input by faculty. Through this experience, undergraduate students developed understandings of how to establish and maintain relationships between researchers and communities. In particular, undergraduates' conceptualizations of the process of effective science communication shifted away from that of unidirectionally conveying and communicating scientific ideas to laypersons, and toward a bidirectional, discourse-oriented approach. Importantly, students' perceptions of the role of community members moved from the periphery—where they are being spoken to by scientists as 'consumers' of completed research—to a central location wherein community members have a voice in the co-creation of all aspects of a research project. By partnering with majority-Indigenous communities, and constructing non-hierarchical research relationships to collaboratively address community-defined challenges, these student-facilitated PAR initiatives served to advance SDGs related to "Universal Human Values".

Despite their expressed commitments to the fundamental tenets of PAR, the undergraduates who participated in the PAR-based URE pilot described challenges switching their research mindset, or methodological orientation, from science-focused to community-engaged. They were cognizant of the fundamental shifts required and, during post-URE interviews, reflected on their own successes and struggles reconciling their former research training with their emerging self-concept as community-based researchers. Breaking out of the traditional hierarchical structure of STEM research, in which researchers are accustomed to being in total control, was uncomfortable and perhaps even unsettling. The emergent nature of PAR, as not pre-planned but community-driven, combined with its reliance on relationship- and trust-building with community members, required a patience and persistence students had not anticipated prior to beginning their work. Compared to STEM research, and to (post-)positivist research more generally, PAR is unique in its emergent and evolving nature, as well as its deliberate and democratic inclusion of community members throughout the process. Students within and beyond STEM who have been previously enculturated into positivistic epistemological and methodological paradigms will likely face similar challenges in PAR-based UREs due to the fundamental perspective-shift that it necessitates. Therefore, in order to support students' development as community-engaged researchers, we recommend that students receive PAR training prior to their participation in PAR-based UREs. This training should specifically call out divergences in the scope, aims, and methods of positivist versus participatory research, and emphasize that PAR is simultaneously a "process of 'unlearning' as well as new learning" [35] (p. 138). By deliberately involving undergraduates in community-engaged research with marginalized groups to collectively act for their own empowerment, HEIs may simultaneously reaffirm their civic missions, while prefiguring the "Universal Values" that define a sustainable future.

3.3. Earth Preconditions

The "Earth Preconditions" cluster highlights the role of a stable biosphere and climate system for a sustainable future [3]. "Preconditions" refers to the need for steady functioning of Earth systems as "a prerequisite for a thriving global society" [57] (p. 305). The *Climate Action* (SDG 13) goal describes the need for urgent action to combat climate change and its impacts, as climate change is impacting individuals and communities, as well as disrupting economies, in every country around the globe [1]. Conservation, management, and sustainability of *Life Below Water* (SDG 14; i.e., oceans, seas, marine resources) is essential to maintaining a sustainable biosphere, as is protecting *Life on Land* (SDG 15) by managing deforestation and desertification, as well as reversing or interrupting land degradation and biodiversity loss [1].

3.3.1. Earth Preconditions and PAR-Based UREs

Climate change has been characterized as a global problem with local solutions. That is, although climate change is a geographically diffuse and complex phenomenon, its immediate consequences are localized—or experienced in unique ways by specific communities at different times and in different places [58,59]. For example, communities often face wildly different climatological threats (e.g., extreme weather events) based on the geophysical features of their environments, and strengthening community resilience requires attention to psychosocial, political, and infrastructural realities of individual localities. As a result, local-level (e.g., city, county) initiatives have emerged in recent years as critical to climate change mitigation, adaptation, and disaster risk reduction (SDG 13) [60]—initiatives that have inevitably translated into protections for life below water and above land (SDG 14; SDG 15).

What makes localized programs especially effective in protecting the biosphere, specifically, are the same features that position PAR as a promising strategy to address a diverse range of community problems, within and beyond the scope of environmental degradation. Compared to (inter)national policies and programs, smaller-scale initiatives are relatively less encumbered by multi-level considerations in processes of development, approval, and implementation. Moreover, local partnerships create conditions conducive to fostering awareness around specific features of local environments that can facilitate success, such as local opportunities, resources, and barriers [8,61]. Such considerations often translate into policies and programs with place-based, social and cultural relevance to specific communities, where top-down models are often inadequate. PAR-based UREs—as local, bottom-up, grassroots initiatives—seek to integrate multiple perspectives through diverse stakeholder engagement, and in so doing, generate plans and products meaningful to the lived realities of community members. PAR has been applied, across a variety of geographic contexts, to address wide ranging environmental issues, including climate change adaptation in Canada (SDG 13) [62], estuary management in South Africa (SDG 14) [63], and Central American agroecology (SDG 15) [64].

3.3.2. Reflections and Recommendations for Student Development: Student as (Interdisciplinary) Scholar

Projects in the PAR-based URE pilot were directly relevant to the "Earth Preconditions" SDG cluster. Specifically, student-facilitated PAR initiatives centered on problems arising from climate change, including land loss due to saltwater intrusion and land subsidence. As is typical in PAR, the 'products' of students' PAR collaborations went beyond traditional academic dissemination modes (e.g., journal articles) to include non-traditional products. For example, one student's PAR-based URE experience culminated in a mobile phone application to promote land-loss awareness among community members. The app simultaneously served as a data collection strategy and educational platform that compiled and featured oral histories, video testimony, historical and current photographs, and geographic data. This research product was not merely information to be consumed at one point in time or on one occasion by the community; rather, it was designed for regular and ongoing use—and development—by the community over time beyond the summer URE period.

Researchers conducting PAR are tasked with regularly considering and negotiating the needs of a broad range of community partners and stakeholders to facilitate processes of research and action. Further, as academics, they face additional pressure to disseminate and advance knowledge through conventional disciplinary channels [65]. A key success of the PAR-based URE pilot was its simultaneous attention to the demands of community and academic contexts. Specifically, students were positioned to contribute to the improvement of communities through collaborative research and action, while they were simultaneously being supported in ways that may allow them to succeed within the prevailing academic structure. In PAR collaborations, a range of dissemination modes is commonly employed. These can include community events (e.g., workshops, training seminars), political organizing and action (e.g., campaign materials), arts-based approaches (i.e., art exhibitions, performances), or the production and distribution of online or print resources (e.g., websites, newsletters) [66]. Yet these non-traditional research products may not be perceived as valuable 'academic currency'—or, alternatively, the development of highly regarded academic skills—within the rigid, disciplinary institutional norms and expectations that define research productivity in today's academic institutions. Therefore, in order to more appropriately support students as (interdisciplinary) scholars, we recommend providing students with opportunities and recognition for dissemination that include both traditional academic (i.e., journal article, conference presentation) and perhaps non-traditional dissemination modes that result from the PAR process (e.g., creative educational products). In these ways, PAR-based UREs may serve as a mechanism through which HEIs cultivate (interdisciplinary) sustainability scholars, advance SDG attainment, and prefigure ideal university-community relations by 'giving back' to their communities—applying their skills and resources in the service of local residents.

3.4. Sustainable Resource Use

The fourth SDG cluster encompasses avenues for "Sustainable Resource Use" [3]. The implications of access to *Clean Water and Sanitation* (SDG 6) are far-reaching, and enhancements to infrastructure will ensure an adequate supply of water, sanitation, and hygiene for all [1]. *Affordable and Clean Energy* (Goal 7) is perhaps the cornerstone upon which addressing many other SDGs depends [1]. Energy systems that supply reliable, sustainable energy will be transformative as they support all sectors and help address inequalities such as those in food production, jobs, education, infrastructure, and health. *Ensuring Responsible Production and Consumption* (SDG 12) includes both sustainable management as well as efficient use of natural resources that will increase quality of life [1]. Accomplishing this will result in a better quality of life for all with the focus on efficient resource and energy use, the development of a sustainable infrastructure, and increased access to basic services and decent jobs.

3.4.1. Sustainable Resource Use and PAR-Based UREs

Central to controversies around defining, characterizing, and acting towards sustainable development is the 'wicked' nature of sustainability challenges, which require new modes of inquiry and action due to their increasing level of complexity [67]. Advancing sustainability requires consideration of the interconnected—and sometimes contradictory—nature of solutions across multiple systems and scales, including the geographic, political, social, environmental, and economic dimensions of sustainable transformation [57,68,69]. Like many SDGs, the specific goals related to "Sustainable Resource Use" demand collaboration across boundaries of campus, discipline, and nation.

PAR-based UREs practice these forms of 'boundary-spanning' on multiple levels. First, through university-community partnerships, undergraduate students are encouraged to traverse the boundaries of the university campus and to work in collaboration with communities for their own improvement and empowerment. Further, PAR-based UREs apply a multidisciplinary mentor model, providing undergraduates with exposure to diverse research traditions (e.g., epistemologies and methodologies), within and beyond their major or specialty. With experience working across disciplines and in partnership with communities, PAR-based UREs have the capacity to develop students who are able to comprehend, communicate about, and address complex socio-scientific issues—or societal dilemmas with ties to science that, like wicked problems, are "typically contentious in nature, can be considered from a variety of perspectives, do not possess simple conclusions, and frequently involve morality and ethics" [70] (p. 5). For example, though not organized as UREs, previous studies have documented PAR initiatives around all SDGs in this cluster, including clean water [71], sanitation and hygiene [72,73], clean energy [74], and responsible production and consumption [75,76]. Through SDG-oriented PAR-based UREs, participating students may develop the capabilities to speak across boundaries—with scientists, researchers, community partners, and the public—in ways that, at present, hinder integrated action on complex sustainability challenges.

3.4.2. Reflections and Recommendations for Student Development: Student as Agent of Change

In the PAR-based URE pilot, undergraduate students completed projects that integrated traditional ecological knowledge with Western science. For example, one project incorporated local knowledge as it simultaneously drew from ethnobotony, atmospheric science, geography, environmental science, and social science. This project centered on vulnerable plant species with cultural and medicinal value to community members and faith healers. The aims were to identify and record data using geospatial information systems (GIS) technology, to understand and document the importance and location of these plants used by the region's Native American tribes, and also explore potential solutions that would enable the sustainable production of the vulnerable plant species. In light of the diverse content areas and methods integrated during this PAR collaboration, and considering the specific sustainability-oriented issues addressed, the PAR-based URE pilot was especially relevant to the "Sustainable Resource Use" SDG cluster.

Notable outcomes of this PAR-based URE, as documented during interviews with student participants, included undergraduates' transformed views of how knowledge is generated, as well as their deeper understanding of and respect for traditional ecological knowledge [11]. Students also gained an appreciation for the challenges and rewards of community-engaged research, an expanded understanding of the social dimensions of their work, and came to realize the empowering impacts of community engagement—not only for community partners, but for themselves. For example, undergraduate students developed a sense of agency to transform *their own science networks* by discussing the value of interdisciplinary research with their peers and mentors, and by continuing to engage with communities in their future work.

A key strength of this PAR-based URE was its positioning of students as 'boundary-spanners' as they facilitated the PAR process with community members. During the pilot, students were tasked with developing relationships with community members, learning about the history of the region and the problems perceived by community members, and co-constructing projects to address local environmental problems. This required full-time investment by the students throughout the duration of the program, as well as the support of a constellation of academic mentors from multiple disciplines who provided advice on their specific PAR initiatives. These included mentors in STEM, social science, and qualitative methodology. Further, they were each assigned a community liaison who provided mentorship and guidance as they integrated themselves into the communities. As a result, student participants in the PAR-based URE became part of a community-engaged and interdisciplinary network, which fostered their growth as civically-engaged scholars committed to the improvement of communities. Throughout the program, they regularly communicated across cultural (e.g., with community members) as well as disciplinary (e.g., social and physical science) boundaries. By the end of the program, students had gained confidence in their communication abilities as well as their potential to be agents of change. Given these positive outcomes related to student empowerment, we recommend that in any PAR-based URE, students should be encouraged and supported in speaking and collaborating across boundaries, especially by communicating their work in a variety of academic contexts, and in community settings. By supporting students as agents of change through PAR-based UREs, HEIs simultaneously demonstrate their commitment to addressing global sustainability challenges of the present and future, while prefiguring sustainability through community-engaged research that enables action in the 'here and now'.

3.5. Social and Economic Development

According to the SDG framework, "Social and Economic Development" [3] are key features necessary to ensure global peace and security. The SDG *Decent Work and Economic Growth* (SDG 8) centers on inclusive and sustainable growth towards ensuring equitable opportunities for employment and decent work [1]. In addition to eradicating slave and child labor, economic productivity and prosperity are encouraged through the promotion of development-oriented policies. The implications of sustainable *Industry, Innovation, and Infrastructure* (SDG 9) are far-reaching. Adequate infrastructure is central to the success of many SDGs, as is sustainability-oriented innovation around industrialization [1]. Finally, *Sustainable Cities and Communities* (SDG 11) are emphasized in this cluster, as cities are hubs for "ideas, commerce, culture, science, productivity, social development, and more" [1]. Inclusive, safe, and resilient cities and communities are framed, within this cluster, as paving a path toward further social and economic advancements.

3.5.1. Social (and Economic) Development and PAR-Based UREs

Of the many controversies surrounding the SDGs, debates around their inclusion of economic growth have been most contentious [77]. In light of the present-day existence of extreme poverty coupled with income and wealth inequality (i.e., threats to human flourishing), as well as overexploitation of resources due to a culture of extraction (i.e., threats to ecological sustainability), many see unfettered economic growth as a clear and immediate threat to promoting human development within planetary boundaries [4,9,57]. In critiquing the '3P model' (i.e., people, planet, profit)—the framework that undergirds the SDGs, and which is known by a handful of other names (e.g., three pillar model; triple bottom line; tripartite model)—many have argued that economic growth, as measured by GDP, should not be among the key SDG priorities [4,9,57,77]. Apart from doing away with economic goals entirely, many have argued that at the very least, the well-being of people and planet should come before profit. We agree with Holden et al. that "sustainable development constitutes a set of constraints on human activities, including economic activities" [4] (p. 3). As such, in this section, we constrain our discussion of the potentialities of PAR-based UREs to two themes: (1) Sustainable innovation; and (2) sustainable cities and communities. Within these themes, we discuss how PAR-based UREs may build capacity within aspects of each SDG in the cluster, without losing sight of economically-driven threats to the wider ecology of the planet.

PAR-based UREs advance sustainable innovation as well as the sustainability of cities and communities. We view sustainable innovation (SDG 9) as the creation of new methods, ideas, or products that embody or advance human flourishing and planetary well-being. Relatedly, a key premise for building sustainable cities and communities (SDG 11) is that " ... human settlements can be incubators for innovation and ingenuity and key drivers of sustainable development" [2]. Sustainable innovation is a concept that describes both process and outcome of PAR-based UREs. In terms of process, providing opportunities for undergraduates to engage with local residents for collaborative, community-driven, SDG-oriented research and action through PAR-based UREs *already* challenges the status quo—specifically of entrenched academic modes of insular, disciplinary research that is often disengaged from communities. Additionally, as discussed, the outcomes of the PAR process—as community-defined—often fall outside the typical range of recognized and rewarded scholarly products (e.g., journal articles), but rather tend to encompass innovative modes of dissemination and action that are more likely to reach and to resonate with community members. This is because, in PAR, ownership of the process, knowledge generated, outcomes, and actions lies with community members, which can strengthen the adoption and sustainability of community-driven initiatives, making them ultimately more successful [78,79]. PAR has been applied in a number of contexts related to sustainable innovation as well as sustainable cities and communities. For example, by facilitating youth-led climate action in diverse yet neighboring communities [80], through research emphasizing the implications of unreliable transportation systems on negative birth outcomes in communities in Nigeria [81] and Uganda [82], and by bringing together representatives from various sectors to address sustainable household waste management challenges in Brazil [83].

3.5.2. Reflections and Recommendations for Student Development: Student as (Sustainable) Co-Innovator

Our empirical investigation of the impacts of the PAR-based URE pilot documented only students' views of the process, leaving our understanding of its impacts on community members incomplete. However, during interviews, students articulated a common perception that the collaborative process strengthened community members' sense of agency to address environmental problems through their own ability to conduct research and to engage in self-advocacy. Further, students commented upon the potential of PAR-based UREs, through processes of collaborative research and action, to strengthen communities' capacity for self-determination [11]. In brief, in the eyes of student PAR facilitators, the process was empowering to community members in that it created the conditions under which they could gain further control over their own affairs [49]. Both by representing a new type of program that engages undergraduates in community-based research based on PAR principles, and through the creation of novel community-designed resources (e.g., a mobile app) focused on environmental threats, this PAR-based URE served to advance SDGs related to "Sustainable Innovation" and "Sustainable Cities and Communities".

Key strengths of the PAR-based URE were the motivation and willingness of community members to work collaboratively with the undergraduates, and the scope and quality of the resulting projects—especially given the relatively short duration of the program (i.e., 10 weeks). However, these features of the pilot were only possible due to strong connections established prior to the URE between community residents and the community-engaged faculty who provided mentorship to students during the program. These longstanding relationships provided a strong foundation of trust, which allowed for students' seamless integration into the process. As discussed in greater detail previously [11], given the significant bi-directional investment involved in relationship-building—upon which the success of any PAR initiative rests—PAR-based UREs should more often be designed to augment existing, long-term, PAR-focused faculty-community relationships, rather than to establish one-off, short-term, or URE-focused faculty-community relationships. Correspondingly, in order to support students' development as (sustainable) co-innovators through PAR-based UREs, we recommend the scope and specific nature of students' contributions always and completely serve the current and evolving needs of the collaborative relationship. As such, PAR-based UREs, as HEI-supported student opportunities, prefigure or demonstrate sustainable innovation within cities and communities, just as they promote sustainable innovation by serving as vehicles of transformative community-led change.

3.6. Governance and Partnerships

The sixth and final SDG cluster encompasses "Governance and Partnership" goals [3]. *Peace, Justice, and Strong Institutions* (SDG 16) advocates for equitable global standards for justice, a commitment to peace, and a responsibility to addresses inequalities by way of effective, accountable, and inclusive institutions across all contexts [1]. Aims within this goal are expansive, ranging from strengthening national institutions, to the reduction of corruption and organized crime, the provision of legal identity for all, and also the abolition of abuse, exploitation, and trafficking of children. *Partnerships for the Goals* (SDG 17) is the sole SDG entirely devoted to means of implementation, with its emphasis on domestic and global partnerships focused on finance, technology, capacity building, and policy [1].

3.6.1. Governance, Partnerships, and PAR-Based UREs

It is with respect to the "Governance and Partnerships" SDG cluster that the specific dynamics (and capacities) of PAR-based UREs truly resonate. Not only do PAR-based UREs hold the potential of paving a path toward peace and justice by advancing the previously discussed SDG clusters (i.e., Basic Human Needs, Universal Values, Earth Preconditions, Sustainable Resource Use, and Social and Economic Development) through the community-driven scope of projects undertaken, these collaborations typify the sort of university-community partnership that may genuinely strengthen ties between HEIs and the communities within which they reside (SDG 16) [1]. Moreover, the very mechanism through which these processes may occur—partnership—forms the basis of SDG 17 and PAR-based UREs [1,11]. In short, through partnerships between students, communities, universities, and the public, PAR-based UREs may simultaneously advance the SDG agenda with respect to both content (SDGs 1–16) and means of implementation (SDG 17) [1].

PAR-based UREs employ methods falling under the broader umbrella of action research, which has been described by Reason and Bradbury [84] as cited by Gayá and Brydon-Miller [7] (pp. 37–38) as that which takes place "in participation with others" towards:

> ... the pursuit of practical solutions to issues of pressing concern to people, and more generally the flourishing of individual persons and their communities ... [and towards] a more equitable and sustainable relationship with the wider ecology of the planet of which we are an intrinsic part. [84] (pp. 1–2)

As such, the general philosophy of action research shares fundamental commitments with the SDG agenda [2], as well as to the very definition of "sustainable development" proposed by Griggs et al. to accommodate the era in which we now find ourselves, the anthropocene: Sustainable development, to them, is that which "meets the needs of the present while safeguarding Earth's life-support system, on which the welfare of current and future generations depends" [57] (p. 306). By involving undergraduates in PAR-based UREs, HEIs may contribute not only to cultivating the 'next generation' of community-engaged, justice-bound, and sustainability-oriented citizens and scholars; they may expedite the enactment—the realization—of these aspirational ideals now. This present-oriented, lived embodiment of 'future' goals is the essence of prefiguring social and ecological sustainability through PAR-based UREs.

3.6.2. Reflections and Recommendations for Student Development: Student as Institutional Representative

During the PAR-based URE, the undergraduate student facilitators served as institutional representatives. In their work with community members, they became the face of academia, their universities, and given the nature of the URE, science. As young people collaborating with community members, as students pooling their knowledge with local expertise, and as researchers at the nexus of social and physical science, undergraduates in the PAR-based URE were able to interface, communicate, learn, and disseminate knowledge across boundaries. A key success of the PAR-based URE was its capacity to build and bolster bridges through research and action, whether that meant strengthening connections among community groups, between students and communities, across disciplinary boundaries, or between universities and the public. During the pilot, all of these critical connections—within and between actors and institutions—were forged or reinforced in some way. As such, the PAR-based URE pilot, to a degree perhaps outperforming all other clusters, served to advance SDGs related to "Governance and Partnerships".

Despite these capacities, PAR-based UREs face numerous institutional barriers. Related to the nature of PAR, for example, the perspectives of community members continue to be devalued in many academic science circles [85,86], and the prolonged duration of engagement typical of PAR is perceived as a threat to academic career prospects given a culture of hyperproductivity at many research universities [87]. Moreover, PAR-based UREs face structural challenges related to their specific characteristics. For example, many universities lack faculty incentives for facilitating undergraduate research [88–90]. Finally, PAR-based UREs such as the pilot we describe, which spanned physical and social science, may face challenges due to their interdisciplinary nature (e.g., related to disparate methods, languages, publishing outlets; [91,92]). We authors emphasize that these barriers to PAR-based UREs lie not in the specific capacities and configurations of the programs themselves, but in the rigid cultures and modes of academic research within which they operate. With these prohibitive factors in mind, we bring our attention to the critical role of HEIs in supporting the adoption and proliferation of PAR-based UREs. In place of a specific recommendation, we offer an appeal—one grounded in the potential of PAR-based UREs to simultaneously contribute to sustainable development as well as student development: By facilitating the implementation of PAR-based UREs, HEIs are in the position to usher in a new era of undergraduate training—one in which students become institutional representatives contributing to the advancement of peace and justice through strong ties between universities and their surrounding communities, while prefiguring sustainability through accessible and robust community-driven research and action.

4. Conclusions

The unanimous adoption of the SDGs by the UN General Assembly has been heralded as a major global achievement. However, the substantive impact of countries' universal agreement around this set of ambitious goals will ring hollow without concrete support and concerted action on the part of institutions and governments around the world [9]. In our view, HEIs have a critical role to play in the success of the SDGs. As centers for innovation and exchange, HEIs are uniquely well-positioned to offer infrastructure, personnel, and recognition to galvanize collaborative research and action towards global sustainability and human development.

PAR-based UREs represent a promising pathway towards realizing the vision of the SDGs. Beyond fostering relationships between students, communities, researchers, and the public, due to their flexibility and scalability, PAR-based UREs offer a mechanism for the proliferation of community-driven, action-oriented research to simultaneously address sustainability challenges and promote well-being in local contexts. In these ways, PAR-based UREs offer a prefigurative pathway to bring much-needed transformation to communities in the 'here and now,' rather than in the abstract or distant future. Moreover, PAR-based UREs have the potential to advance students' capabilities as community-engaged collaborators, learners, and researchers; interdisciplinary, boundary-spanning scholars and innovators; and empowered agents of change representing and transforming HEIs and their disciplines as they interface with local communities.

In this paper, we have merely sketched the contours of the symbiotic relationship between PAR-based UREs and SDG achievement. The role of HEIs in supporting their combined success is a matter of procedural and cultural transformation. Procedurally, HEIs must—on the front end—establish alternative proposal-review (e.g., funding, institutional review board) mechanisms that comprehend and embrace the emergent and evolving nature of PAR, and—on the back end—devise reward systems (e.g., tenure and promotion) that recognize the value of undergraduate research and the development of non-traditional academic products resulting from PAR (e.g., community, policy impact). Culturally, HEIs must continue along a growing trend of incentivizing bridge-building beyond the boundaries of discipline and university campus, first by prioritizing interdisciplinary collaboration, and relatedly, by reestablishing firm roots within their surrounding communities through partnerships and prefigurative practice.

The SDGs envision a world of human flourishing within planetary boundaries [1,93]. Their achievement now requires alternative modes of research and action to address critical social and environmental problems [7,65]. Prefigurative methodologies, such as PAR, bring these seemingly soaring ambitions 'down to earth' by emphasizing individual and collective transformation in the present—change that is firmly rooted in the embodied practice of collaborative inquiry and action. Through PAR-based UREs, HEIs will continue to represent a global force for positive change—though not hidden behind paywalls or in ivory towers, but on the ground, in lock step with communities in need.

Author Contributions: C.D.T. led the conceptualization of this manuscript and provided expertise on prefiguration and sustainability. The article was improved by the contributions of all co-authors at various stages of the research and writing process. Conceptualization, C.D.T., A.E.W. and L.B.S.M.; Visualization, C.D.T., A.E.W. and L.B.S.M.; Writing—original draft, C.D.T., A.E.W. and L.B.S.M.; Writing—review and editing, C.D.T., A.E.W. and L.B.S.M.

Funding: This research was made possible by funding from the National Science Foundation award number 1538532.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

References

1. UN 2015: Transforming Our World: The 2030 Agenda for Sustainable Development. United Nations General Assembly, 2015. Available online: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E (accessed on 21 June 2018).
2. UN 2018: United Nations Sustainable Development Agenda. Available online: https://www.un.org/sustainabledevelopment/development-agenda/ (accessed on 21 June 2018).
3. *TWI2050. Concept Note*; International Institute for Applied Systems Analysis (IIASA): Laxenburg, Austria, 2017; Available online: http://www.iiasa.ac.at/web/home/research/twi/Concept-note-TWI2050-3page-Apr2017.pdf (accessed on 21 June 2018).
4. Holden, E.; Linnerud, K.; Banister, D. The imperatives of sustainable development. *Sustain. Dev.* **2017**, *25*, 213–226. [CrossRef]
5. Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin, F.S., III; Lambin, E.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; et al. Planetary boundaries: Exploring the safe operating space for humanity. *Ecol. Soc.* **2009**, *14*, 32. [CrossRef]
6. Trott, C.D. Constructing alternatives: Envisioning a critical psychology of prefigurative politics. *J. Soc. Political Psychol.* **2016**, *4*, 266–285. [CrossRef]
7. Gayá, P.; Brydon-Miller, M. Carpe the academy: Dismantling higher education and prefiguring critical utopias through action research. *Futures* **2017**, *94*, 34–44. [CrossRef]
8. Hutchins, L.; Lindenfeld, L.A.; Bell, K.P.; Leahy, J.; Silka, L. Strengthening Knowledge Co-Production Capacity: Predicting Interest in Community-University Partnerships. *Sustainability* **2013**, *5*, 5744–5770. [CrossRef]
9. Stafford-Smith, M.; Griggs, D.; Gaffney, O.; Ullah, F.; Reyers, B.; Kanie, N.; Stigson, B.; Shrivastava, P.; Leach, M.; O'Connell, D. Integration: The key to implementing the sustainable development goals. *Sustain. Sci.* **2017**, *12*, 911–919. [CrossRef] [PubMed]
10. Jha, A.; Kickbusch, I.; Taylor, P.; Abbasi, K. Accelerating achievement of the sustainable development goals: A game changer in global health. *BMJ* **2016**, *352*, i409. [CrossRef] [PubMed]
11. Weinberg, A.E.; Trott, C.D.; Sample McMeeking, L.B. Who produces knowledge? Transforming undergraduate students' views of science through participatory action research. *Sci. Educ.* **2018**, 1–21. [CrossRef]
12. Hall, B.L. Participatory research, popular knowledge and power: A personal reflection. *Convergence* **1981**, *14*, 6–19.
13. Kindon, S.; Pain, R.; Kesby, M. Participatory action research: Origins, approaches, and methods. In *Participatory Action Research Approaches and Methods: Connecting People, Participation and Place*; Kindon, S., Pain, R., Kesby, M., Eds.; Routledge: Abingdon, UK, 2007; pp. 9–18, ISBN 978 0 415 40550 8.
14. Brydon-Miller, M. Participatory action research: Psychology and social change. *J. Soc. Issues* **1997**, *53*, 657–666. [CrossRef]
15. Wadsworth, Y. What Is Participatory Action Research? Paper 2. Action Research International, 1998. Available online: https://www.montana.edu/cpa/news/images/articles/hires/img200603291143660763-1.pdf (accessed on 21 June 2018).

16. Torre, M.E.; Fine, M.; Stoudt, B.G.; Fox, M. Critical participatory action research as public science. In *APA Handbook of Research Methods in Psychology*; Cooper, H., Camic, P.M., Long, D.L., Panter, A.T., Rindskopf, D., Sher, K.J., Eds.; American Psychological Association: Washington, DC, USA, 2012; pp. 171–184, ISBN 9781433810039.
17. National Academies of Sciences, Engineering, and Medicine. *Undergraduate Research Experiences for STEM Students: Successes, Challenges, and Opportunities*; The National Academies Press: Washington, DC, USA, 2017; ISBN 978 0 309 45280 9.
18. Craney, C.; McKay, T.; Mazzeo, A.; Morris, J.; Prigodich, C.; De Groot, R. Cross-discipline perceptions of the undergraduate research experience. *J. High. Educ.* **2011**, *82*, 92–113. [CrossRef]
19. Russell, J.E.; D'Costa, A.R.; Runck, C.; Barnes, D.W.; Barrera, A.L.; Hurst-Kennedy, J.; Sudduth, E.B.; Quinlan, E.L.; Schlueter, M.; Haining, R. Bridging the undergraduate curriculum using an integrated course-embedded undergraduate research experience (ICURE). *CBE Life Sci. Educ.* **2015**, *14*, 1–10. [CrossRef] [PubMed]
20. Seymour, E.; Hunter, A.B.; Laursen, S.L.; DeAntoni, T. Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. *Sci. Educ.* **2004**, *88*, 493–534. [CrossRef]
21. Lopatto, D.; Tobias, S. *Science in Solution: The Impact of Undergraduate Research on Student Learning*; Council on Undergraduate Research: Tucson, AZ, USA, 2010; ISBN 978-0-941-9334-6.
22. Maton, K.I.; Hrabowski, F.A.; Schmitt, C.L. African American college students excelling in the sciences: College and postcollege outcomes in the Meyerhoff Scholars Program. *J. Res. Sci. Teach.* **2000**, *37*, 629–654. [CrossRef]
23. Graham, C.R.; Woodfield, W.; Harrison, J.B. A framework for institutional adoption and implementation of blended learning in higher education. *Internet High. Educ.* **2013**, *18*, 4–14. [CrossRef]
24. Junge, B.; Quiñones, C.; Kakietek, J.; Teodorescu, D.; Marsteller, P. Promoting undergraduate interest, preparedness, and professional pursuit in the sciences: An outcomes evaluation of the SURE program at Emory University. *CBE Life Sci. Educ.* **2010**, *9*, 119–132. [CrossRef] [PubMed]
25. Day, R. Hegemony, affinity and the newest social movements. In *Post-Anarchism: A Reader*; Rousselle, D., Evren, S., Eds.; Pluto Press: New York, NY, USA, 2011; pp. 96–116, ISBN 9780745330860.
26. Greenwood, D.J.; Whyte, W.F.; Harkavy, I. Participatory action research as a process and as a goal. *Hum. Relat.* **1993**, *46*, 175–192. [CrossRef]
27. Trott, C.D.; Sample McMeeking, L.B.; Weinberg, A.E. Participatory action research experiences for undergraduates: Forging critical connections through community engagement. in review.
28. Newman, J. Service learning as an expression of ethics. *New Dir. High. Educ.* **2008**, *142*, 17–24. [CrossRef]
29. Austin, D.E. Coastal exploitation, land loss, and hurricanes: A recipe for disaster. *Am. Anthropol.* **2006**, *108*, 671–691. [CrossRef]
30. Larkin, M.; Thompson, A. Interpretative phenomenological analysis. In *Qualitative Research Methods in Mental Health and Psychotherapy: A Guide for Students and Practitioners*; Harper, D., Thompson, A.R., Eds.; Wiley: Malden, MA, USA, 2012; pp. 101–116, ISBN 978 0 470 66373 8.
31. Atkinson, H.; Wade, R. Introduction. In *The Challenge of Sustainability: Linking Politics, Education and Learning*; Atkison, H., Wade, R., Eds.; Policy Press: Bristol, UK, 2015; pp. 1–8, ISBN 9781322497341.
32. Redclift, M.R. Sustainable development (1987–2005): An oxymoron comes of age. *Horizontes Antropológicos* **2006**, *12*, 65–84. [CrossRef]
33. World Commission on Environment and Development. *Our Common Future*; Oxford University Press: Oxford, UK, 1987; ISBN 019282080X.
34. Spangenberg, J.H. Hot air or comprehensive progress? A critical assessment of the SDGs. *Sustain. Dev.* **2017**, *25*, 311–321. [CrossRef]
35. *TWI2050: Annual Report 2017*; International Institute for Applied Systems Analysis (IIASA): Laxenburg, Austria, 2017. Available online: http://www.iiasa.ac.at/web/home/research/twi/Annual_Report_TWI2050.pdf (accessed on 21 June 2018).
36. TWI2050. *Transformations to Achieve the Sustainable Development Goals*; International Institute for Applied Systems Analysis (IIASA): Laxenburg, Austria, 2018. Available online: http://pure.iiasa.ac.at/15347 (accessed on 21 June 2018).
37. Brydon-Miller, M.; Greenwood, D.; Maguire, P. Why Action Research? *Action Res.* **2003**, *1*, 9–28. [CrossRef]

38. Guba, E.G.; Lincoln, Y.S. Competing paradigms in qualitative research. In *Handbook of Qualitative Research*, 1st ed.; Denzin, N.K., Lincoln, Y.S., Eds.; Sage Publications: Thousand Oaks, CA, USA, 1994; pp. 105–117, ISBN 0803946791.
39. Reza, M.H. Participatory action research (PAR): Revisiting the history, concept and ethics. *BRAC Univ. J.* **2007**, *4*, 27–34.
40. Linn, M.C.; Palmer, E.; Baranger, A.; Gerard, E.; Stone, E. Undergraduate research experiences: Impacts and opportunities. *Science* **2015**, *347*, 1–8. [CrossRef] [PubMed]
41. Hopkins, P.E. Positionalities and Knowledge: Negotiating Ethics in Practice. *ACME Int. J. Crit. Geogr.* **2007**, *6*, 386–394.
42. Kannan, S.; Schulz, A.; Israel, B.; Ayra, I.; Weir, S.; Dvonch, T.J.; Rowe, Z.; Miller, P.; Benjamin, A. A community-based participatory approach to personalized, computer-generated nutrition feedback reports: The Healthy Environments partnership. *Prog. Community Health Partnersh.* **2008**, *2*, 41–53. [CrossRef] [PubMed]
43. McDougall, C.; Jiggins, J.; Pandit, B.H.; Rana, S.K.T.M.; Leeuwis, C. Does adaptive collaborative forest governance affect poverty? Participatory action research in Nepal's community forests. *Soc. Nat. Resour.* **2013**, *26*, 1235–1251. [CrossRef]
44. Ponzoni, E. Windows of understanding: Broadening access to knowledge production through participatory action research. *Qual. Res.* **2016**, *16*, 557–574. [CrossRef]
45. Wartenweiler, D.; Mansukhani, R. Participatory action research with Filipino street youth: Their voice and action against corporal punishment. *Child Abuse Rev.* **2016**, *25*, 410–423. [CrossRef]
46. Fals-Borda, O.; Rahman, M.A. *Action and Knowledge: Breaking the Monopoly with Participatory Action Research*; The Apex Press: New York, NY, USA, 1991.
47. Kindon, S.; Elwood, S. Participatory action research in geographic teaching, learning and research. *J. Geogr. High. Educ.* **2009**, *33*, 51–65. [CrossRef]
48. Brown, K.; Westaway, E. Agency, capacity, and resilience to environmental change: Lessons from human development, well-being, and disasters. *Annu. Rev. Environ. Resour.* **2011**, *36*, 321–342. [CrossRef]
49. Perkins, D.D.; Zimmerman, M.A. Empowerment theory, research, and application. *Am. J. Community Psychol.* **1995**, *23*, 569–579. [CrossRef] [PubMed]
50. Roberts, D.M.; Brown, A.M.; Edwards, L. Participatory action research in two primary schools in a rural Tanzanian village: An exploration of factors to cultivate changes in teaching and learning. *Educ. Action Res.* **2015**, *23*, 366–382. [CrossRef]
51. Aziz, A.; Shams, M.; Khan, K.S. Participatory action research as the approach for women's empowerment. *Action Res.* **2011**, *9*, 303–323. [CrossRef]
52. Dias, S.M.; Ogando, A.C. Rethinking gender and waste: Exploratory findings from participatory action research in Brazil. *Work Organ. Labour Glob.* **2015**, *9*, 51–63. [CrossRef]
53. Hague, G.; Thiara, R.K.; Turner, A. Bride-price and its links to domestic violence and poverty in Uganda: A participatory action research study. *Womens Stud. Int. Forum* **2011**, *34*, 550–561. [CrossRef]
54. Arellano, R.; Balcaza, F.E.; Alvarado, F.; Suarez, S. A participatory action research method in a rural community of Mexico. *Univ. Psychol.* **2015**, *14*, 1197–1208. [CrossRef]
55. Johnson, K.; Martínez Guzmán, A. Rethinking concepts in participatory action research and their potential for social transformation: Post-structuralist informed methodological reflections from LGBT and trans-collective projects. *J. Community Appl. Soc. Psychol.* **2013**, *23*, 405–419. [CrossRef]
56. Langhout, R.D.; Thomas, E. Imagining participatory action research in collaboration with children: An introduction. *Am. J. Community Psychol.* **2010**, *46*, 60–66. [CrossRef] [PubMed]
57. Griggs, D.; Stafford-Smith, M.; Gaffney, O.; Rockström, J.; Öhman, M.C.; Shyamsundar, P.; Steffen, W.; Glaser, G.; Kanie, N.; Noble, I. Sustainable development goals for people and planet. *Nature* **2013**, *495*, 305–307. [CrossRef] [PubMed]
58. Chapman, D.A.; Trott, C.D.; Silka, L.; Lickel, B.; Clayton, S. Psychological perspectives on community resilience and climate change: Insights, examples, and directions for future research. In *Psychology and Climate Change: Human Perceptions, Impacts, and Responses*; Clayton, S., Manning, C., Eds.; Elsevier Academic Press: London, UK, 2018; pp. 267–288.

59. Intergovernmental Panel on Climate Change [IPCC]. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Available online: https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-PartA_FINAL.pdf (accessed on 2 July 2018).
60. Betsill, M.; Bulkeley, H. Looking back and thinking ahead: A decade of cities and climate change research. *Local Environ.* **2007**, *12*, 447–456. [CrossRef]
61. Bulkeley, H.; Betsill, M. *Cities and Climate Change: Urban Sustainability and Global Environmental Governance*; Routledge: London, UK, 2003; ISBN 9780415359160.
62. Plante, S.; Vasseur, L.; DaCunha, C. Adaptation to climate change and participatory action research (PAR): Lessons from municipalities in Quebec, Canada. In *Climate Adaptation Governance in Cities and Regions: Theoretical Fundamentals and Practical Evidence*; Knieling, J., Ed.; Wiley-Blackwell: Hoboken, NJ, USA, 2016; pp. 69–88, ISBN 978 1 118 45171 7.
63. Sowman, M. An evolving partnership: Collaboration between university 'experts' and net-fishers. *Gateways* **2009**, *2*, 119–143. [CrossRef]
64. Méndez, V.E.; Caswell, M.; Gliessman, S.R.; Cohen, R. Integrating agroecology and participatory action research (PAR): Lessons from Central America. *Sustainability* **2017**, *9*, 705. [CrossRef]
65. Silka, L. Becoming part of the solution: Engaged research on sustainability. In *University Engagement and Environmental Sustainability*; Inman, P., Robinson, D., Eds.; Manchester University Press: Manchester, UK, 2014; pp. 110–123.
66. Cahill, C.; Torre, M.E. Beyond the journal article: Representations, audience, and the presentation of participatory research. In *Participatory Action Research Approaches and Methods: Connecting People, Participation and Place*; Kindon, S., Pain, R., Kesby, M., Eds.; Routledge: Abingdon, UK, 2007; pp. 196–205, ISBN 9780415405508.
67. Brown, V.A.; Harris, J.A.; Russell, J.Y. *Tackling Wicked Problems through the Transdisciplinary Imagination*; Earthscan: New York, NY, USA, 2010; ISBN 9781844079247.
68. Davis, J.M. *Young Children and the Environment: Early Education for Sustainability*, 2nd ed.; Cambridge University Press: Port Melbourne, Australia, 2015; ISBN 9781107636347.
69. McGreavy, B.; Hutchins, K.; Smith, H.; Lindenfeld, L.; Silka, L. Addressing the complexities of boundary work in sustainability science through communication. *Sustainability* **2013**, *5*, 4195–4221. [CrossRef]
70. Sadler, T.D.; Zeidler, D.L. The morality of socioscientific issues: Construal and resolution of genetic engineering dilemmas. *Sci. Educ.* **2004**, *88*, 4–27. [CrossRef]
71. Trott, C.D.; Even, T.L.; Frame, S. Engaging local youth in water policy: A STE(A)M environmental justice program in Jacmel, Haiti. in preparation.
72. Manomaivibool, P.; Srivichai, M.; Unroj, P.; Dokmaingam, P. Chiang Rai Zero Waste: Participatory action research to promote source separation in rural areas. *Resour. Conserv. Recycl.* **2018**, *136*, 142–152. [CrossRef]
73. Olaseha, I.O.; Sridhar, M.K.C. Participatory action research: Community diagnosis and intervention in controlling urinary schistosomiasis in an urban community in Ibadan, Nigeria. *Int. Q. Community Health Educ.* **2004**, *24*, 153–160. [CrossRef] [PubMed]
74. Lacey-Barnacle, M.; Bird, C.M. Intermediating energy justice? The role of intermediaries in the civic energy sector in a time of austerity. *Appl. Energy* **2011**, *226*, 71–81. [CrossRef]
75. Harohau, D.; Sulu, R.J.; Phillips, M.J.; Sukulu, M.; Pickering, T.; Schwarz, A.M. Improving household tilapia (*Oreochromis mossambicus*) aquaculture through participatory action research. *Aquaculture* **2016**, *465*, 272–286. [CrossRef]
76. Whitman, G.P.; Pain, R.; Milledge, D.G. Going with the flow? Using participatory action research in physical geography. *Prog. Phys. Geogr.* **2015**, *39*, 622–639. [CrossRef]
77. Jackson, T. *Prosperity without Growth: Foundations for Economy of Tomorrow*, 2nd ed.; Routledge: London, UK, 2017; ISBN 9781317388227.
78. Elwood, S.; Feliciano, R.; Gems, K.; Gulasingam, N.; Howard, W.; Mackin, R.; Medina, E.; Ramos, N.; Sierra, S. Participatory GIS, the Humboldt/West Humboldt Park Community GIS Project, Chicago, USA. In *Participatory Action Research Approaches and Methods: Connecting People, Participation and Place*; Kindon, S., Pain, R., Kesby, M., Eds.; Routledge: Abingdon, UK, 2007; pp. 170–178, ISBN 978 0 415 40550 8.
79. Ferreira, M.P.; Gendron, F. Community-based participatory research with traditional and indigenous communities of the Americas: Historical context and future directions. *Int. J. Crit. Pedagog.* **2011**, *3*, 153–168.

80. Trott, C.D. Engaging Key Stakeholders in Climate Change: A Community-based Project for Youth-led Participatory Climate Action. Ph.D. Dissertation, Colorado State University, Fort Collins, CO, USA, 2017.
81. Esienumoh, E.; Allotey, J.; Waterman, H. Empowering members of a rural southern community in Nigeria to plan to take action to prevent maternal mortality: A participatory action research project. *J. Clin. Nurs.* **2018**, *27*, E1600–E1611. [CrossRef] [PubMed]
82. Ekirapa-Kiracho, E.; Namazzi, G.; Tetui, M.; Mutebi, A.; Waiswa, P.; Oo, H.; Peters, D.H.; George, A.S. Unlocking community capabilities for improving maternal and newborn health: Participatory action research to improve birth preparedness, health facility access, and newborn care in rural uganda. *BMC Health Serv. Res.* **2016**, *16*, 638. [CrossRef] [PubMed]
83. Gutberlet, J. More inclusive and cleaner cities with waste management co-production: Insights from participatory epistemologies and methods. *Habitat. Int.* **2015**, *46*, 234–243. [CrossRef]
84. Reason, P.; Bradbury, H. Introduction: Inquiry and participation in search of a world worthy of human aspiration. In *Handbook of Action Research: Participative Inquiry and Practice*; Reason, P., Bradbury, H., Eds.; Sage Publications: London, UK, 2001; pp. 1–14, ISBN 978-0761966456.
85. Nicholas, G. It's Taken Thousands of Years, but Western Science Is Finally Catching Up to Traditional Knowledge. *The Conversation*, 15 February 2018. Available online: https://theconversation.com/its-taken-thousands-of-years-but-western-science-is-finally-catching-up-to-traditional-knowledge-90291?xid=PS_smithsonian (accessed on 2 July 2018).
86. Smith, L.T. *Decolonizing Methodologies: Research and Indigenous Peoples*, 2nd ed.; Zed Books Ltd.: London, UK, 2013; ISBN 9781848139534.
87. Altbach, P.G. What counts for academic productivity in research universities? *Int. High. Educ.* **2015**, *79*, 6–7. [CrossRef]
88. Anderson, W.A.; Banerjee, U.; Drennan, C.L.; Elgin, S.C.R.; Epstein, I.R.; Handelsman, J.; Hatfull, G.F.; Losick, R.; O'Dowd, D.K.; Olivera, B.M.; et al. Changing the culture of science education at research universities. *Science* **2011**, *331*, 152–153. [CrossRef] [PubMed]
89. Brownell, S.E.; Tanner, K.D. Barriers to faculty pedagogical change: Lack of training, time, incentives, and . . . tensions with professional identity? *CBE Life Sci. Educ.* **2012**, *11*, 339–346. [CrossRef] [PubMed]
90. Eagan, M.K.; Sharkness, J.; Hurtado, S.; Mosqueda, C.M.; Chang, M.J. Engaging undergraduates in science research: Not just about faculty willingness. *Res. High. Educ.* **2011**, *52*, 151–177. [CrossRef] [PubMed]
91. O'Meara, K. Encouraging multiple forms of scholarship in faculty reward systems: Have academic cultures really changed? *New Dir. Inst. Res.* **2006**, *2006*, 77–95. [CrossRef]
92. Van Noorden, R. Interdisciplinary research by the numbers. *Nat. News* **2015**, *525*, 306–307. [CrossRef] [PubMed]
93. Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; de Vries, W.; de Wit, C.A.; et al. Planetary boundaries: Guiding human development on a changing planet. *Science* **2015**, *347*, 736–746. [CrossRef] [PubMed]

sustainability

MDPI

Article

Expanding Student Engagement in Sustainability: Using SDG- and CEL-Focused Inventories to Transform Curriculum at the University of Toronto

Rashad Brugmann [1], Nicolas Côté [2], Nathan Postma [2], Emily A. Shaw [3,*], Danielle Pal [2] and John B. Robinson [4]

1 Faculty of Applied Science and Engineering, University of Toronto, Toronto, ON M5S 1A4, Canada; r.brugmann@mail.utoronto.ca

2 Faculty of Arts and Science, University of Toronto, Toronto, ON M5S 3G3, Canada; nicolas.cote@mail.utoronto.ca (N.C.); nathan.postma@mail.utoronto.ca (N.P.); danielle.pal@mail.utoronto.ca (D.P.)

3 London School of Economics and Political Science, London WC2A 2AE, UK

4 Munk School of Global Affairs & Public Policy, University of Toronto, Toronto, ON M5S 1H8, Canada; johnb.robinson@utoronto.ca

* Correspondence: emily.shaw@mail.utoronto.ca; Tel.: +44-7789-992729

Received: 16 November 2018; Accepted: 15 January 2019; Published: 20 January 2019

Abstract: The Expanded Student Engagement Project (ESE) has developed three comprehensive inventories which aim to increase student knowledge of sustainability-related course content and increase student engagement in on- and off-campus, curricular, and non-curricular sustainability projects at the University of Toronto (U of T). The first is a sustainability course inventory (SCI) generated using keyword search based on the UN Sustainable Development Goals (SDGs). This is the first SCI that has been based on the SDGs. The inventory identified 2022 unique sustainability courses and found that SDG 13 had the greatest representation and SDG 6 had the least. The second inventory is a community-engaged learning (CEL) sustainability inventory which found 154 sustainability-focused CEL courses and identified 86 faculty members who teach sustainability CEL. Finally, an inventory of sustainability co-curricular and extracurricular opportunities revealed that U of T has 67 sustainability-focused student groups and identified 263 sustainability-focused opportunities. These inventories are an important foundation for future initiatives to increase student engagement in sustainability on campus and in the community. The ESE will integrate this data into U of T's course management system and use the inventories to develop a new sustainability pathways program.

Keywords: sustainable development goals; SDGs; higher education institutions; sustainability in higher education; agent of change; curriculum innovation; sustainability course inventory; student engagement

1. Introduction

The University of Toronto's President's Advisory Committee on the Environment, Climate Change, and Sustainability (CECCS) has developed a project intended to support undergraduate student engagement with sustainability issues that challenge the university and its neighbouring communities. This project, titled the Expanded Student Engagement Project (ESE), is working to expand student knowledge of sustainability-related course content and increase both on- and off-campus student engagement through sustainability focused curricular and non-curricular projects. The ESE's work presented here was conducted by five undergraduate research assistants and their supervisor, chair of the CECCS, over a period of 14 months.

The motivation for this work was to identify existing sustainability opportunities at the University of Toronto (U of T) and provide a foundation for the development of future opportunities and sustainability programs. This paper investigates the process by which the ESE created its primary deliverables: three inventories which catalogue (1) undergraduate courses with sustainability content (2) undergraduate courses with sustainability focused community-engaged learning (CEL) opportunities and (3) undergraduate co-curricular and extracurricular opportunities actively promoting sustainability at the U of T. Additionally, we discuss the process of clustering the first inventory around a novel framework derived from the United Nations (UN) Sustainable Development Goals (SDGs), and clustering the second inventory by adapting McRae and Johnson's Global Work-Integrated Learning Framework [1]. This paper presents some of the first course inventory methodologies in the literature. Further, although Yale University has organized faculty research interests using the SDGs [2], this paper presents the first usage of the SDGs to identify and cluster sustainability courses at higher education institutions (HEIs). We seek to emphasize the practical use of the SDGs as indicators for sustainability course content. We demonstrate how the inventories work in service of embedding sustainability pedagogy into curricula across the numerous departments operating at U of T.

This paper is intended to serve as a case study for other HEIs working to expanding student engagement in sustainability. We have paid particular attention to the many tensions that appeared during the development of our inventories. It is our hope that the practical lessons presented in their resolutions will prove useful to sustainability practitioners at other HEIs. To achieve this goal, we will begin this paper by grounding our work in the theoretical frames which detail the changing role of the university in society, as well as curriculum innovation for sustainability education. Following this review we discuss relevant contextual factors at U of T to provide a basis for comparative analysis between institutions. The methodologies for creating these inventories are then closely examined, including a review of methods used by other HEIs and our use of the SDG framework, before the results are presented. To conclude, the relevance of this work to the creation of sustainability pathways and the future work of the ESE are discussed.

2. Context

The role of the University as an actor in society has been changing from its traditional role as a knowledge institution. Its new purpose manifests a wider, outward facing scope for University activities. In other words, collaboration with external partners is becoming standard practice for HEIs such that the human capital, research and expertise already produced by the University have the greatest impact in society [3–5]. Thus, the University emerges as an Agent of Change (AOC) in its immediate community through mutually beneficial relationships within its local context. Further, with knowledge transfer among HEIs becoming ever more consistent, there is meaningful potential to expand the impact of these collaborations globally and in a large variety of local contexts.

Another change in HEIs is a greater emphasis on experiential learning to solve pressing issues identified by society [6]. Specifically, this has involved creating more opportunities for solutions-based pedagogy, often guided by collaboration with partners outside academia (this could include operational staff at the university, civil society organizations, or private sector actors) [7]. This educational strategy is called the "Living Lab" approach at U of T, also called "real-world laboratories," "urban living labs," and "sustainability learning labs" [8–10]. HEIs employing the model demonstrate a few consistent principles across "Living Lab" activities [9,11,12]:

(1) Formal and equitable collaboration with both operational and community partners to identify and solve real sustainability issues;
(2) Training of career ready graduates through external placements;
(3) Emphasis on promoting and expanding experiential learning opportunities;
(4) Intentional knowledge transfers beyond academic circles; and
(5) Institutional commitment to transdisciplinary thinking [4,5,11,13–15].

Living Lab activities which engage students also significantly impact their educational experience and foster sustainability thinking.

It is widely acknowledged that sustainability is a perspective inextricably tied to complex and systemic problems, and its approaches are necessarily framed by the attempt to develop relevant practical solutions that integrate theories, practices and insights from diverse bodies of knowledge [16–19]. Hence, as Aktaş suggests, "a viable way to increase the role of sustainability in higher education is to foster interdisciplinary research and teaching" [20] (p. 354). Although U of T's School of the Environment offers interdisciplinary B.A. and B.Sc. programs which span the natural sciences, social sciences, and humanities, it is the vision of the ESE to make such options available throughout all undergraduate programs at U of T. Creating widely available interdisciplinary training in sustainability requires going beyond the disciplinary structure of degree programs to create an overarching and interdisciplinary trajectory in sustainability. Every department is relevant to sustainability research and can be represented in curricular sustainability offerings.

In addition, as Wright, Cain, and Monsour argue, to generate the mindset required for transformative sustainability education, curriculum development must adopt more experiential, community-integrated, and practice-oriented approaches to teaching [21]. With the support of campus leaders and administrators, curriculum innovation for sustainability should look like "creative and critical application of knowledge and skills (that) are supported by authentic experience within the classroom." [21] (p. 2). Such sustainability curriculum innovation in HEIs requires top-down support [22,23]. To this end the ESE aims to provide administrative tools for the development of interdisciplinary and eventually transformative sustainability experiential learning initiatives.

A motivating curriculum structure that encourages interdisciplinarity and experiential sustainability learning is Sustainability Pathways. The ESE's concept of sustainability pathways derives from the University of British Columbia (UBC)'s sustainability curriculum initiative called the Sustainability Learning Pathways (SLP) [24]. The main goal of the SLP is that any student, regardless of their degree program, will have access to an education in sustainability through a learning trajectory complementing and weaving through their disciplinary education. The UBC SLP program outlines the following attributes for a trajectory of for-credit sustainability pathway courses:

(1) Accessible to all undergraduate students regardless of degree program;
(2) Interdisciplinary;
(3) Can be completed by students through their existing degree program;
(4) Involves research, co-curricular projects and/or community-engaged learning courses; and
(5) Provides a coherent sustainability education [24].

Recent developments in sustainability leadership at the University of Toronto have identified such development as a priority for the institution. Understanding the policy and structural context of the University of Toronto is important to situate how such widely available interdisciplinary and experiential sustainability opportunities could be developed.

The University of Toronto is the largest HEI in Canada, with over 89,000 full-time and part-time undergraduate and graduate students [25]. It has three campuses across the Greater Toronto Area; the University of Toronto St. George (UTSG) is the university's main campus and is located in downtown Toronto. Two smaller campuses are located outside of downtown Toronto in Mississauga (University of Toronto Mississauga, UTM) and in Scarborough (University of Toronto Scarborough, UTSC). Each campus has a Sustainability Office, which is tasked with ensuring the sustainability of Facilities and Services operations.

In 2016, U of T faced significant pressure from students to divest from fossil fuels. Subsequently, the Office of the President outlined new goals and commitments for sustainability action in the 2016 report *Beyond Divestment: Action on Climate Change* which included the creation of the President's Advisory Committee on Environment, Climate Change, and Sustainability (CECCS): a committee of faculty, staff, students and alumni who are tasked to ensure that the goals of the report are implemented [26]. After four months of operating, the CECCS published the *Annual Report 2017* which outlined the strategy and action items for the CECCS as well as setting the priorities for three subcommittees: the Campus as a Living Lab Subcommittee (CLL), the Agent of Change Subcommittee (AOC), and the Curriculum Innovation Subcommittee (CI) [3]. Each subcommittee has priorities and action items that are consistent with the literature explored in the sections above. The ESE works to achieve the objectives of the CI subcommittee and acts as the informal operating arm. This work is summarized in the ESE's four central goals:

(1) Create a sustainability inventory that is made available to students interested in choosing sustainability related courses;
(2) Create a list of faculty teaching in the sustainability area that is available to all those faculty members, hopefully contributing to a greater sense of common identity and community;
(3) Contribute to the creation of curricular 'sustainability pathways' for U of T students; and
(4) Develop more curricular and co-curricular student engagement opportunities related to sustainability, in collaboration with U of T organizations, specifically through the use of the community-engaged learning inventory.

In its *Annual Report 2018*, the CECCS identifies significant progress on these items related to curriculum innovation, as well as some additional highlights which cross-cut the committee's operations:

(1) The CLL subcommittee has identified six living lab projects and is developing a template for student engagement alongside a Charter of Principles for these projects;
(2) The AOC subcommittee has prepared a typology of forms of engagement with partners on sustainability projects;
(3) On behalf of the CI subcommittee, the ESE project developed inventories of undergraduate sustainability courses, sustainability-oriented community-engaged learning courses, and of student clubs with a sustainability focus; and
(4) The CI subcommittee has begun work on implementing sustainability pathways in four divisions [27].

U of T does not have an interdisciplinary academic division devoted to developing sustainability curriculum across academic disciplines, resulting in limited financial and labour resources available for such purposes [28]. As well, U of T has less of a pre-existing culture and research interest in sustainability compared to universities in British Columbia and Quebec [28].

Despite these challenges, there is great potential for effective curriculum innovation in sustainability education at U of T due to its size and existing interdisciplinary program structures such as those in the Faculty of Arts and Science (FAS) [29]. In addition, U of T is engaged in several inter-institutional networks which seek to foster knowledge transfer and communication of best practices, notably the Association for the Advancement of Sustainability in Higher Education (AASHE) [30] and the University Climate Change Coalition (UC3) [31].

In addition to these opportunities to embed and connect sustainability education throughout the university, U of T, along with every university and college in the province, has signed a Strategic Mandate Agreement (SMA) with the Government of Ontario's Ministry of Advanced Education and Skills Development [32]. These SMAs outline "System-Wide" and "Institution-Specific" targets to formalize "shared objectives and priorities" between educational and governmental entities (p. 6). Importantly for the ESE, one of U of T's SMA metrics commits the university to "the expansion of high-quality, pedagogically-sound work-integrated learning and experiential learning (WIL/EL) opportunities across undergraduate, graduate and professional programs" (p. 4). The U of T Task Force on Experiential Learning is responsible for achieving this priority and has released a white paper that standardizes the definition of experiential learning in the U of T context. The white paper concludes by recommending that the university better catalogue its experiential learning opportunities [8], thus demonstrating high-level administrative support for inventory work.

3. Methods

We shaped this paper as a case study to illustrate the challenges which arose throughout the project, and the reasons for choosing particular solutions. To paraphrase Bruno Latour, a case study opens the possibility to show a step-by-step project in-the-making rather than a ready-made solution [33]. The case study as a communicative approach has been adopted by other HEIs wanting to outline their development of sustainability programs, commitment to curriculum innovation and establishment of living labs [34–36]. As Dmochowski noted in a case study of the University of Pennsylvania (Penn), "the purpose of this paper is to share the strategy used at [Penn] and provide an evaluation of its success and guidance to others creating similar programs" [37]. This format is a critical asset for developing sustainability programs at other HEIs like the ones developed at the University of Toronto.

In this following section we will review the methods used to create the three inventories of sustainability opportunities available to undergraduate students at U of T.

3.1. Sustainability Course Inventory Method

Sustainability course inventories (SCIs) are common practice for universities who participate in sustainability reporting systems, such as the AASHE Sustainability Tracking, Assessment, and Rating System (STARS) [38]. Course inventories increase awareness of sustainability course offerings and highlight the inherent interdisciplinarity of sustainability [37]. Additionally, SCIs provide a metric to track changes in the amount of focus on sustainability in the curriculum across the university [39] and offer increased access to sustainability education opportunities at institutions.

A review of sustainability course inventories developed by North American universities revealed three popular methods to identifying courses for SCIs:

(1) Review of course titles and descriptions by the department, office, or group that is creating the inventory (e.g., [40–42])
(2) Survey of academic deans, chairs, or instructors to identify sustainability courses (e.g., [43,44])
(3) Keyword search of course catalogue (e.g., [45–47])

Many HEIs develop inventories using combinations of the above methodologies. Surveys of faculty members are sometimes conducted to confirm the results of inventories done by reviewing courses or keyword searches [43,45,48]. This method provides validation of the inventory results but does not rely on a high survey response rate to create a complete inventory.

The U of T Sustainability Course Inventory was developed using a keyword search of Course Finder [49], the central and exhaustive database of the tri-campus undergraduate courses. This methodology was chosen because resources were not available to individually review the more than 8000 undergraduate courses at U of T. Further, university regulations prevented us from using a survey method to identify courses. Finally, the method is transparent and requires least subjective judgement, making it easy to operationalize for updating the inventory in future years [50]. Graduate courses are not included in the SCI because U of T does not have a central graduate course catalogue in which a keyword search could be conducted.

The keywords used for the SCI were developed using the United Nation's Sustainable Development Goals (SDGs). Two to seven keywords were chosen for each SDG to describe each Goal as completely and precisely as possible without overlapping with the other SDGs. The keywords were selected by the ESE team based on a list of SDG keywords provided by the Sustainable Development Solutions Network (SDSN) Australia/Pacific Branch [50] and approved by the members of the CECCS.

The keyword search results were reviewed by course title and course description when necessary, and non-sustainability courses were removed from the inventory. This secondary filtering process is subjective but transparent, and a list of deleted courses was kept available. Such filtering was required because several keywords refer to different topics based on context, such as "environment" in "business environment". Courses were tagged with all SDGs for which they returned a keyword. About 25% of all search results were filtered out.

The taxonomy of SDGs and keywords is presented in Table 1. An effort was made to use a similar number of keywords for each SDG however priority was given to selecting a set of keywords that spanned, and are unique to, the problem area of each SDG. Additional effort was made to minimize repetition of keywords, however exceptions were made for *water* (SDGs 6 and 14), *conserv** (SDGs 14 and 15) and *pollute* (SDGs 14 and 15), as they were identified as essential keywords which could not be limited to one SDG. The keyword *sustainab** was not included because it is not specific to one SDG, and we found that it did not yield any courses that were not already identified by other keywords.

Table 1. Sustainable Development Goal keywords used to create the sustainability course inventory (SCI) (Sustainable Development Goal (SDG) text from [51]).

Sustainable Development Goal	Keywords [1]
Goal 1 End poverty in all its forms everywhere	*poverty, income distribution, wealth distribution, socio economic*
Goal 2 End hunger, achieve food security and improved nutrition and promote sustainable agriculture	*agriculture, food, nutrition*
Goal 3 Ensure healthy lives and promote well-being for all at all ages	*health, well being*
Goal 4 Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	*educat*, inclusive, equitable*
Goal 5 Achieve gender equality and empower all women and girls	*gender, women, equality, girl, queer*
Goal 6 Ensure availability and sustainable management of water and sanitation for all	*water, sanitation*
Goal 7 Ensure access to affordable, reliable, sustainable and modern energy for all	*energy, renewable, wind, solar, geothermal, hydroelectric*
Goal 8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	*employment, economic growth, sustainable development, labour, worker, wage*
Goal 9 Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	*infrastructure, innovation, industr*, buildings*
Goal 10 Reduce inequality within and among countries	*trade, inequality, financial market, taxation*
Goal 11 Make cities and human settlements inclusive, safe, resilient and sustainable	*cities*, urban, resilien*, rural*
Goal 12 Ensure sustainable consumption and production patterns	*consum*, production, waste, natural resources, recycl*, industrial ecology, sustainable design*
Goal 13 Take urgent action to combat climate change and its impacts	*climate, greenhouse gas, environment, global warming, weather*
Goal 14 Conserve and sustainably use the oceans, seas and marine resources for sustainable development	*ocean, marine, water, pollut*, conserv*, fish*
Goal 15 Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	*forest, biodiversity, ecology, pollut*, conserv*, land use*
Goal 16 Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	*institution, justice, governance, peace, rights*

[1] An asterisk next to an abbreviated word is syntax for the search engines used to search all variants of that abbreviation. For example, searching *educat** returns results including *educate*, *education*, and *educator*.

The Sustainable Development Goals were designed as a framework to identify and cluster sustainability courses because of their international adoption, expert formulation, and comprehensiveness on the topic of sustainability [52] (Le Blanc argues that the SDGs have better integration across sectors than their predecessors, the MDGs. This integration is understood as improved comprehensiveness of the interconnected challenges in sustainability.) The SDGs consist of a set of 17 goals, 169 targets, and 243 indicators that UN member states designed and adopted to use as a framework for development policy until 2030 [53]. They are an extension of the Millennium Development Goals (MDGs) and were adopted by world leaders in 2015 as a part of the 2030 Agenda for Sustainable Development [51]. These goals are not legally binding, therefore governments are expected to design their own process for implementation of policy to further these goals [54]. Goal 17, "Strengthen the means of implementation and revitalize the goal partnership for sustainable development," was excluded from our methodology, as it encompasses the act of achieving the other goals rather than bringing a new perspective to sustainability, making it poorly-fitting for this purpose.

Since the development of the SDGs, the United Nations (UN) and its affiliated organizations have strongly encouraged the use of the goals to frame problem solving in higher education institutions [55]. The UN Sustainable Development Solution Network (SDSN), is a UN General-Secretary organization working to develop and coordinate global research and technological expertise to promote practical solutions for sustainable development, specifically the implementation of the SDGs [55]. It argues that universities play a critical role in sustainable development, as the task of achieving the SDGs is so large, universities have the potential to accelerate action in SDGs. The SDGs provide a new way to communicate to the public about the relevancy of HEIs, especially as drivers of solving global problems while also providing a single framework for addressing global problems [50]. These arguments for engaging with the SDGs all relate to the growing role of HEIs to train students to develop problem-solving skills [5,56]. Yet, the use of the SDGs as global indicators is often contested, even with specific targets and indicators for the goals, the goals are still described as broad, vague, and confusing [54]. Our judgement was that, despite these concerns, the SDGs provided a powerful basis for assessing the sustainability content for U of T courses.

3.2. CEL Sustainability Inventory Method

The Community-Engaged Learning (CEL) Sustainability Inventory is an inventory of CEL courses at U of T in which students work on sustainability projects. The inventory seeks to identify opportunities for students to contribute to for-credit projects working on sustainability in a community, locally or internationally. The definition of community-engaged learning used by the inventory was adopted to align with the definition of CEL set out in the previously mentioned U of T white paper on experiential learning. CEL is viewed as an experiential learning activity "in which students contribute to meaningful projects within a community for the purpose of addressing existing needs of individuals, agencies or organizations that are not currently being met, as well as enhancing student learning and development" [8]. CEL opportunities are a type of living lab activity in which students contribute solutions to real sustainability challenges with the guidance of external partners.

To identify CEL sustainability courses, we again used a keyword search methodology. This methodology was used for the same reasons as for the SCI, however different keywords were needed to identify CEL courses. The CEL keywords were: **placement*, **community*, **experiential*, **internship*, **partner*, **client*, and **service*. The ESE team then assessed the search results by reading each course description and documented the courses which satisfied two criteria: (1) they explicitly mentioned integration of CEL, and (2) they included CEL opportunities that were likely to address challenges related to sustainability. In an effort to foster a community of sustainability educators and partners at the university, the instructor name(s), email(s), and max course enrolment were recorded where available. The CEL sustainability inventory was developed separately from the SCI because CEL courses offer an educational experience for which students may search specifically.

A challenge that arose when developing this inventory methodology was the level of subjectivity present in the second screening criteria mentioned above. Information about the projects students would work on was not available to our team because (1) the variety of projects possible in a course is not listed in the course descriptions; and (2) a centralized list of all community partners involved in curricular projects does not exist at U of T. Thus, without knowing the partners involved, nor the projects offered, we were required to assess whether a course captured by the CEL keywords was likely to have sustainability focused placement opportunities. The difficulty of this judgement is seen in the course APS111: Engineering Strategies & Practice I. One group of engineering students in APS111 (Engineering Strategies & Practice I) may design a net-positive student space for a client, but a different cohort in the same course designs a production line process. Our team decided to apply an inclusive filter wherein the potential presence of sustainability projects was sufficient for inclusion in the CEL inventory. In this instance, APS111 was included in the inventory.

Another challenge, which also appeared with the SCI, was organizing CEL inventory data in a way that communicated the strengths and gaps present in the current course offerings. Colleagues at the Center for Community Partnerships, a U of T administrative unit focused on developing experiential learning opportunities, recommended the "Global Work Integrated Learning (WIL) Curricular Framework" [1]. This framework allowed the ESE to cluster the CEL inventory based on "type" of placement, such as Applied Learning versus Internship courses. We further refined the data by sorting the courses by academic division. The clustering achieved its purpose—as will be discussed in the result section—thus we highly recommend seeking out clustering frameworks that prove relevant to each HEI context.

3.3. Sustainability Co-Curricular and Extracurricular Inventory Method

The Sustainability Co-Curricular and Extracurricular Inventory is a two-part inventory which lists all non-course-based sustainability opportunities for students at U of T. The first part of the inventory is a list of the sustainability-focused co-curricular activities at the university which are recognized by the U of T Co-curricular Record (CCR) [57]. The CCR is a database of student clubs, programs, and other co-curricular opportunities maintained by central administration. If students participate in a CCR recognized club, they can gain distinction for extra-curricular involvement on their academic record. The ESE believes that increasing the visibility of these opportunities through inventory work is an effective way to expand student engagement because such participation is already incentivized by the University.

The Co-Curricular Inventory was developed using the same SDG keyword-search methodology as the SCI. The keywords were searched in the Opportunity Directory on the CCR website.

The second part of the inventory is a list of sustainability-focused student groups at the U of T St. George campus. It was developed in a collaborative effort with the Sustainability Commission of the University of Toronto Students Union (SCUTSU) and the University of Toronto Sustainability Office (UTSO), to provide a shareable resource for students. It lists all sustainability-focused extracurricular student groups at the university, including those that are not recognized by the CCR. Given U of T's scale, the ESE believed creating this resource would render club initiative operating in disparate corners of the university visible to one another, thus opening potential for collaboration between student groups on sustainability projects.

The extracurricular inventory was developed by reading club descriptions on ULife, the official U of T online clubs directory [58], by canvassing interpersonal student group networks, and through other university websites and networks. The inventory is organized by affiliation or topic, including subject-focused groups, college-based groups, and student unions.

4. Results

4.1. Sustainability Course Inventory Results

The SCI found 2022 sustainability courses, which represents 25% of the 8158 undergraduate courses offered at U of T. Unique courses were defined as a course with a unique course code in its term (i.e., Fall or Winter). Different lecture sections of the same course were not counted as unique. The U of T SCI documents the following information: course code, course title, credits, campus, department, term, year level, total number of SDGs, keywords, the SDG(s) to which the course is related, and a link to the course description. A sample page of the inventory is provided in Figure 1. The inventory is hosted on the website of the U of T Sustainability Office, available at: http://www.fs.utoronto.ca/SustainabilityOffice/Resources/SustainabilityCourses (See Supplementary Materials).

Course Code	Course Title	Campus	Department	Term	SDGs Covered
WGS347H5	Indigenous Feminisms and Decolonization	Mississauga	Historical Studies	2018 Fall	SDG 5, SDG 16
CIV401H1	Design and Optimization of Hydro and Wind Electric Plants	St. George	Civil Engineering	2018 Fall	SDG 7
CHM211H5	Fundamentals of Analytical Chemistry	Mississauga	Chemical and Physical Sciences	2018 Fall	SDG 13
RLG213H1	Reading Sacred Texts	St. George	Department for the Study of Religion	2018 Fall	SDG 13
MIE516H1	Combustion and Fuels	St. George	Mechanical & Industrial Engineering	2018 Fall	SDG 9, SDG 14, SDG 15
HMB441H1	Genetics of Human Disease	St. George	Human Biology Program	2018 Fall	SDG 3
ESS462H1	Global Biogeochemical Cycles	St. George	Earth Sciences	2018 Fall	SDG 14
WGS451H1	Independent Study in Women and Gender Studies Issues	St. George	Women and Gender Studies Institute	2018 Fall	SDG 5
JGE331H1	Resource and Environmental Theory	St. George	Geography and Planning	2018 Fall	SDG 13, SDG 14, SDG 15, SDG 16

Figure 1. A condensed sample page of the University of Toronto (U of T) Sustainability Course Inventory. (SDG = Sustainable Development Goal).

The SCI was compared with results from other Canadian HEIs that report sustainability courses through AASHE STARS [59]. Figure 2 shows that the maximum percentage of undergraduate courses that are sustainability course offerings is 32%, the minimum is 1%, and the median is 10%. U of T is in the upper quartile of these institutions. However it is difficult to draw conclusions by comparing inventory results with other self-reporting HEIs, because institutions may use different definitions of "sustainability courses" and different methods for identifying and counting courses.

The sustainability courses are found in six academic divisions across the university's three campuses. The Faculty of Kinesiology & Physical Health is the only division which offers undergraduate courses but does not have any identified sustainability courses. Table 2 shows the repartition of sustainability courses by division and year level.

The inventory reveals that most sustainability courses at U of T are third- and fourth-year courses (42% and 30% of all sustainability courses, respectively). Most divisions offer the most sustainability courses in third year, however the Faculty of Applied Science & Engineering (FASE) offers significantly more sustainability courses (58%) in fourth year. This is for several reasons: some FASE 400-level courses are undergraduate/graduate mixed classes; the largest number of engineering courses are offered in fourth year overall; and, all engineering students take a fourth-year capstone design course which generally considers some aspect of sustainability.

Part of the work of creating the SCI included identifying the total number of undergraduate courses offered as this information was not readily available from university administration. Table 3 presents the number sustainability courses as a portion of total undergraduate courses by division and year level. These findings reveal that whereas the Faculty of Arts and Science (FAS) offers the most sustainability courses overall, there is a higher concentration of sustainability courses in the Faculty of Applied Science & Engineering (FASE), University of Toronto Mississauga (UTM), University of Toronto Scarborough (UTSC), and the John H. Daniels Faculty of Architecture, Landscape, & Design (FALD).

The highest concentration of sustainability courses is in FALD, in which 47% of undergraduate courses contain sustainability content. Impressively, 67% of third-year courses offered by FALD include sustainability content, compared to 30% of third-year courses across the university.

Tables 2 and 3 show that just 8% of all sustainability courses are offered in first year, which represents 18% of all 100-level courses. However, further research found that these courses have high enrolment; therefore, they are important for future curriculum innovation initiatives as they have the capacity to reach many students.

The SCI findings reveal that the most common SDG content in U of T sustainability courses are Goals 13 (climate change), 16 (peaceful and inclusive societies), and 5 (health, well-being) (Figure 3). These SDGs are represented in 25%, 20%, and 19% of total courses in the inventory respectively. These results reflect the focus of sustainability courses across U of T, however the results may be more useful at the divisional or departmental level.

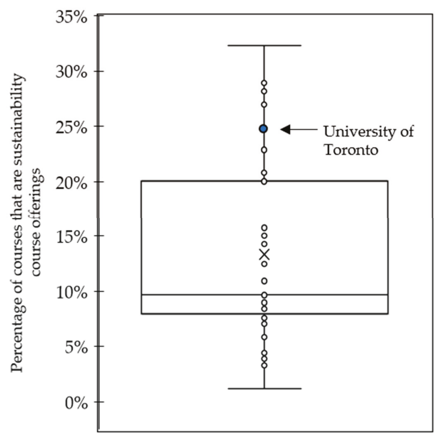


Figure 2. Percentage of undergraduate sustainability course offerings at Canadian higher education institutions (HEIs) with data from the Advancement of Sustainability in Higher Education Sustainability Tracking, Assessment, and Rating System (AASHE STARS) [59]. Courses that include sustainability encompass both "sustainability courses" and "courses that include sustainability" in the STARS framework. The cross represents the mean of the data; the blue dot indicates the U of T Sustainability Course Inventory (SCI).

Table 2. Representation of undergraduate sustainability courses by academic division and year level.

Academic Division	100-Level	200-Level	300-Level	400+ Level [1]	Total
Faculty of Arts and Science	81	174	329	260	844
Faculty of Applied Science & Engineering	10	18	46	116	190
University of Toronto Mississauga	29	102	235	111	477
University of Toronto Scarborough	32	122	202	104	460
Faculty of Music	0	1	2	4	7
John H. Daniels Faculty of Architecture, Landscape, & Design	4	6	29	5	44
Faculty of Kinesiology & Physical Education	0	0	0	0	0
Total	**156**	**423**	**843**	**600**	**2022**

[1] 400+ Level courses refer to both undergraduate and mixed undergraduate/graduate courses.

Table 3. Portion of sustainability courses by academic division and year level.

Academic Division	100-Level	200-Level	300-Level	400+ Level	Total
Faculty of Arts and Science	24%	23%	26%	20%	**23%**
Faculty of Applied Science & Engineering	23%	22%	30%	49%	**37%**
University of Toronto Mississauga	25%	26%	37%	26%	**30%**
University of Toronto Scarborough	12%	32%	35%	22%	**27%**
Faculty of Music	0%	1%	2%	2%	**1%**
John H. Daniels Faculty of Architecture, Landscape, & Design	44%	25%	67%	28%	**47%**
Faculty of Kinesiology & Physical Education	0%	0%	0%	0%	**0%**
Total	**18%**	**24%**	**30%**	**22%**	**25%**

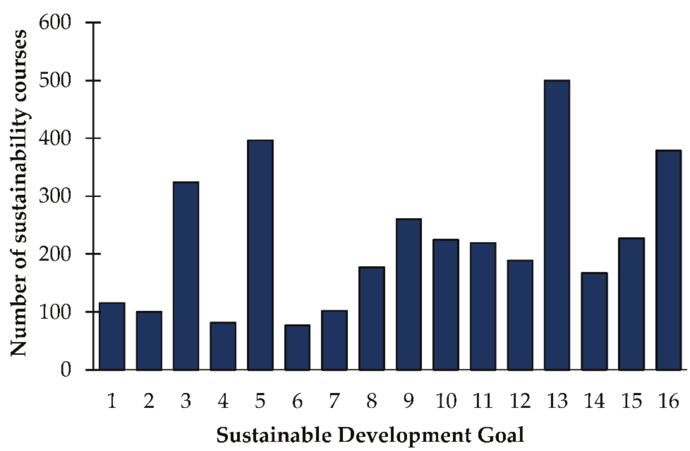


Figure 3. Number of sustainability courses covering each SDG. Note that courses may cover more than one SDG.

On the level of the academic division, emphasis on SDGs in particular subject areas becomes more apparent. For instance, in UTSC, UTM, and the Faculty of Arts and Science at UTSG, SDG 3 (health, well-being) and SDG 5 (gender equality) together represent more than half of the sustainability courses. In the Faculty of Applied Science and Engineering, more than half of the sustainability courses are represented under SDG 9 (sustainable infrastructure and innovation) and another quarter under SDG 7 (sustainable energy). Another interesting finding of the SDGs by subject area is that SDG 13 (climate change) does not represent the majority of sustainability courses in any one academic division, despite being the most represented SDG in the inventory.

Further analysis of the inventory sought to identify bias in the course results which may have resulted from using different numbers of keywords for each SDG. No relationship was found between the ratio of number of courses to number of keywords between different SDGs. The ratio of courses per keyword varied from 17 courses per keyword for SDG 7 (6 keywords) and 162 courses per keyword for SDG 3 (2 keywords).

The number of SDGs covered by a course was considered indicative of the degree of sustainability focus in the course. Many SDGs suggests that the course is multidisciplinary and teaches many sustainability issues. Further, the research efforts at Yale University which used the SDGs to identify sustainability scholarship found that using the SDGs as a clustering scheme is a productive way to identify transdisciplinary connections and build sustainability networks [2].

4.2. CEL Sustainability Inventory Results

The CEL Sustainability Inventory includes 154 CEL courses with sustainability content at U of T, which represents 36% of the 425 CEL courses identified by the keyword search. The CEL Sustainability includes course code, course title, credits, campus, department, term, division, associated keywords, and a hyperlink to the course description. A sample page from the inventory is provided in Figure 4.

Course Code	Course Title	Campus	Department	Term	Division
CSC454H1	The Business of Software	St. George	Computer Science	2019 Winter	Faculty of Arts and Science
SOC315H1	Domestic Violence	St. George	Sociology	2019 Winter	Faculty of Arts and Science
HST330H1	Population Health	St. George	University College	2019 Winter	Faculty of Arts and Science
GGR313H5	Gender and the City	Mississauga	Geography	2019 Winter	University of Toronto Mississauga
WRI411H5	Professional Writing and Communication Internship II	Mississauga	Institute of Communication and Culture	2019 Winter	University of Toronto Mississauga
CHM399Y5	Research Opportunity Program	Mississauga	Chemical and Physical Sciences	2019 Winter	University of Toronto Mississauga
FRED06H3	Language Practice VIII: Oral French	Scarborough	Centre for French and Linguistics (UTSC)	2019 Winter	University of Toronto Scarborough
CCT410H5	CCIT Internship I	Mississauga	Institute of Communication and Culture	2019 Winter	University of Toronto Mississauga
MIE315H1	Design for the Environment	St. George	Mechanical & Industrial Engineering	2019 Winter	Faculty of Applied Science & Engineering
CIV523H1	Geotechnical Design	St. George	Civil Engineering	2019 Winter	Faculty of Applied Science & Engineering

Figure 4. A condensed sample page of the U of T community-engaged learning (CEL) Sustainability Inventory.

Table 4 summarizes the CEL Sustainability Inventory by academic division, summarizing the faculty teaching CEL, across how many courses, and the total student enrolment therein. The courses are also tagged using an adapted version of McRae and Johnson's Global Work-Integrated Learning Framework [1], summarized in Table 5. The framework was changed to exclude the categories Apprenticeship, Clinic, and Co-op as they did not align with our definition of CEL.

Table 5 reveals how clustering the CEL inventory reveals gaps and trends in CEL sustainability course offerings. For example:

(1) The Faculty of Applied Science & Engineering offers vast Applied Research Sustainability CEL courses.

(2) The University of Toronto Scarborough does not offer any Sustainability Internship courses, whereas these courses make up over half (58%) of the University of Toronto Mississauga Sustainability CEL offerings.

(3) Applied Research Sustainability courses only comprise 16% of all Sustainability CEL courses at U of T. Curricular Community Service Learning and Internship offerings are predominant with 36% and 27% of total U of T Sustainability CEL courses respectively.

Table 4. Number of faculty, sustainability community-engaged learning (CEL) courses, and max enrolment in sustainability CEL courses.

Academic Division	Instructors Teaching Sustainability CEL	Total Sustainability CEL Courses	Max Student Enrolment
Faculty of Arts and Science	34	63	1783
Faculty of Applied Science & Engineering	18	15	1492
University of Toronto Mississauga	24	38	1173
University of Toronto Scarborough	10	34	878
Faculty of Music	0	0	0
John H. Daniels Faculty of Architecture, Landscape, & Design	N/A [1]	3	20
Total	**86**	**154**	**5346**

[1] Instructors were identified as available on the U of T Course Finder. Instructor names were not available for the Faculty of Architecture at the time of the inventory, and therefore were not counted.

Table 5. Sustainability CEL courses clustered into categories from McRae and Johnson's Global Work-Integrated Learning Framework [1].

Academic Division	Applied Research	Curricular Community Service Learning	Internship	Field Placement	Practicum/Clinical Placement	Work Experience
Faculty of Arts and Science	6	29	16	2	7	3
Faculty of Applied Science & Engineering	12	2	2	0	0	0
University of Toronto Mississauga	2	10	22	0	3	1
University of Toronto Scarborough	5	14	0	0	12	3
Faculty of Music	0	0	0	0	0	0
John H. Daniels Faculty of Architecture, Landscape, & Design	0	1	2	0	0	0
Total	**25**	**56**	**42**	**2**	**22**	**7**

These data are highly instrumental and compelling. They are the raw data with which curricula interventions could be justified. As a concrete example, the ESE argued in its Annual Report (2017) that there is clearly potential to expand the amount of Applied Research course offerings on the Mississauga and Scarborough campuses, and fortunately these may be the easiest to develop. Applied Research courses like ENV461 (The U of T Campus as a Living Lab of Sustainability) pull clients from the everyday operating departments of the University itself. In other words, the projects and clients are already present on campus. All that remains is finding a faculty member willing to organize the clients and evaluate the students' work.

The ESE explored the relationship between the results of our SCI inventory and the CEL inventory. Initially, the team's assumed that if we used Excel to cross-reference the inventories and reveal duplicates that many courses would appear. Both inventories capture sustainability courses, but with different sets of keywords as outlined in the methodology sections of both inventories. Yet, in cross-referencing the 2022 SDG courses with the 154 CEL courses the ESE team found only 65 courses that conformed to both sets of keywords. The disconnect between perception and the inventory's reality was found in the particular language used in CEL course descriptions. These course descriptions were often general about the types of projects or placements offered because they change regularly. The SDG keywords sought to capture substantive phrases which were not found in the course descriptions and therefore there is limited intersection between the inventories.

4.3. Sustainability Co-Curricular and Extracurricular Inventory Results

The Sustainability Co-Curricular Inventory keyword search identified 263 sustainability-focused opportunities for students which are approved for the university's Co-Curricular Record. The CCR inventory includes the name of the opportunity, number of positions available to students, keywords, related SDGs, and a hyperlink to a description of the position.

In the Extracurricular Inventory 67 sustainability-focused student groups were identified with the help of the Students Union Sustainability Commission and other sustainability student networks. It includes the group name, how the group was identified for the inventory, and the school year that the contact was last updated. The inventory also includes personal contact information for the club executives to help interested students contact the clubs directly to become involved.

These two inventory lists are not mutually exclusive, however they meet two different objectives for students searching for sustainability-focused opportunities. Student networks have reported to us that they look for CCR opportunities when they are searching for official work placements or internships, whereas they look for lower-commitment, student group involvement on the ULife website and other club listings. Sample pages of the Co-Curricular and Student Groups Inventory are provided in Figure 5.

The ESE is pleased to report that the Sustainability Commission of the University of Toronto Students Union used the first version of our Extracurricular Inventory to hold Sustainability Commissions throughout the 2017–2018 school year. Sustainability student groups were identified and brought together for a visioning process to identify gaps in U of T's sustainability infrastructure. Projects to reduce energy consumption, expand composting programs, and reduce food packaging were undertaken and student leaders pledged the unique resources of their clubs in a deeply collaborative manner. We believe this is an excellent first step towards creating a network of sustainability champions at U of T.

(a)

Group	Source	Contact Last Updated (Academic Year)
General Sustainability		
University of Toronto Environmental Resource Network	Website	2017–2018
University of Toronto Student Union Sustainability Commission	SO Connection	2017–2018
Environmental Justice Collective	ULife	2016–2017
Leap Chapter UofT	ULife	2017–2018
Regenisis UofT		2016–2017
Greenpeace Student Network		2016–2017
UofT Environmental Action	UTERN	2016–2017

Figure 5. *Cont.*

(b)

Activity	Positions	SDGs Covered
Development League, Faculty of Kinesiology & Physical Education	1	SDG 4
Urban Non-Violent Initiatives Through Youth (UNITY), Student Organization	8	SDG 11, SDG 13
Waawaahte Northern Lights Initiative	1	SDG 4
ILead: Graduate Group, Faculty of Applied Science & Engineering	7	SDG 2
Student Staff, Factor-Inwentash Faculty of Social Work	N/A	SDG 3, SDG 4, SDG 5
Urban Studies Student Union (URSSU), Student Organization	7	SDG 11, SDG 12
Student Staff, John H. Daniels Architecture, Landscape & Design	N/A	SDG 4, SDG 6, SDG 9, SDG 11, SDG 12, SDG 13, SDG 14, SDG 15
Camp U of T	1	SDG 3, SDG 13
Rotman Commerce Pride Alliance, Student Life—Rotman Commerce, Student Organizations	6	SDG 4

Figure 5. Condensed sample pages of the U of T (**a**) Co-Curricular and (**b**) Extracurricular Sustainability Inventory. Student contacts have been omitted for privacy.

5. Ongoing and Future Work

The creation of the three sustainability inventories is a fundamental step towards the third objective of the ESE, to develop sustainability pathways accessible to all students within their degree program. We have developed a proposal for a three-tiered pathways program which uses the inventories to identify curricular and non-curricular opportunities for student engagement in sustainability. The first tier, Sustainability Citizen, acknowledges co-curricular and extracurricular involvement in sustainability extracurricular activities. The second, Sustainability Scholar, is a curricular pathway where students would earn a certificate for completing a trajectory of existing for-credit courses. The third, Sustainability Leader, is a more intensive pathway through which students follow a trajectory of co-curricular activities, curricular courses, international experience, and a capstone course. The SCI is a central tool for the development of such Sustainability Scholar and Sustainability Leader programs. The number of SDGs to which a course is tagged can be used to indicate the degree to which they are sustainability-focused, and a variety of SDGs can be represented in each pathway to ensure interdisciplinary groups of courses. Similarly, the CEL Sustainability Inventory and Sustainability Co-curricular and Extracurricular Inventories are critical to lists of opportunities for building the Sustainability Citizen and Sustainability Leader pathways. Work on the pathways is ongoing within several academic divisions at the university.

Beyond contributing to the development of sustainability pathways, future work for the ESE includes confirming the results of the SCI through a survey of all faculty and instructors. This feedback will help validate the results of the keyword search, identify any courses not found through the search, and flag any courses which contained the keywords but which the instructor does not believe is a sustainability course. Challenges exist to releasing such a survey due to the university's restrictions on mass emails to faculty and staff.

Additionally, future work exists to make the inventories highly accessible to students. In addition to hosting the SCI on the website of the UTSO, we hope future developments will allow the inventory to be integrated into U of T's major course selection platforms, making sustainability course options more visible to students.

We hope to expand the SCI to include graduate courses. There is not a central catalogue of graduate courses and therefore this demands increased resources. If it is not possible to conduct a keyword search, a different inventory method could be investigated.

To continue building a community of sustainability educators at the university, and to increase experiential learning opportunities in sustainability, a workshop is being planned in collaboration with the U of T Centre for Community Partnerships to help instructors identify methods to increase CEL in their courses.

6. Conclusions

There is growing movement for universities to take a more active role in society by conducting solution-driven research and engaging with community partners, for the benefit of both students and the broader community [4,5,20]. In 2017, the University of Toronto formed a Presidential Advisory Committee on Environment, Climate Change, and Sustainability which set goals for the university to contribute [3]. Under the directive of the Curriculum Innovation subcommittee of the CECCS, the Expanded Student Engagement project set out four goals to identify sustainability content in the undergraduate curriculum and to provide guidance towards creating a transformative sustainability education through experiential learning.

The first goal—creating a set of sustainability inventories—was achieved. A keyword search methodology was developed using 16 of the 17 UN Sustainable Development Goals to create an SCI. The number of 2022 undergraduate sustainability courses was identified, 25% of all undergraduate courses. Further, a CEL Sustainability Inventory was developed which identified 154 CEL courses with sustainability content. These courses were clustered by type of learning activity using an adapted version of McRae and Johnson's Global Work-Integrated Learning Framework. Finally, inventories were developed of sustainability-focused co-curricular and extracurricular opportunities available to students at the university. Two hundred and sixty three university-recognized opportunities and 67 student groups were identified. These inventory methods, now in place, are designed to be easily updated in future years. These course inventory methodologies are some of the first presented in the literature and may be useful to other HEIs who wish to undertake a similar initiative. The second goal—creating a list of faculty teaching sustainability and sustainability-CEL courses—was achieved through the SCI and CEL Sustainability Inventory. During the keyword search, faculty teaching of each sustainability course was identified. This list has been made available to the CECCS.

The ESE's future research developments and goals focus on the third and fourth goal. The third goal is to contribute to the creation of curricular sustainability pathways for all U of T students. Several steps forward have been made towards this goal by using the course inventories to inform strategies for pathways courses and engagement opportunities. As described above, the ESE will continue to work with the CECCS to further develop the pathways. Finally, the fourth goal of the ESE is to develop more curricular and co-curricular student engagement opportunities related to sustainability. The creation of the CEL Sustainability Inventory is a necessary first step to identify courses where these opportunities can be provided and the ESE is currently working on hosting workshops to develop these opportunities further.

The inventories work as infrastructure to support a bottom-up groundswell of sustainability engagement in the University of Toronto. They are designed to connect instructors who teach sustainability and CEL content, enhance sustainability programs through collaboration, provide a meaningful tool for curriculum innovation in sustainability, increase student enrolment in sustainability courses by effectively communicating their presence, and increase awareness of opportunities in sustainability outside of the classroom. Clustering the inventories highlights the gaps, unexpected connections, and areas of growth for sustainability initiatives from actors across HEIs. Hence, through achieving the above four goals, the ESE hopes to meaningfully support the integration of sustainability content into all aspects of students' academic experience at U of T. If the ESE is successful, a new generation of leaders will have the opportunity and tools to address sustainability challenges faced in our local and global communities.

Supplementary Materials: The complete U of T Sustainability Course Inventory is available online at: http://www.fs.utoronto.ca/SustainabilityOffice/Resources/SustainabilityCourses.

Author Contributions: R.B., N.C., N.P., and E.S. authored the manuscript of this paper. R.B., N.C., N.P., D.P., and E.S. developed the methodologies and collected the original data for the CECCS for the University of Toronto. Both the writing of this paper and the original research was supervised by J.B.R., who also contributed to writing this paper.

Funding: The original research by the ESE was funded by University of Toronto Faculty of Arts and Science through the Advancing Teaching and Learning in Arts and Science grant. Subsequent funding for updating the inventory was provided through the University of Toronto Learning & Education Advancement Fund.

Acknowledgments: This paper research was originally designed for the purpose of the CECCS and we worked closely with the members of the committee, especially the Curriculum Innovation sub-committee. We would like to acknowledge these members for their support: Conor Anderson, Maria Banda, Aimy Bazylak, Kenneth Corts, Jason Hinde, Shashi Kant, Tim Lang, Amy MacDonald, Daniella Mallinick, Liat Margolis, Fiona Miller, Jenifer Murphy, Derek Newton, Locke Rowe, Kimberly Strong, and Ron Swail.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. McRae, N.; Johnston, N. The Development of a Proposed Global Work-Integrated Learning Framework. *Asia-Pac. J. Coop. Educ.* **2016**, *17*, 337–348.
2. Goodall, M.; Moore, E. *Yale Scholarship and the Sustainable Development Goals*; Yale Office of Sustainability: New Haven, CT, USA, 2015; Available online: https://sustainability.yale.edu/academics-research/scholarship-and-sdgs (accessed on 19 January 2019).
3. *President's Advisory Committee on the Environment, Climate Change, and Sustainability*; Annual Report 2017; University of Toronto: Toronto, ON, Canada, 2017; Available online: http://www.president.utoronto.ca/the-2017-annual-report-of-the-presidents-advisory-committee-on-the-environment-climate-change-and-sustainability (accessed on 19 January 2019).
4. Robinson, J.; Berkhout, T.; Campbell, A. The University as an Agent of Change for Sustainability. In *Policy Horizons Canada*; University of British Columbia: Vancouver, BC, Canada, 2011.
5. Samarasekera, I.V. Universities need a new social contract. *Nature* **2009**, *462*, 160–161. [CrossRef] [PubMed]
6. Domask, J.J. Achieving goals in higher education: An experiential approach to sustainability studies. *Int. J. Sustain. High. Educ.* **2007**, *8*, 53–68. [CrossRef]
7. Munro, A.; Marcus, J.; Dolling, K.; Robinson, J.; Wahl, J. Combining forces: Fostering sustainability collaboration between the city of Vancouver and the University of British Columbia. *Int. J. Sustain. High. Educ.* **2016**, *17*, 812–826. [CrossRef]
8. University of Toronto. *Rethinking Higher Education Curricula: Increasing Impact Through Experiential, Work-Integrated, and Community-Engaged Learning*; University of Toronto: Toronto, ON, Canada, 2017.
9. Schäpke, N.; Bergmann, M.; Stelzer, F.; Lang, D.J. Labs in the Real World: Advancing Transdisciplinary Research and Sustainability Transformation: Mapping the Field and Emerging Lines of Inquiry. *GAIA Ecol. Perspect. Sci. Soc.* **2018**, *27*, 8–11. Available online: https://www.ingentaconnect.com/contentone/oekom/gaia/2018/00000027/a00101s1/art00005# (accessed on 19 January 2019). [CrossRef]
10. Wittman, A.; Crews, T. *Engaged Learning Economies: Aligning Civic Engagement and Economic Development in Community-Campus Partnerships*; Campus Connect; Campus Compact: Boston, MA, USA, 2012; Available online: https://compact.org/engaged-learning-economies-linking-civic-engagement-and-economic-development/ (accessed on 19 January 2019).
11. Menny, M.; Palgan, Y.V.; McCormick, K. Urban Living Labs and the Role of Users in Co-Creation. *GAIA Ecol. Perspect. Sci. Soc.* **2018**, *27*, 68–77. [CrossRef]
12. Krütli, P.; Pohl, C.; Stauffacher, M. Sustainability Learning Labs in Small Island Developing States: A Case Study of the Seychelles. *GAIA Ecol. Perspect. Sci. Soc.* **2018**, *27*, 46–51. [CrossRef]
13. Waheed, M.H. *A Revolution for Post-16 Education—Part 1: A Case for the Living Lab*; The Environmental Association for Universities and Colleges: Cheltenham, UK, 2017.

14. Waheed, M.H. *A Revolution for Post-16 Education—Part 2: How do Living Labs Work?* Environmental Association for Universities and Colleges: Cheltenham, UK, 2017.
15. Brundiers, K.; Wiek, A. Educating Students in Real-world Sustainability Research: Vision and Implementation. *Innov. High. Educ.* **2011**, *36*, 107–124. [CrossRef]
16. Komiyama, H.; Takeuchi, K. Sustainability science: Building a new discipline. *Sustain. Sci.* **2006**, *1*, 1–6. [CrossRef]
17. Costanza, R.; Stern, D.; Fisher, B.; He, L.; Ma, C. Influential publications in ecological economics: A citation analysis. *Ecol. Econ.* **2004**, *50*, 261–292. [CrossRef]
18. Porter, A.L.; Roessner, J.D.; Cohen, A.S.; Perreault, M. Interdisciplinary research: Meaning, metrics and nurture. *Res. Eval.* **2006**, *15*, 187–196. [CrossRef]
19. Rafols, I.; Meyer, M. Diversity and network coherence as indicators of interdisciplinarity: Case studies in bionanoscience. *Scientometrics* **2010**, *82*, 263–287. [CrossRef]
20. Aktaş, C.B. Reflections on interdisciplinary sustainability research with undergraduate students. *Int. J. Sustain. High. Educ.* **2015**, *16*, 354–366. [CrossRef]
21. Wright, M.F.; Cain, K.D.; Monsour, F.A. Beyond Sustainability: A Context for Transformative Curriculum Development. *Transform. Dialogues Teach. Learn. J.* **2015**, *8*, 1–19.
22. Blake, J. *Community Engagement Towards a Sustainable Future: PedRIO Paper 3*; Pedagogic Research Institute and Observatory, University of Plymouth: Plymouth, UK, 2018; Available online: https://www.plymouth.ac.uk/research/institutes/pedagogic/pedrio-occasional-papers (accessed on 19 January 2019).
23. Pedagogic Research Institute and Observatory. *Third Annual Report: 2013*; Pedagogic Research Institute and Observatory, University of Plymouth: Plymouth, UK, 2013; p. 36. Available online: https://www.plymouth.ac.uk/research/institutes/pedagogic (accessed on 19 January 2019).
24. UBC Sustainability Initiative. *Transforming Sustainability Education at UBC: Desired Student Attributes and Pathways for Implementation*; UBC Sustainability Initiative: Vancouver, BC, Canada, 2013.
25. Universities Canada Enrolment by University 2017. Available online: https://www.univcan.ca/universities/facts-and-stats/enrolment-by-university/ (accessed on 5 November 2018).
26. Gertler, M.S. *Beyond Divestment: Taking Decisive Action on Climate Change*; University of Toronto: Toronto, ON, Canada, 2016; p. 45.
27. *President's Advisory Committee on the Environment, Climate Change, and Sustainability*; Annual Report 2018; University of Toronto: Toronto, ON, Canada, 2018; Available online: http://www.president.utoronto.ca/the-2018-annual-report-of-the-presidents-advisory-committee-on-the-environment-climate-change-and-sustainability (accessed on 19 January 2019).
28. Bieler, A.; McKenzie, M. Strategic Planning for Sustainability in Canadian Higher Education. *Sustainability* **2017**, *9*, 161. [CrossRef]
29. University of Toronto Faculty of Arts and Science Program Enrolment—Current Students. Available online: http://www.artsci.utoronto.ca/current/program/enrolment-instructions/index_html (accessed on 5 November 2018).
30. AASHE Home. Available online: http://www.aashe.org/ (accessed on 18 January 2019).
31. The University Climate Change Coalition. Available online: https://secondnature.org/initiative/uc3-coalition/ (accessed on 18 January 2019).
32. *Strategic Mandate Agreement between the Ministry of Advanced Education and Skills Development and University of Toronto 2017–2020*; University of Toronto; Government of Ontario Ministry of Advanced Education and Skills Development: Toronto, ON, Canada, 2017; Available online: https://www.utoronto.ca/sites/default/files/University%20of%20Toronto%20SMA%202017-20%20%28for%20publication%29.pdf (accessed on 19 January 2019).
33. Latour, B. *Science in Action: How to Follow Scientists and Engineers through Society*; 11. print.; Harvard Univ. Press: Cambridge, MA, USA, 2003; ISBN 978-0-674-79291-3.
34. Vezzoli, C.; Penin, L. Campus: "lab" and "window" for sustainable design research and education: The DECOS educational network experience. *Int. J. Sustain. High. Educ.* **2006**, *7*, 69–80. [CrossRef]
35. Evans, J.; Jones, R.; Karvonen, A.; Millard, L.; Wendler, J. Living labs and co-production: university campuses as platforms for sustainability science. *Curr. Opin. Environ. Sustain.* **2015**, *16*, 1–6. [CrossRef]
36. Hill, L.M.; Wang, D. Integrating sustainability learning outcomes into a university curriculum: A case study of institutional dynamics. *Int. J. Sustain. High. Educ.* **2018**, *19*, 699–720. [CrossRef]

37. Dmochowski, J.E.; Garofalo, D.; Fisher, S.; Greene, A.; Gambogi, D. Integrating sustainability across the university curriculum. *Int. J. Sustain. High. Educ.* **2016**, *17*, 652–670. [CrossRef]
38. Urbanski, M.; Rowland, P. STARS as a Multi-Purpose Tool for Advancing Campus Sustainability in US. In *Sustainable Development and Quality Assurance in Higher Education*; Fadeeva, Z., Galkute, L., Mader, C., Scott, G., Eds.; Palgrave Macmillan: London, UK, 2014; pp. 153–182. ISBN 978-1-349-49873-4.
39. White, G.B.; Koester, R.J. STARS and GRI: Tools for Campus Greening Strategies and Prioritizations. *Sustain. J. Rec.* **2012**, *5*, 100–106. [CrossRef]
40. Colorado State University Colorado State University | Scorecard | Institutions | AASHE STARS. Available online: https://stars.aashe.org/institutions/colorado-state-university-co/report/2017-02-07/ (accessed on 5 November 2018).
41. Western University Western University | Scorecard | Institutions | AASHE STARS. Available online: https://stars.aashe.org/institutions/university-of-western-ontario-on/report/2018-02-01/ (accessed on 5 November 2018).
42. Yale University Yale University | Scorecard | Institutions | AASHE STARS. Available online: https://stars.aashe.org/institutions/yale-university-ct/report/2018-06-29/ (accessed on 5 November 2018).
43. University of Alberta University of Alberta | Scorecard | Institutions | AASHE STARS. Available online: https://stars.aashe.org/institutions/university-of-alberta-ab/report/2017-06-30/ (accessed on 5 November 2018).
44. Drogos, D.J. Sustainability Curriculum Inventory and Literacy Assessment: The Influence of Values on Knowledge of and Perceived Importance of Sustainability Components. Master's Thesis, Southern Illinois University Carbondale, Carbondale, IL, USA, 2013. Theses Paper 1316. Available online: https://opensiuc.lib.siu.edu/cgi/viewcontent.cgi?article=2330&context=theses (accessed on 19 January 2019).
45. California State University, Los, Angeles California State University, Los Angeles | Scorecard | Institutions | AASHE STARS. Available online: https://stars.aashe.org/institutions/california-state-university-los-angeles-ca/report/2016-06-06/ (accessed on 5 November 2018).
46. Southern Illinois University Carbondale Southern Illinois University Carbondale | Scorecard | Institutions | AASHE STARS. Available online: https://stars.aashe.org/institutions/southern-illinois-university-carbondale-il/report/2016-11-23/ (accessed on 5 November 2018).
47. University of Pennsylvania University of Pennsylvania | Scorecard | Institutions | AASHE STARS. Available online: https://stars.aashe.org/institutions/university-of-pennsylvania-pa/report/2018-02-21/ (accessed on 5 November 2018).
48. University of Toronto Course Finder. Available online: http://coursefinder.utoronto.ca (accessed on 18 January 2019).
49. Wilfrid Laurier University Wilfrid Laurier University | Scorecard | Institutions | AASHE STARS. Available online: https://stars.aashe.org/institutions/wilfrid-laurier-university-on/report/2013-12-20/ (accessed on 5 November 2018).
50. Sustainable Development Solutions Network—Australia/Pacific. *Getting Started with the SDGs in Universities: A Guide for Universities, Higher Education Institutions, and the Academic Sector*; SDSN: Melbourne, Australia, 2017.
51. *Transforming Our World: The 2030 Agenda for Sustainable Development*; United Nations General Assembly: New York, NY, USA, 2015.
52. Le Blanc, D. Towards Integration at Last? The Sustainable Development Goals as a Network of Targets: The sustainable development goals as a network of targets. *Sustain. Dev.* **2015**, *23*, 176–187. [CrossRef]
53. United Nations General Assembly. *Work of the Statistical Commission Pertaining to the 2030 Agenda for Sustainable Development*; United Nations General Assembly: New York, NY, USA, 2017; p. 25.
54. Janoušková, S.; Hák, T.; Moldan, B. Global SDGs Assessments: Helping or Confusing Indicators? *Sustainability* **2018**, *10*, 1540. [CrossRef]
55. Sustainable Development Solutions Network Sustainable Development Solutions Network | Vision and Organization. Available online: http://unsdsn.org/about-us/vision-and-organization/ (accessed on 5 November 2018).
56. Grin, J. The politics of transition governance in Dutch agriculture. Conceptual understanding and implications for transition management. *Int. J. Sustain. Dev.* **2012**, *15*, 72. [CrossRef]

57. University of Toronto Career & Co-Curricular Learning Network. Available online: https://clnx.utoronto.ca/ccr/overview.htm (accessed on 18 January 2019).
58. University of Toronto Ulife. Available online: https://www.ulife.utoronto.ca/ (accessed on 18 January 2019).
59. Association for the Advancement of Sustainability in Higher Education STARS Participants & Reports. Available online: https://stars.aashe.org/institutions/participants-and-reports/ (accessed on 5 December 2018).

sustainability

Article

It's a Hit! Mapping Austrian Research Contributions to the Sustainable Development Goals

Annemarie Körfgen [1,*], Klaus Förster [1], Ingomar Glatz [1], Stephan Maier [2], Benedikt Becsi [3], Anna Meyer [4], Helga Kromp-Kolb [3] and Johann Stötter [1]

1 Faculty of Geo- and Atmospheric Sciences, Institute of Geography, University of Innsbruck, 6020 Innsbruck, Austria; klaus.foerster@uibk.ac.at (K.F.); ingomar.glatz@student.uibk.ac.at (I.G.); hans.stoetter@uibk.ac.at (J.S.)
2 Faculty of Civil Engineering, Institute of Technology and Testing of Construction Materials, Graz University of Technology, 8010 Graz, Austria; stephan.maier@tugraz.at
3 Centre for Global Change and Sustainability, University of Natural Resources and Life Sciences, 1180 Vienna, Austria; benedikt.becsi@boku.ac.at (B.B.); helga.kromp-kolb@boku.ac.at (H.K.-K.)
4 Resources Innovation Center Leoben, Montanuniversitaet Leoben, 8700 Leoben, Austria; anna.meyer@unileoben.ac.at
* Correspondence: annemarie.koerfgen@uibk.ac.at; Tel.: +43-512-507-54072

Received: 30 August 2018; Accepted: 13 September 2018; Published: 14 September 2018

Abstract: The UN Sustainable Development Goals (SDGs) present a global agenda addressing social, economic, and environmental challenges in a holistic approach. Universities can contribute to the implementation of the SDGs by providing know-how and best-practice examples to support implementation and by integrating issues of sustainability into their operations, research, education, and science-society interactions. In most of the signatory countries of the Agenda 2030, an overview of the extent to which universities have already addressed the SDGs in research is not available. Using the example of universities in Austria, this study presents a tool to map research that addresses sustainability topics as defined by the SDGs. The results of an analysis of scientific projects and publications show current focus areas of SDG related research. Research on SDG 3 (Good Health and Well-Being) and SDG 4 (Quality Education) is well represented by universities in Austria, while other SDGs, such as SDG 1 (No Poverty) or SDG 14 (Life Below Water), are under-represented research fields. We anticipate the results will support universities in identifying the thematic orientation of their research in the framework of the SDGs. This information can facilitate inter-university cooperation to address the challenge of implementing the SDGs.

Keywords: SDGs; agenda 2030; higher education; responsible science; grand challenges; keyword search; research database; interdisciplinarity; university cooperation; sustainable development goals and universities

1. Introduction

The Anthropocene is the epoch characterised by steadily increasing human impact on all natural environmental systems [1]. The effects of human activity on ecosystems have caused an overshoot of planetary boundaries in many cases [2], which results in environmental, social, and technical challenges, such as the loss of biodiversity or structural changes in society and technology. Typically, these change processes are marked by high complexity, resulting from multiple interactions and interdependencies among themselves [3]. To cope with such complex challenges, integrated approaches to sustainable development and integration of stakeholders at all levels is necessary. Here, the UN Sustainable Development Goals (SDGs) present a global political agenda, which addresses a range of social, economic, and environmental challenges [4]. Building upon the UN Millennium Development

Goals (MDGs) [5], the 17 SDGs, with their 169 targets, aim towards more sustainable lifestyles, economic patterns, and provision of ecosystem services. Like many other nations, Austria has pledged the implementation of the SDGs on a national level [6]. The need for a holistic commitment to the SDGs by integrated policy approaches that respect interdependencies between sustainability challenges was outlined [7–9]. To make the extensive SDG package more easily accessible, different clustering approaches were suggested, aiming to reduce the complexities of the original UN framework. Considering these clusters, SDGs could be grouped according to systems [10], such as 'Energy and climate' (SDGs 7 and 13), 'Agriculture, food, and terrestrial' (SDGs 2 and 15), or 'Economic development and equity' (SDGs 1, 5, 8, 9, and 11). Other approaches interlink SDGs according to their functions, such as 'Social objectives' (SDGs 1, 3, 4, 5, and 10), 'Economy' (SDGs 8, 9, 11, and 12), or 'Environment' (SDGs 13, 14, and 15) [10,11]. Despite these efforts, political strategies are often still 'siloed' and tackle single issues instead of packages of topics [7], and achievement of the SDGs is still far off. To systematically measure the success of SDG implementation in different countries, a set of indicators was introduced by the UN [12] and broken down to different levels, such as the European Union [13] or nation states [14]. These indicators guide countries with distinct statistics to define their contributions to fulfilling the Agenda 2030. Until now, the performance of all 193 global UN member states is generally situated on a low level, and not a single country is on track towards achieving all SDGs [15]. Many countries, among them Austria, reach an ecological footprint far beyond the worldwide bio-capacity [16]. Life-cycle analyses show that Austria exceeds its natural budget by even higher factors [17]. In light of these facts, there is clearly still a long way to go towards fulfilment of the SDGs. Efforts must be made in various realms and areas of societal and political, as well as educational and scientific, life.

When thinking about implementing the SDGs, higher education institutions (HEIs) have a major responsibility to act as a driving force [18–21]. Scientifically, the SDG framework is understood neither as a substitute nor as a final solution for the process of critically discussing sustainable development, which remains a basic scientific duty. However, the SDGs represent a helpful momentum to introduce sustainable development to universities, who can contribute to this topic in a variety of ways: Basic and applied research can address real-world problems, societal needs, mind sets, and technologies necessary to break new ground of and for sustainability. Moreover, it can ask curiosity-driven questions that have not been asked before [22] and support the co-production of knowledge that needs to develop further in the relevant scientific fields [23]. HEIs can take on a role as change agents for societal transformation at the interface between scientific, political, and societal stakeholders and institutions. In this context, knowledge production should be understood as a participative process, transforming science from 'research that informs' towards 'research that transforms' [20].

To support societal change, systemic views across disciplines are needed [20]. Not only in research, but also in education, this holistic view is essential to educate future decision makers in critical and system thinking. Thus, HEIs can substantially contribute to strengthening sustainable development by integrating issues of sustainability into research, education, and science-society interaction, fostering reflective thinking, and supporting students in developing the skills to cope with complex problems, like Global Grand Challenges [8,21,24]. Students are often change agents, who drive sustainability movements at universities. Thus, they play a vital role in transforming HEIs, while at the same time experiencing and learning how to implement sustainability practices in their surroundings [25]. Further, HEIs can model sustainability practices for society, like implementing sustainable measures on the campus itself, and thus, as a first mover, they offer a leading example for practical processes of sustainability implementation [26].

Moving out of the campuses and labs, HEIs further interact with policy and fields of implementation of sustainability measures. Therefore, on the one hand, governmental support and strong partnerships are needed to strengthen HEIs as important drivers of sustainable development, [20]. On the other hand, HEIs can inform public policy regarding sustainable development and provide the knowledge base necessary for decision making and developing options for sustainability pathways [22]. Therefore, links and partnerships between political and scientific players need to be strengthened [8].

To summarise, HEIs can support an implementation of SDGs through:

- Performing problem-oriented real-world research;
- critically reflecting the SDGs and associated measures;
- educating future decision makers by fostering critical and systems-thinking;
- offering best-practice examples for sustainable development on campus; and
- strengthening the nexus at the policy-science-society interfaces.

To support HEIs in these tasks, the Austrian network, 'Alliance for Sustainable Universities', has initiated the project, *UniNEtZ—Universitäten und nachhaltige Entwicklungsziele* (*translation: Universities and Sustainable Development Goals*). This project aims at strengthening cooperation and networks between universities to integrate sustainable development as framed by the SDGs into research and education. Further, *UniNEtZ* aims to strengthen the interactions between science, society, and policy. In the sense of a value oriented third mission of universities [27,28], the project finally aims at signposting options for actions to political and societal decision makers regarding the implementation of SDGs in Austria, thus going far beyond a pure, classical assessment report of focus areas of research in the fields of the SDGs. The participating universities take over responsibility for the coordination of research, education, and communication activities on different SDGs. Steps taken so far have included numerous meetings between participating universities to develop the project as well as extensive negotiations with the relevant political stakeholders. Interlinkages between SDGs and targets are of particular importance to develop options that are compatible with multiple SDGs. By means of multiplication of sustainability topics into the education system, students and teacher educators will be involved into these activities as well. Several discussions between the participating universities have been dedicated to the question of how education for sustainable development can be fostered at universities. Sustainability issues should be integrated into training, study programmes from Bachelor up to PhD, teacher education, and life-long learning offers for alumni groups. A strong collaboration with political stakeholders, an incorporation of SDGs into the universities' structures, and the knowledge of available competencies and initiatives in the field of sustainability research, amongst others, have been identified as factors of success of *UniNEtZ*. Against this background, the aims of the project require knowledge about existing expertise in the research field of sustainable development, identifying both focus areas and topics that are hitherto underrepresented. This knowledge might help to detect focus research fields that can already provide support for political decisions with regard to the SDGs, and identify other research fields that still need to be strengthened to provide specific options for political action. Furthermore, this information provides docking points for establishing networks between different HEIs or research institutions that collaborate in implementing the SDGs.

However, an analysis of the extent to which universities in Austria have already addressed the SDGs in research is not available yet. Our study investigates how the SDGs are represented in the current Austrian research landscape in order to build upon existing expertise. For this purpose, digital mapping was conducted with thirteen universities in Austria to find current focus areas of sustainability research. The approach of this study is to develop a tool to map sustainability efforts in research at HEIs, based on the definition of sustainable development proposed by the SDGs. This tool can easily be adapted for similar analyses for other institutions and internationally to also map research activities on the SDGs on an even wider scale.

2. Materials and Methods

With the overall aim to identify SDG related focus areas of academia in Austria, the study design grounds on a keyword search, utilising an iteratively developed database of SDG terminology (Figure 1). The keyword search was applied to map scientific publications and research projects of the participating universities from the period, 2013–2017. This period was chosen because it encompasses the most recent activities, which—given an average project run time of three years—ended no more than two years before.

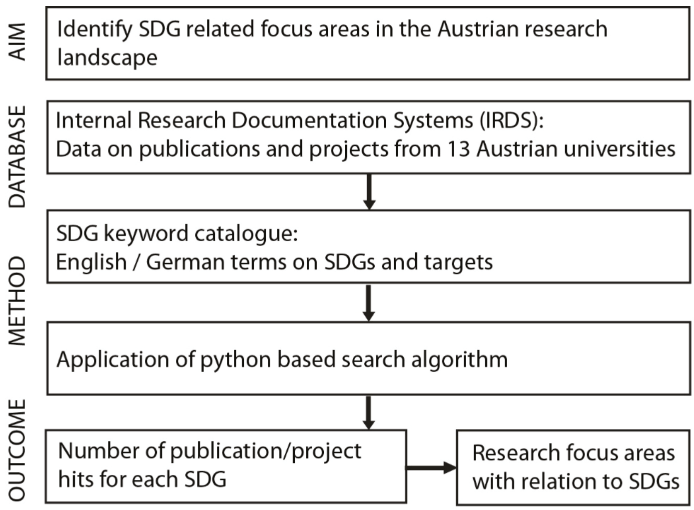


Figure 1. Work flow and study design for the Sustainable Development Goals (SDG) mapping of research activities of universities in Austria.

2.1. Data Basis

For the analysis, datasets from 13 universities in Austria (of 22 universities in Austria overall) with major, technical, artistic, musical, or medical scope were available, comprising about 155,000 publications and 17,000 projects in total. These datasets were extracted from the internal research documentation systems of the universities (IRDS). To ensure homogeneous data, some requirements for the provided datasets were defined for all universities. As a minimum, datasets included title, ID, authors, type of publication, publication year, and, as far as available, abstracts or project descriptions.

2.2. Keyword Catalogue

To map current research activities on the SDGs, a detailed keyword catalogue was developed. The official documents on the UN Sustainable Development Goals [4], including the 169 targets, were screened for prevalent words. In a semantic approach, synonyms were derived from these basic words. Additionally, the list was matched with existing catalogues [29]. In an interdisciplinary process, including stakeholders from the partner universities, the SDG keyword catalogue was continuously discussed and developed. To improve the suitability and accuracy of the catalogue with regards to the SDGs, the keywords were tested in an iterative process. In a test run, keywords were applied to a database from one of the universities and then manually screened for errors. Some keywords were excluded from the list because the range of hits was too broad. As a consequence, publications and projects unrelated to the SDGs were identified by the algorithm. Other keywords had to be generalised because terminologies defined too narrowly did not deliver any hits, whereas some words had to be used in collocations to avoid misleading hits (Table 1). In the scope of this publication/project, the term, 'hits', refers to publications/projects with relation to SDGs. If several keywords within one SDG match a publication/project, this publication/project is counted as just one single hit. Publications/projects that are assigned to various SDGs are counted as one hit each in all of the relevant SDGs. After this transparent and participative process, the final catalogue comprised a total of ca. 1000 keywords, formulated in English and German.

Table 1. Examples from the keyword list, with applied keywords and excluded terminologies.

Keyword	SDG	Comment
breadline	1	tested and validated
sustainable agriculture	2	tested and validated
untreated wastewater	6	tested and validated
coral bleaching	14	tested and validated
mental health	3	tested and validated collocation, adapted from 'mental', because of word confusion: 'Mental' can be misleading when a component of other words, e.g., 'fundamental'
care	4	excluded, because of word confusion: 'Care' can be misleading when a component of other words, e.g., 'calcareous alps'
emissions	7	excluded, because not precise enough, leading to unsuitable hits

2.3. Keyword Search

The Python programming language was used to import the datasets into a PostgreSQL database and run queries to filter publications and projects matching the developed SDG keyword list. For the search, keywords were reduced to word roots, allowing the identification of word variations. The algorithm further includes Boolean operators. By applying this code, publications and projects were automatically assigned to one or more of the 17 SDGs. We applied the search to titles and abstracts of the datasets, as far as they were available. Through this approach, statistics on the distribution of the SDGs were retrieved from the analysed datasets.

3. Results

To identify SDG-relevant research activities of universities in Austria, the sum of publications and projects that generated hits in the keyword search was assumed as an indicator for the involvement of the university in the respective SDG. The search algorithm allowed for the option of attributing the entity of one publication or project to more than one SDG due to thematic intersections. For instance, a publication dealing with climate change education could be assigned to both SDG 4 (Quality Education) and SDG 13 (Climate Action), as keywords from both categories create hits for the publication. Table 2 shows the total number of analysed publications and projects (n_{tot}) compared to the total number of hits for all SDGs from the keyword search (n_{hits}). About 18% of the analysed publications and about 21% of the analysed projects are related to SDGs.

Viewing the accumulated publications for each SDG (Figure 2b), SDG 3 (Good Health and Well-Being) shows a high percentage, followed by SDG 4 (Quality Education), SDG 15 (Life on Land), and SDG 11 (Sustainable Cities and Communities). The analysis of projects shows a strong presence of SDG 4 (Quality Education), followed by SDG 15 (Life on Land), SDG 11 (Sustainable Cities and Consumption), and SDG 13 (Climate Action). Some SDGs, such as SDG 1 (No Poverty), SDG 2 (Zero Hunger), or SDG 14 (Life Below Water), are less pronounced. While the analysis patterns are similar for most of the SDGs when comparing the publications and projects analysis, SDG 3 is obviously more represented in publications than in research projects. In contrast, the share of projects is higher than the share of publications in the field of SDG 4.

As stated in Table 2, a smaller set of projects than publications was analysed with the methodology described. For clarification, it needs to be added that some universities were not able to provide project data as secrecy regulations and infringements hinder any analyses of project databases. Therefore, the number of projects does not mirror the total number of projects implemented by the 13 universities, which delivered data for the mapping.

Table 2. Database with number of total analysed and hits for publications and research projects. Publications/projects can refer to single SDGs (x = 1) or several SDGs (x = 2–15).

Database		Publications	Projects
n_{tot} Total no. of analysed publications/projects		154,806	17,071
n_{pubs} Total no. of publications/projects related to SDGs		28,229	3581
No. of publications with [x] related SDGs	x = 1	19,859	1964
	x = 2	4677	669
	x = 3	1957	297
	x = 4	800	214
	x = 5	419	146
	x = 6	245	101
	x = 7	121	69
	x = 8	69	52
	x = 9	39	28
	x = 10	20	21
	x = 11	7	12
	x = 12	10	3
	x = 13	5	3
	x = 14	1	1
	x = 15	0	1

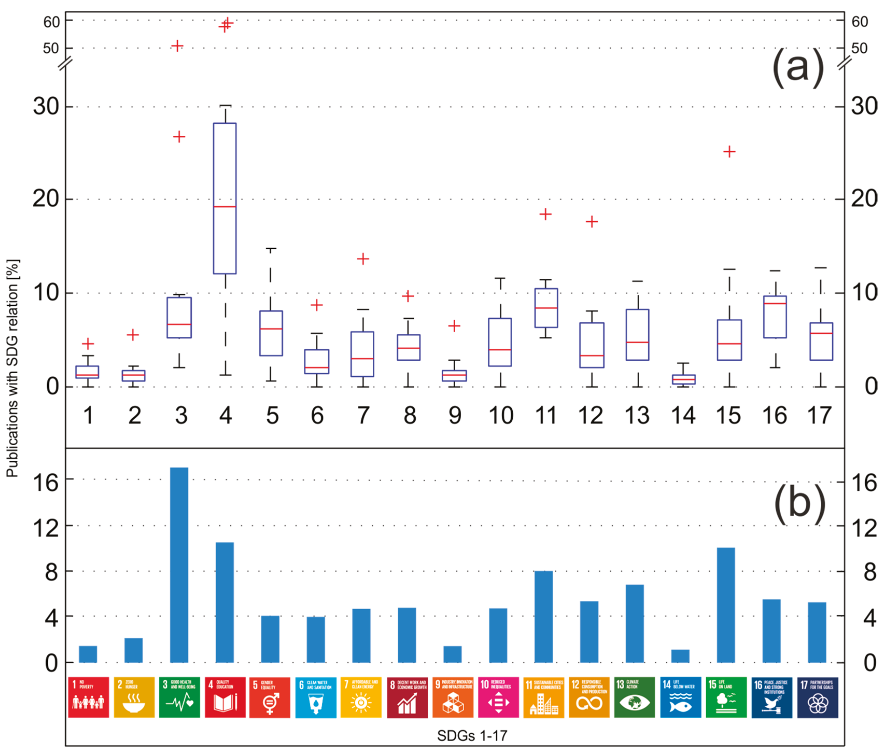


Figure 2. Publications of all universities: (**a**) Boxplots indicating mean and standard deviation, red crosses indicate outliers, and (**b**) accumulated distribution in percent.

A closer look at these results reveals that there are differences in the distribution of thematic focus areas between universities, which are indicated by the spread of the boxplot diagrams (Figures 2a and 3a). The location of the median indicates whether this spread follows a normal distribution (median located in the middle of the box), if there are just a few universities with a strong focus (median close to the lower limit of the box), or only a few laggards (median close to the upper limit of the box) in the respective SDG. For instance, there is a high share of publication hits related to SDG 3 (Figure 2b), however, the median shown in Figure 2a is low compared to the maximum. This suggests that SDG 3 has a strong publishing focus at a few universities, while the average is lower. These results highlight that there are some SDGs that are rather well covered by universities focusing on thematic niches, however, they do not represent the mainstream of SDG related research at universities in Austria. For example, in the case of SDG 3 (Good Health and Well-Being), topics are mostly covered by medical universities. On the other hand, research on SDGs, such as SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities), is covered by a broad range of universities.

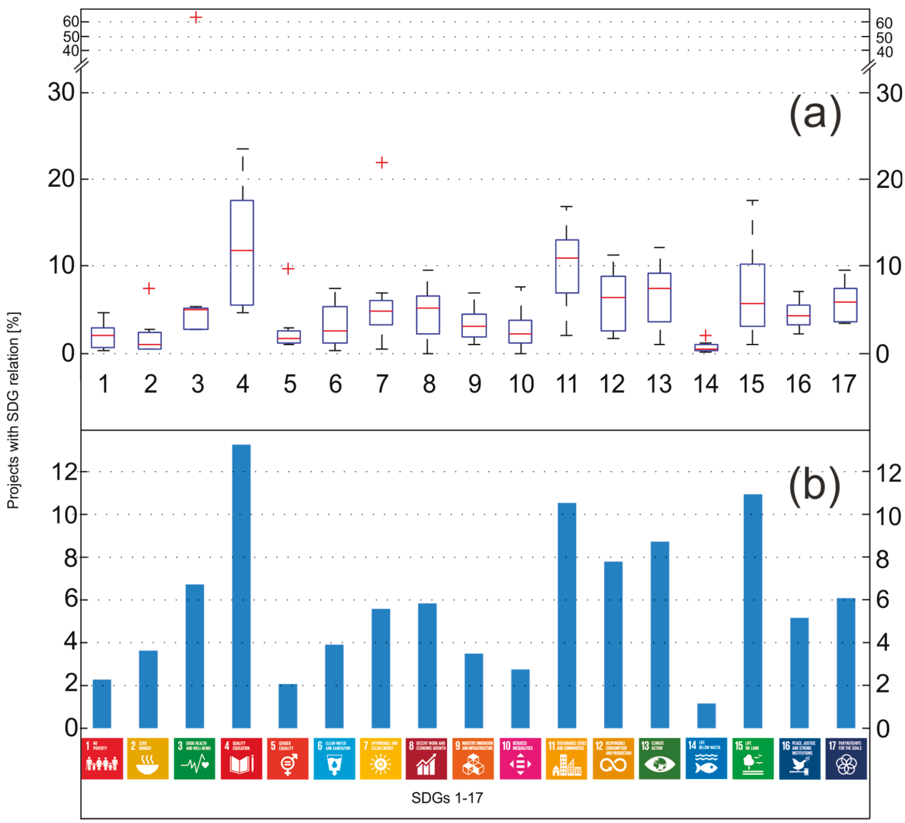


Figure 3. Projects of all universities: (**a**) Boxplots indicating mean and standard deviation, red crosses indicate outliers, and (**b**) accumulated distribution in percent.

4. Discussion

The study at hand draws a picture of the current focus areas of research at universities in Austria concerning the SDGs. This quantitative assessment of publication and project activities is considered to be an impression, not the final picture, as not all universities in Austria are represented. Some universities in Austria have started their own efforts to analyse their SDG-related activities and have arrived at results with varying degrees of agreement with the results of this study. As they applied other mapping methods, the results are not directly comparable. However, considering the high number of analysed publications and research projects, as well as the observation period of five years integrated into the study at hand, some statements can be derived from the general status of research with relation to the SDGs at universities in Austria.

4.1. Discussion of the Methods

In the frame of this investigation, publications and projects have been analysed. To gain a holistic impression of research activities, different dissemination formats of research should be considered. For example, universities with an artistic, dramatic, or musical scope do not primarily focus on peer-reviewed publications, but might rather disseminate scientific outcomes through other formats, such as theatre plays or artwork. The fact that this analysis exclusively focuses on publications and projects does not express a preference for these formats. The societal outreach of artistic formats might even be higher in some cases [30]. However, in the frame of this study design, an analysis of other formats was not possible, but could be the subject of further research.

Integrating education for sustainable development into HEIs plays a crucial role in SDG implementation. Therefore, a similar mapping applied to those education formats addressing sustainability topics would deliver valuable insights and help to foster a stronger integration into the education system. The role of universities as educators for future teachers, who are multipliers of sustainability knowledge, should be highlighted at this point. However, as the database for education formats was incomplete in most cases, a mapping could not yet be applied and will be the subject of further research.

In addition, the selection of keywords influences the outcome. As the list of keywords comprises about 1000 carefully selected words, the output is regarded as relatively robust. The method can be automated to some extent and is able to handle big data sets. Further, the results are reproducible, comparable, and replicable, and, thus, the tool can be applied to other institutions as well. Nevertheless, a disadvantage of the application of this method in an interdisciplinary academic approach is that the necessary steps can be quite time consuming, especially when identifying the right keywords, reiteratively discussing keywords with experts and stakeholders, programming software for the analysis, gaining access to the datasets, and testing the outcomes for plausibility. Alternative methodologies could include questionnaires with stakeholders at the respective institutions. The decision was made against such an interview approach because there could be too great a bias in selecting interviewees based on existing cooperation, which, consequently, would not deliver representative results. Further, only researchers that are familiar with the concept of the SDGs would identify their publications as being relevant in this context. It was assumed that, in some cases, SDG related research is conducted without consciously being labelled as that. Further, the method of identifying relevant stakeholders by a snowball system bears the potential to focus on one community, while losing sight of other stakeholders or disregarding some that have been unknown so far. Database mapping is a commonly applied tool in research on university activities and presents a more homogeneous approach. Stakeholders and activities that are not yet involved in the networking activities on SDGs at universities in Austria can also be identified with this method. However, a pure quantitative approach, like the one applied here, could ignore some facts. As the keyword search does not include a weighing of the direct relevance of SDG research, a qualitative completion of the study is recommended.

4.2. Discussion of the Outcomes

Generally, social and economic goals are reasonably well-represented by the SDGs, whereas environmental targets are only slightly integrated into policy measures [31]. This trend is also reflected by the outcomes of our study, where social objectives prevail. Because basic human needs are underpinned by environmental systems, some argue that environmental objectives should be mainstreamed, e.g., by integrating respective targets more strongly also into those SDGs with a social or economic focus [32]. Especially, goals, such as SDG 8 (Decent Work and Economic Growth), bear the potential to be achieved through undermining the 'Earth's life-support system' [32].

The strong representation of SDG 4 (Quality Education) in publications and projects across all universities (Figures 2a and 3a) can be seen as an advantage because SDG 4 is the goal with the most impact on all other SDGs, and is considered to influence the whole SDG system [32]. Of course, it should be considered that this quantitative approach cannot express single research niches, which might not stand out in the results; however, nonetheless, it delivers valuable contributions to understanding and addressing the SDGs.

A central question that needs to be addressed is whether some sustainability goals, such as SDG 1 (No Poverty), require more attention. Comparing the results of the study at hand with the status of Austrian SDG achievement can deliver some insights here. According to the SDG Index and Dashboards Report [15], Austria is ranked ninth in an international comparison between signing parties of the Agenda 2030. It has to be noted that SDGs with indicators measuring social and economic wellbeing are already on a comparably high level in Austria, meaning they are much closer to being reached than in other countries with less wealth. However, SDGs by their origin are defined as issues on a global scale, therefore, an SDG achievement of a nation, or on a national scale, must be considered differently than an achievement on the global scale [33]. For instance, the SDG ranking demonstrates that Austria is on a good track with SDG 1, whereas for the achievement of all other SDGs, either significant challenges or major challenges remain (Figure 4). The good performance of SDG 1, however, ignores the fact that economic wealth is often built on an externalisation of side-effects in countries with worse SDG indexes. Environmental impacts of production and consumption in industrial states are often shifted to developing countries [34]. Lim et al. further argue that SDG 1 shows some gaps, as it 'does not facilitate the redistribution and restructuring of wealth required to address poverty as a global issue' [32] (p. 5). Thus, achievement of SDG 1 in one country does not necessarily indicate progress on a global scale. There are interdependencies between SDG 1 and other goals, such as SDG 2 (Zero Hunger) or SDG 12 (Responsible Consumption and Production), due to spillover effects, especially generated by OECD countries in trade [15]. These spillovers generally describe the negative or positive impacts of one country on the SDG performance of another country and are calculated into the SDG index [35]. According to the SDG Index and Dashboards Report 2018, 'especially high-income countries generate high environmental, economic, and security spillovers, which undermine other countries' efforts to achieve the SDGs' [15] (p. 8). The low performance in SDG 12, SDG 13, and SDG 17 demonstrated in the SDG Index and Dashboards Report might be a hint that international cooperation should be fostered in Austria, as these topics represent issues that can only be solved on a global scale. Strengthening international cooperation on the institutional level is the aim of SDG 17, therefore, Austria should focus more on this goal to address these unmet challenges. These results encourage deeper research to support advancements there. The findings of the SDG mapping at hand indicate that SDGs 12 and 13 already seem to be quite well addressed in research projects (Figure 3b) and are covered to some extent in publication activities (Figure 2b). In contrast, SDG 17 seems not to get the attention it needs in order to address the issues suggested in the SDG Index and Dashboards Report [15] (Figures 2b and 3b).

Further, the SDG Index and Dashboards Report [15] suggests that advancements in SDG 14 (Life Below Water) are necessary, as most states perform badly, including Austria. Although SDG 14 is not of great relevance to Austria at first glance, a low performance is the result of spillover effects through pollutants and the use of global commons, such as the ocean. Considering the low representation of research activities in Austria related to SDG 14 (Figures 2b and 3b), additional research would be useful to contribute to a deeper understanding of the relevant processes.

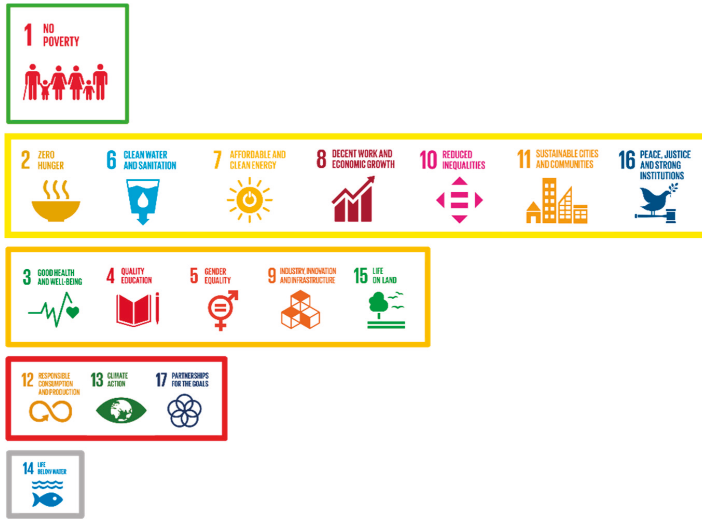


Figure 4. Results from the SDG Index and Dashboards Report 2018 for the country profile of Austria. The index is calculated based on the SDG indicators. Size of the icons correlates with SDG progress. A green rating denotes SDG achievement. Yellow and orange ratings indicate that significant challenges remain. Red indicates that major challenges must be overcome if the country is to meet the goal. Grey: Not sufficient (less than 50%) indicator data available for the respective SDG (Source: Adapted based on SDG Index 2018, p. 96).

5. Conclusions

The project, *UniNEtZ*, wants to build on existing SDG expertise and further empower universities to fulfil their new role as transformative forces. The results of the keyword search delivered valuable information on the status quo of university-based SDG research and aided the 13 universities in finding their roles and responsibilities within the project. Foremost, it highlights the currently existing SDG research competences at universities in Austria. This will be the cornerstone for formulating options for SDG implementation and will serve as an input for integrating sustainable development into research and education at universities in Austria. The results demonstrate that there is already strong expertise related to specific SDGs in research. In most cases, the picture of current focus areas in research on SDGs presented here corresponds well with the assessment of the SDG Index and Dashboards Report (SDG Index 2018). Thus, with their focus on research fields where challenges remain to achieve SDGs, universities in Austria seem to be able to contribute to paving the way to support the Austrian government in meeting the SDGs. In interpreting these findings, we need to consider that current basic research activities, which are not directly linked to the SDGs, can also substantially contribute to the development of SDG solutions; for example, by understanding natural and social processes or by identifying sustainability challenges. A key issue that has to be addressed is whether research activities in Austria should focus only on those sustainability challenges which mainly affect the country itself, or also on SDGs with indirect global interactions, such as SDG 14.

Further, the analysis provides a basis for network-building, delivering a comprehensive list of relevant research groups for each SDG. Collaboration between different scientific disciplines and political, as well as societal, stakeholders is key for preparing political options, even within a single goal. This holds true especially for interlinkages between SDGs, where measures to reach one target might jeopardise another [36]. Considering the status of the SDG Index, science could support the monitoring of SDG advancement and achievement, especially for those SDGs that are characterised by high complexity and mutual interactions. Further research into these SDG interactions in Austria will be necessary to understand the effects and consequences of each measure that is recommended by the researchers. It will also support clustering the SDGs according to their interactions, be they synergistic or antagonistic. Additionally, it enables evaluation of the options at hand, creating the possibility to tie packages of options with high synergistic potential for several SDGs or no-regret-options.

The transfer with and to societal and political stakeholders is decisive for the achievement of SDGs. For that, both scientific knowledge on the society side as well as societal knowledge on the science side is a vital pre-requisite and, thus, mandatory. In this sense, further research could investigate the exchange of knowledge between scientific and non-scientific stakeholders and monitor the transfer of such knowledge into practical fields of SDG implementation.

Last, but not least, the analysis in itself helped to improve the SDG competences of participating researchers and the project team, leading to ongoing discussions about the strengths and shortcomings of the keyword method, along with a deeper engagement with SDG terminology.

UniNEtZ will proceed with building strong cooperation between universities in Austria, further integrating issues of sustainability into research and education, and supporting governmental decisions. The project aims at signposting definite opportunities for action to advance towards sustainable development as defined by the SDGs.

Author Contributions: Conceptualization, A.K., I.G., K.F., S.M., B.B., A.M., H.K-K. and J.S.; Methodology, A.K., K.F., I.G., H.K-K. and J.S.; Software, K.F.; Formal Analysis, A.K., K.F., I.G. and J.S.; Writing—Original Draft Preparation, A.K. and J.S.; Writing—Review & Editing, A.K., I.G., S.M., B.B., A.M., H.K-K. and J.S.; Visualization, A.K., I.G., S.M. and J.S.; Supervision, H.K-K. and J.S.

Funding: The research was funded by the Austrian Federal Ministry of Education, Science and Research (BMBWF) BMBWF-37.782/0001-WF/V/4a/2017, the University of Innsbruck and the Graz University of Technology.

Acknowledgments: Special thanks to the great cooperation with the universities involved in UniNEtZ: Alpen-Adria University Klagenfurt, Danube University Krems, Graz University of Technology, Johannes Kepler University Linz, Medical University of Graz, Medical University of Innsbruck, Montanuniversitaet Leoben, Mozarteum University Salzburg, University of Applied Arts Vienna, University of Art and Design Linz, University of Graz, University of Innsbruck, University of Music and Performing Arts Vienna, University of Music and Performing Arts Graz, University of Natural Resources and Life Sciences Vienna, and Paris Lodron University of Salzburg.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Crutzen, P.J. Geology of mankind. *Nature* **2002**, *415*, 23. [CrossRef] [PubMed]
2. Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; Vries, W.; de Wit, C.A.; et al. Planetary boundaries: Guiding human development on a changing planet. *Science* **2015**, *347*, 1259855. [CrossRef] [PubMed]
3. Pradhan, P.; Costa, L.; Rybski, D.; Lucht, W.; Kropp, J.P. A Systematic Study of Sustainable Development Goal (SDG) Interactions. *Earth's Future* **2017**, *5*, 1169–1179. [CrossRef]
4. United Nations. *Transforming Our World: The 2030 Agenda for Sustainable Development*; United Nations: New York, NY, USA, 2015.
5. United Nations. *United Nations Millennium Declaration*; A/RES/55/2; United Nations: New York, NY, USA, 2000.
6. Bundeskanzleramt Österreich. *Annahme der 2030 Agenda für Nachhaltige Entwicklung, Umsetzung durch Österreich: Vortrag an den Ministerrat*; BKA-400.000/0008-IV/2015; Bundesministerium für Europa, Integration und Äußeres: Vienna, Austria, 2016.
7. Obersteiner, M.; Walsh, B.; Frank, S.; Havlík, P.; Cantele, M.; Liu, J.; Palazzo, A.; Herrero, M.; Lu, Y.; Mosnier, A.; et al. Assessing the land resource-food price nexus of the Sustainable Development Goals. *Sci. Adv.* **2016**, *2*, e1501499. [CrossRef] [PubMed]
8. Vaughter, P. *Beacons, Not Towers: How Higher Education Can Help Achieve the Sustainable Development Goals*; UNU-IAS Policy Brief Series; United Nations University: Tokyo, Japan, 2018.
9. Gratzer, G.; Keeton, W.S. Mountain Forests and Sustainable Development: The Potential for Achieving the United Nations' 2030 Agenda. *Mt. Res. Dev.* **2017**, *37*, 246–253. [CrossRef]
10. TWI2050 (Ed.) *Pathways toward Sustainable Future: TWI20150 Annual Meeting*; IIASA: Vienna, Austria, 2017.

11. Elder, M.; Bengtsson, M.; Akenji, L. An Optimistic Analysis of the Means of Implementation for Sustainable Development Goals: Thinking about Goals as Means. *Sustainability* **2016**, *8*, 962. [CrossRef]
12. United Nations. *Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development*; A/RES/71/313; United Nations: New York, NY, USA, 2018.
13. Eurostat. EU SDG Indicator Set 2018: Result of the Review in Preparation of the 2018 Edition of the EU SDG Monitoring Report. Available online: https://ec.europa.eu/eurostat/documents/276524/7736915/EU+SDG+indicator+set+2018+-+public+web+version+with+cover+note/c86cd681-a537-4f0c-9680-197f04888f12 (accessed on 14 September 2018).
14. Statistik Austria. Monitoring der UN Agenda 2030. 2017. Available online: http://www.statistik.at/web_de/statistiken/internationales/agenda2030_sustainable_development_goals/un-agenda2030_monitoring/index.html (accessed on 13 August 2018).
15. SDG Index. Global Responsibilities: Implementing the Goals. SDG Index and Dashboards Report. Available online: http://www.sdgindex.org/assets/files/2018/01%20SDGS%20GLOBAL%20EDITION%20WEB%20V9%20180718.pdf (accessed on 14 September 2018).
16. Wackernagel, M.; Hanscom, L.; Lin, D. Making the Sustainable Development Goals Consistent with Sustainability. *Front. Energy Res.* **2017**, *5*, 18. [CrossRef]
17. Narodoslawsky, M. Sustainable process index. In *Assessing and Measuring Environmental Impact and Sustainability*; Klemeš, J.J., Ed.; Butterworth-Heinemann: Oxford, UK, 2015; pp. 73–86.
18. Balsiger, J.; Förster, R.; Mader, C.; Nagel, U.; Sironi, H.; Wilhelm, S.; Zimmermann, A.B. Transformative Learning and Education for Sustainable Development. *GAIA—Ecol. Perspect. Sci. Soc.* **2017**, *26*, 357–359. [CrossRef]
19. German Advisory Council on Global Change (WBGU). *A Social Contract for Sustainability*; WBGU: Berlin, Germany, 2011.
20. Tilbury, D. Higher Education for Sustainability: A Global Overview of Commitment and Progress. In *Higher Education in the World 4: Higher Education's Commitment to Sustainability: From Understanding to Action*; Global University Network for Innovation (GUNI), Ed.; Palgrave Macmillan: Hampshire, UK, 2012.
21. Stephens, J.C.; Hernandez, M.E.; Román, M.; Graham, A.C.; Scholz, R.W. Higher education as a change agent for sustainability in different cultures and contexts. *Int. J. Sustain. Higher Educ.* **2008**, *9*, 317–338. [CrossRef]
22. Schmalzbauer, B.; Visbeck, M. *The Contribution of Science in Implementing the Sustainable Development Goals*; German Committee Future Earth: Stuttgart/Kiel, Germany, 2016.
23. Jasanoff, S. *States of Knowledge: The Co-Production of Science and the Social Order*; Routledge: Abingdon, UK, 2004.
24. Morin, E. Complex Thinking for a Complex World: About Reductionism, Disjunction and Systemism. *Syst. Connect. Matter Life Cult. Technol.* **2014**, *2*, 14–22.
25. Tappeser, V.; Meyer, A. Change-agents in sustainability governance institutional transformation at three institutions of higher education. In *Sustainable Development at Universities: New Horizons*; Leal, W.F., Ed.; Peter Lang Scientific Publishers: Frankfurt, Germany, 2012.
26. Ferrer-Balas, D.; Adachi, J.; Banas, S.; Davidson, C.I.; Hoshikoshi, A.; Mishra, A.; Motodoa, Y.; Onga, M.; Ostwald, M. An international comparative analysis of sustainability transformation across seven universities. *Int. J. Sustain. Higher Educ.* **2008**, *9*, 295–316. [CrossRef]
27. Bundesministerium für Wissenschaft, Forschung und Wirtschaft. *Der Gesamtösterreichische Universitätsentwicklungsplan*; BMWFW: Vienna, Austria, 2015.
28. Krainer, L.; Winiwarter, V. Die Universität als Akteurin der transformativen Wissenschaft: Konsequenzen für die Messung der Qualität transdisziplinärer Forschung. *GAIA Ecol. Perspect. Sci. Soc.* **2016**, *25*, 110–116. [CrossRef]
29. SDSN Australia/Pacific. *Getting Started with the SDGs in Universities: A guide for Universities, Higher Education Institutions, and the Academic Sector*; SDSN Australia/Pacific: Melbourne, Australia, 2017.
30. Heinrichs, H. Sustainability Science with Ozzy Osbourne, Julia Roberts and Ai Weiwei: The Potential of Arts-Based Research for Sustainable Development. *GAIA Ecol. Perspect. Sci. Soc.* **2018**, *27*, 132–137. [CrossRef]
31. Griggs, D.; Stafford Smith, M.; Rockström, J.; Öhman, M.C.; Gaffney, O.; Glaser, G.; Kanie, N.; Noble, I.; Steffen, W.; Shyamsundar, P. An integrated framework for sustainable development goals. *Ecol. Soc.* **2014**, *19*. [CrossRef]
32. Lim, M.M.L.; Jørgensen, S.P.; Wyborn, C.A. Reframing the sustainable development goals to achieve sustainable development in the Anthropocene—A systems approach. *Ecol. Soc.* **2018**, *23*, 22. [CrossRef]

33. Hartinger, R. *Agenda 2030 & die SDGs auf lokaler Ebene, Handlungsmöglichkeiten, Relevanz und Rahmenbedingungen für Kommunen und lokale Akteure*; Ökobüro, Allianz der Umweltbewegung: Vienna, Austria, 2018.
34. Schütz, H.; Moll, S.; Bringezu, S. *Globalisierung und die Verlagerung von Umweltbelastungen: Die Stoffströme des Handels der Europäischen Union*; Wuppertal Institute: Wuppertal, Germany, 2003.
35. Diaz-Sarachaga, J.M.; Jato-Espino, D.; Castro-Fresno, D. Is the Sustainable Development Goals (SDG) index an adequate framework to measure the progress of the 2030 Agenda? *Sustain. Dev.* **2018**, *3*, 1–9. [CrossRef]
36. Nilsson, M.; Griggs, D.; Visbeck, M. Map the interactions between Sustainable Development Goals. *Nature* **2016**, *534*, 320–322. [CrossRef] [PubMed]

sustainability

MDPI

Article

Assessing the Impacts of Higher Education Institutions on Sustainable Development—An Analysis of Tools and Indicators

Florian Findler [1,*], Norma Schönherr [1], Rodrigo Lozano [2] and Barbara Stacherl [1]

[1] Institute for Managing Sustainability, WU Vienna University of Economics and Business, Welthandelsplatz 1, A-1020 Vienna, Austria; norma.schoenherr@wu.ac.at (N.S.); barbara.stacherl@wu.ac.at (B.S.)
[2] Department of Industrial Development, IT and Land Management, University of Gävle, Kungsbäcksvägen 47, SWE-80176 Gävle, Sweden; rodrigo.lozano@hig.se
* Correspondence: florian.findler@wu.ac.at; Tel.: +43-1-31336-5133

Received: 31 October 2018; Accepted: 15 December 2018; Published: 22 December 2018

Abstract: Many higher education institutions (HEIs) have started to incorporate sustainable development (SD) into their system. A variety of sustainability assessment tools (SATs) have been developed to support HEIs to systematically measure, audit, benchmark, and communicate SD efforts. In recent years, stakeholders have increasingly asked HEIs to demonstrate their impacts on SD. These impacts are the direct and indirect effects an HEI has outside of its organizational boundaries on society, the natural environment, and the economy. This study analyzes to what extent SATs are capable of measuring the impacts that HEIs have on SD. A mixed-method approach, using descriptive statistics and an inductive content analysis, was used to examine 1134 indicators for sustainability assessment derived from 19 SATs explicitly designed for application by HEIs. The findings reveal that SATs largely neglect the impacts HEIs have outside their organizational boundaries. SATs primarily use proxy indicators based on internally available data to assess impacts and thus tend to focus on themes concerning the natural environment and the contribution to the local economy. Updating existing SATs and developing new ones may enable HEIs to fully realize their potential to contribute to SD.

Keywords: sustainable development; higher education; impacts; sustainability assessment; sustainability assessment tools; higher education institutions; sustainability indicators; sustainability reporting; education for sustainable development (ESD)

1. Introduction

Higher education institutions (HEIs) are increasingly acknowledged as a key driver for the development of sustainable societies [1]. Leveraging a unique set of skills, they act as transformative agents by shaping the mindsets and values of future leaders in academia, business, and politics [2,3]. The role of HEIs in achieving sustainable development (SD) was highlighted for the first time in the 1972 Stockholm Declaration on the Human Environment [4]. Since then, HEIs and their stakeholders have increasingly engaged in a number of global initiatives and expressed their commitment to SD in a variety of national and international declarations and charters [5]. Recent examples include the United Nations Higher Education Sustainability Initiative (UN HESI) and the UN Higher Education and Research for Sustainable Development (HESD) platform. Both initiatives foster the implementation of the Sustainable Development Goals (SDGs), as part of a globally agreed policy agenda for SD, in higher education [6,7].

In this context, HEIs have started to systematically assess and report their progress on their SD commitments [8,9]. An increasing number of sustainability assessment tools (SATs) have been developed to help HEIs in this endeavor [10,11]. SATs, in the broadest sense, can be understood as instruments that provide HEIs with a systematic set of procedures and methods to measure, audit, benchmark, and communicate their SD efforts [12,13], including economic, environmental, social, and inter-linking issues in the entire HEI system.

The design of these SATs, as well as the experiences of HEIs using them, and their limitations, have been documented in the literature (e.g., References [10,14]). Previous studies show that the most widely adopted SATs have focused mainly on policies and activities inside the organization, such as energy efficiency measures or measures to enhance sustainability literacy of students in educational programs (e.g., References [15,16]). Less emphasis has been placed on the impacts that HEIs actually have on society, the natural environment, and the economy outside the organization, e.g., contribution to climate change mitigation or alumni sustainability lifestyles [17,18].

The assessment of impacts on SD is a complex endeavor because impacts materialize along complex pathways, particularly in the area of research and education [19]. HEIs are often separated in time and space from such impacts and affected stakeholder groups, and thus they rely on sound instruments that support their assessment approaches. In addition, there is no universally agreed definition of "impact" in literature and practice. However, available studies agree on a number of characteristics central to the term. Impacts on SD are generally understood to comprise direct and indirect effects that an HEI has outside of its organizational boundaries on society, the natural environment, and the economy [20]. They arise from the variety of activities inside the HEIs' core elements, notably education, research, campus operations, outreach, and campus experiences [17,21].

The last decade has seen increased attention to the impacts of SD among stakeholders, including public and private funders, policy-makers, accreditation agencies, students, and faculty [22]. While an initial conceptual work on framing the multiple impacts of an HEI on SD has been proposed (see Reference [17]), the capability of SATs to provide systematic information on these impacts to meet accountability expectations of stakeholders more fully is less explored.

This study analyzes the indicators for sustainability assessment of 19 SATs. More specifically, it elucidates to what extent these indicators measure SD performance (inside the organization) and impacts on SD (outside the organization). The indicators that measure impacts on SD are further analyzed to identify the specific SD impact areas and themes addressed. Finally, the extent to which these indicators are able to capture the complex pathways from HEIs activities to specific SD impacts, i.e., whether they are capable of capturing both direct and indirect impacts, is examined.

The remainder of this article is structured as follows: Section 2 provides an overview of sustainability assessment and SATs in higher education and introduces the concept of impacts on SD; Section 3 describes the sample, the coding strategy, and the steps of the analysis; Section 4 presents the results and Section 5 discusses them; and Section 6 concludes the study.

2. Literature Review

Sustainability assessment and reporting practices in HEIs have gained increasing importance [23]. Consequently, a body of work dealing with sustainability assessment and reporting has developed within the wider literature on sustainability in higher education over the past decade [24]. Sustainability assessment and reporting's main objectives are: (1) Assessing organizations' such as HEIs' sustainability; (2) communicate it to its stakeholders; (3) benchmark against other organizations; (4) analyze how the organization affects and is affected by stakeholders; (5) assess and improve sustainability performance over time; and (6) plan the future direction of change towards SD in HEIs [25–28]. Despite the increasing amount of literature, in practice, sustainability assessment and reporting is still in a developmental stage [24,29].

Limitations of sustainability assessment and reporting in HEIs are the lack of a common understanding of SD, insufficient assessment and reporting guidelines, and the additional resources and time that are required to gather and process data [9,28,30]. In addition, senior management in HEIs demonstrates low responsibility for SD and as a result senior managers do not sufficiently support sustainability assessment and reporting practices [31].

2.1. Sustainability Assessment Tools in Higher Education

A number of SATs have been developed to facilitate sustainability assessment and reporting in practice [10,11]. SATs are instruments that offer HEIs a systematic set of procedures and methods to measure, audit, benchmark, and communicate their SD efforts [12,13]. SATs also provide a basis for organizational planning and strategy development [32] through operationalization and integration of SD into all core elements [13,14].

SATs can use different assessment approaches. Dalal-Clayton and Bass [25] distinguish three main approaches to sustainability assessment: Accounts, narrative, and indicators-based assessments. Accounts assessments draw on raw data, which is converted into a common unit (e.g., monetary, area, or energy). This high level of aggregation makes overall performance easily comparable. Narrative assessments, in contrast, use texts, graphics, and tabular data. They are highly flexible and provide the opportunity to explore detailed and unstructured data of all kinds with the objective of developing a rich picture of SD impacts, including trade-offs and systemic interrelationships. Both kinds of assessments have drawbacks; however, accounts assessments only cover select aspects of sustainability, and the high flexibility of narrative assessments entails limitations in transparency and consistency. Consequently, the usefulness of these approaches for monitoring, decision support, and strategy development is limited [25,33]. Indicator-based assessment is considered the most useful approach to achieve measurable, transparent, and comparable results and thus serves as the foundation of most SATs [34].

Indicators measure a specific aspect of SD (e.g., student sick days) that can be ascribed to a wider attribute or characteristic of a system (e.g., student health) [35]. Indicators are formulated in quantitative, quasi-quantitative, and qualitative terms [36]. Quantitative indicators measure, for example, physical units; quasi-quantitative indicators are based on ratings (e.g., yes/no scores); and qualitative or descriptive indicators include text or also graphics [25]. Indicators can also be divided into direct and indirect (proxy) indicators based on how they measure the phenomena [36].

Available SATs range from simple compliance-oriented tools focusing on operations via contextual explorative approaches to comprehensive approaches that allow interorganizational certification and benchmarking [15]. Previous studies analyzed SATs in higher education based on their sets of indicators and supporting documents and case study applications (see Table 1). Overall, these studies concur that SATs are still at an infant stage. The indicators that are used in these assessments focus mainly on governance issues and campus operations and to a large extent tend to neglect activities in research, education, and outreach (e.g., Reference [16]). In addition, the reviewed SATs have a strong focus on the environmental sustainability dimension neglecting social and economic issues (e.g., References [10,33]).

Table 1. Previous studies of sustainability assessment tools in higher education.

Author(s)	Tools Analyzed	Methodology	Main Findings
Shriberg (2002) [13]	$n = 11$ AISHE, Campus Ecology, Environmental EMS Self-Assessment, Environmental Workbook and Report, Greening Campuses, Grey Pinstripes with Green Ties, Higher Education 21's Sustainability Indicators, Indicators Snapshot Guide, Performance Survey, SAQ, State of the Campus Environment	A content analysis with a focus on strengths and weaknesses of tools was conducted.	The tools vary greatly in their purpose, function, scope, and state of development.
Yarime & Tanaka (2012) [16]	$n = 16$ AISHE, Campus Ecology, Campus Sustainability Selected Indicators Snapshot, College Sustainability Report Card, CSAF, CSAF core, CSARP, EMS Self-Assessment, Environmental Workbook and Report, GASU, Good Company's Sustainable Pathways Toolkit, HEPS, Penn State Indicator Report, SAQ, STARS, State of the Campus Environment	A mixed-method approach with a quantitative and a qualitative part was applied: (1) comparative analysis of criteria and (2) content analysis of individual indicators.	The main focus of the tools is on campus operations and governance issues. Education, research, and outreach are not well addressed.
Sayed et al. (2013) [37]	$n = 4$ SAQ, CSAF, CSRC, STARS	Each tool was rated based on 27 questions related to five areas of campus life of a specific university.	STARS was identified to be the most effective SAT. SAQ and CSAF have limitations in assessing SD in campus operations.
Fischer et al. (2015) [15]	$n = 12$ AISHE, Alternative Universal Appraisal, Conference of Rectors of Spanish Universities, CSAF, German Commission for UNESCO, Graz Model of Integrative Development, Green Plan, Innovación y Educación Ambiental en Iberoamérica, People & Planet, Red de Ciencia, Tecnología, SAQ, STARS, UI GreenMetric	A mixed-method approach with a quantitative and a qualitative part was applied: (1) comparative analysis of criteria and (2) introductory passages in supporting documents.	Indicators and criteria are biased towards the field of operations.
Bullock & Wilder (2016) [10]	$n = 9$ ACUPCC, College Sustainability Report Card, Grey Pinstripes with Green Ties, Pacific Sustainability Index (PSI), Princeton Review's Green Ratings, Sierra Club's Cool Schools, STARS, The Guardian's Green League, UI GreenMetric	Sustainability assessment frameworks and SATs based on the GRI-HE framework were evaluated.	The evaluated sustainability assessments and SATs are not comprehensive and lack coverage of the economic and social dimension of sustainability.
Alghamdi et al. (2017) [33]	$n = 12$ Adaptable Model for Assessing Sustainability in Higher Education, AISHE, Alternative University Appraisal, GASU, Green Plan, SAQ, STARS, Sustainable Campus Assessment System, Sustainable University Model, UI GreenMetric, Unit-based Sustainability Assessment Tool, University Environmental Management System	A desk study approach with quantitative and qualitative elements was applied including a review of research articles, academic books, network platforms, graduate theses, and websites.	The tools share similar characteristics in terms of their criteria and indicators, which can be grouped into: management, academia, environment, engagement, and innovation. Environmental indicators have the highest share among the tools.
Berzosa et al. (2017) [14]	$n = 4$ AISHE, SAQ, Sustain Tool, USAT	A descriptive analysis of SATs based on single case studies was performed.	The SATs positively influence creating specific plans in education, research, outreach, and campus operations. They have a strong focus on the environmental dimension and delivered similar outcomes.

2.2. Impacts of Higher Education Institutions on Sustainable Development

The studies examining SATs, as illustrated in Table 1, have focused on HEIs' policies and activities for SD occurring inside the organization (e.g., measures to enhance energy efficiency or sustainability literacy of students in educational programs [15,16]). However, external stakeholders such as public and private funders, policy-makers, and accreditation agencies have increasingly asked HEIs to more adequately assess and report about their impacts on SD as well—in other words, external stakeholders are increasingly interested to know what HEIs achieve through these activities and policies for wider society and the natural environment [22]. For example, the European Research Framework Program H2020 examines impacts as one of its three evaluation criteria [38], the Research Excellence Framework (REF) in the UK allocates public funding based on the presentation of research impacts by HEIs [39], and the Business School Impact System (BSIS) by the Management Development Network (EFMD) includes impacts into its accreditation evaluations [40]. This has led to an increasing need of HEIs to assess and report about their impacts. In this context, this paper seeks to examine to what extent existing SATs are capable of accounting for impacts that HEIs have on SD (e.g., climate change mitigation, social inclusiveness, and strengthening of the local economy).

Impacts refer to the effects that any organization, such as an HEI, has outside of its organizational or academic boundaries—on its stakeholders, the natural environment, the economy, and society in general [17,41]. Impacts are caused by the HEI as an organization and by its different organizational and individual level activities that take place in the core elements education, research, outreach, campus operations, and campus experiences [21,42]. Impacts may materialize in a variety of different SD impact areas, including the economy, societal challenges, the natural environment, policy making, culture, and demographics. Impacts can be directly (short-term effects, e.g., student sustainability literacy) or indirectly (long-term effects, e.g., sustainable lifestyles of graduates) attributed to the HEI or the activities that take place in its core elements (see Figure 1, [17]).

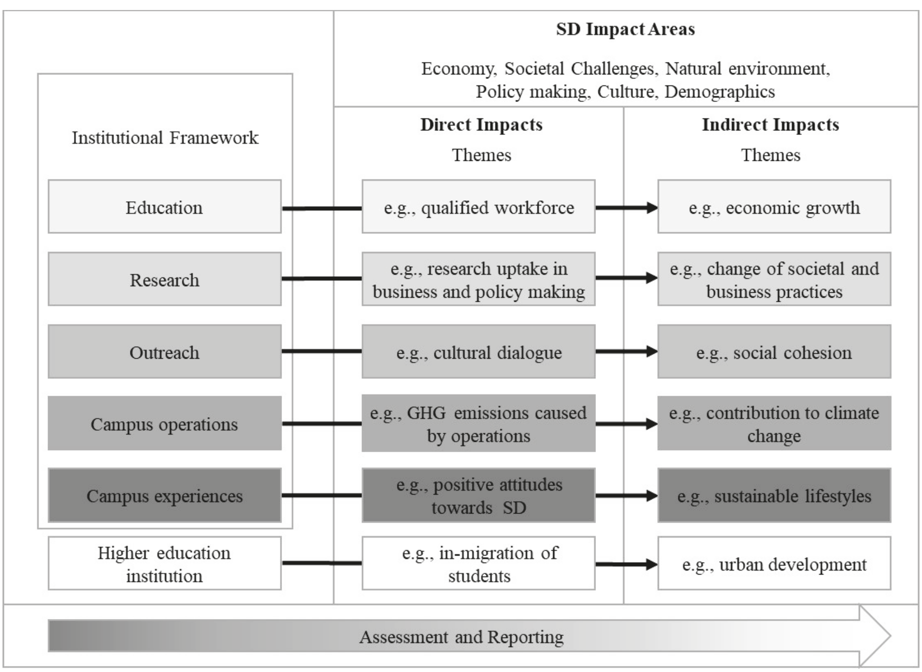


Figure 1. The SD impact framework of HEIs [17].

HEIs have to follow a whole institution approach that takes the impacts of all core elements into account to successfully manage their impacts (strengthening positive and reducing negative ones) [43]. This highlights the importance of broad-scale policies (institutional framework) to facilitate impact orientation in all core elements and the need of SATs to systematically assess and manage impacts [17].

Impact assessment is a challenging process because impacts may materialize along complex pathways [19]. On the one hand, HEIs generate impacts on SD through organizational activities within the core elements of the HEI (e.g., online learning contributes to climate change mitigation and the reduction of greenhouse gas [GHG] emissions, see Reference [44]) or through their sheer existence as an organization in a specific locality (e.g., an HEI attracts national and international students, which causes in-migration, demographic change, and cultural dialogue, see References [45,46]). On the other hand, impacts are caused by individual activities or behaviors (e.g., students with entrepreneurial attitudes may contribute to business creation and thus strengthen local economies). While HEIs may assess and analyze impacts on the organizational level via, for example, internal proxy data, impact assessment at the individual level is much more challenging because it requires additional data collection (e.g., alumni or student surveys).

3. Sample and Method

This research analyzes SATs in higher education by a applying a mixed-method approach based on quantitative and qualitative elements (as used by [47]). The research aims to provide new insights regarding the ability of currently existing SATs to assess impacts of HEIs on SD.

3.1. Sampling Strategy and Description

SATs to be included in the sample were identified based on a review of existing studies of SATs in higher education (e.g., References [14,33]), as well as online research that aimed to identify recently developed tools. The purposive sampling strategy resulted in a final sample composed of SATs that: (a) Follow an indicator-based approach and (b) are applied in practice. The selection aimed to generate a maximum variety of tools to foster a rich comparative assessment (see Reference [48]). A brief description of the included SATs' purpose and content is provided below (in alphabetical order):

1. The Auditing Instrument for Sustainability in Higher Education (AISHE) was developed in 2001 in the Netherlands by the Dutch Foundation for Sustainable Higher Education and aims at measuring sustainable education [49]. The latest version "AISHE 2.0" has 30 indicators across the five modules Identity, Education, Research, Operations, and Societal Outreach, and it offers a five-stage description for each criterion for benchmarking;
2. The Adaptable Model for Assessing Sustainability in Higher Education (AMAS) was developed by Gomez et al. [50] in 2015 at the Pontificia Universidad Católica de Chile. The tool has 25 indicators that are subordinated to a goal, a criterion, and a subcriterion. It aims at enabling HEIs to assess sustainability along different implementation stages;
3. The Business School Impact System (BSIS) is designed to determine the extent of a school's impact upon its regional environment. It was launched in France in 2014 by EFMD Global Network and has 126 indicators across seven categories. Business schools can apply to enter the BSIS process and are then reviewed by an expert team [51];
4. The CSA framework resulted from the Campus Sustainability Assessment Review Project in 2002 at the Western Michigan University (US). The CSA framework includes 43 best practice indicators across 15 dimensions compiled from an analysis of various CSA reports [52]. A benchmarking possibility is provided in the form of a "potential end goal";
5. The Campus Sustainability Assessment Framework (CSAF) has 169 indicators across 10 categories and offers opportunities to benchmark HEIs against predefined scores. It was developed by Lindsay Cole in 2003 to assist Canadian campuses with their sustainability objectives [53,54];

6. Waheed, Khan, and Veitch [55] developed a quantitative sustainability assessment tool using a driving force-pressure-state-exposure-effect-action (DPSEEA) framework to achieve a causality-based impact assessment. The Canadian model is called DPSEEA-Sustainability index Model (D-SiM). The D-SiM includes 56 indicators across five categories;
7. The German Commission for UNESCO (Deutsche UNESCO Kommission [DUK]) developed a sustainability self-assessment concept for HEIs in 2011 containing 10 fields of action/indicators. Each of the fields of action offers five stages of implementation to which HEIs can assign themselves [56];
8. The Graphical Assessment of Sustainability in Universities (GASU) has 174 indicators that build on a modification of the Global Reporting Initiative (GRI) Sustainability Guidelines. It was developed in 2006 by Rodrigo Lozano at Cardiff University (UK) and last updated in 2011. GASU aims to enable analysis and comparison of universities' sustainability efforts [9];
9. The Graz Model of Integrative Development (GMID) evaluates the transformative potentials of sustainability processes within Regional Centers of Expertise (RCE) on Education for Sustainable Development (ESD), and thus focuses on the interrelations between an HEI and regional stakeholders. It includes 15 indicators across the basic principles of Leadership, Social Networks, Participation, Education and Learning, and Research Integration, and it was developed by Clemens Mader in Graz (Austria) [57];
10. People and Planet's University League (P&P) ranks UK universities by environmental and ethical performance using 51 indicators across 13 categories. The university sustainability ranking was first conducted in 2007 and has been updated each year [58];
11. The Penn State Indicators Report (PENN) evaluated the sustainability performance at Pennsylvania State University (US) in 2000. It covers 33 indicators across 10 categories. These indicators were subsequently used by other HEIs for sustainability assessment [59];
12. The Association of University Leaders for a Sustainable Future (ULSF) [60] created the Sustainability Assessment Questionnaire (SAQ) for colleges and universities. It was developed in the US and is designed to assess how sustainable a university's teaching, research, operations, and outreach are with 41 indicators;
13. The National Wildlife Federation's [61] State of the Campus Environment (SCE) is a national (US) report card on Environmental Performance and Sustainability in Higher Education. It covers 69 indicators across 12 categories;
14. Good Company's Sustainable Pathways Toolkit (SPT) developed in 2002 in the US evaluates the social and environmental impacts of HEIs using 29 indicators (20 core indicators and nine supplementary indicators). Along with each indicator goes a benchmark suggesting a desirable performance for the respective area of application [62];
15. The Sustainability Tracking, Assessment and Rating System (STARS) version 2.1 was developed by the Association for the Advancement of Sustainability in Higher Education (AASHE) [63] in North America. It includes 68 indicators with benchmarks that determine possible scoring across the categories Academics, Engagement, Operations, Planning and Administration, and Innovation and Leadership. HEIs that submit a self-assessment using STARS may achieve a gold, silver, or bronze rating;
16. The Sustainability Tool for Auditing for University Curricula in Higher-Education (STAUNCH®), developed by Rodrigo Lozano in 2009 in the UK, enables HEIs to assess their curricula's contribution to sustainable development by using 36 indicators that are subdivided into environmental, economic, social, and cross-cutting themes [64];
17. Lukman, Krajnc, and Glavic [65] created the Three-dimensional University Ranking (TUR) in 2010 at the University of Maribor (SI). The model offers 15 indicators to evaluate HEIs along their research, educational and environmental performance in a way that enables inter-organizational comparison;

18. The UI GreenMetric World University Ranking (UIGM) is an initiative of Universitas Indonesia (ID), launched in 2010. It ranks universities' performance in the categories of Setting and Infrastructure, Energy and Climate Change, Waste, Water, Transportation, and Education using 69 indicators [66]; and,
19. In 2009, the United Nations Environment Programme (UNEP) designed the Unit-based Sustainability Assessment Tool (USAT) to determine to what degree HEIs have integrated sustainability concerns. USAT employs 75 indicators across the dimensions teaching, operations and management, student involvement, and policy and written statements [67].

Some of the included SATs have not been examined before (i.e., BSIS, D-SiM, STAUNCH®, TUR). While nine of the SATs included in the sample were developed by HEIs, external stakeholders such as public and private funding agencies, accreditation agencies, international organizations, and charitable organizations are also found among the developers of SATs.

3.2. Coding Strategy

In total, 1134 indicators were extracted from the sampled SATs. Based on Yarime and Tanaka [16] and Fischer et al. [15], the coding strategy consisted of a deductive and an inductive part.

The deductive part of the analysis aimed to classify the indicators to link them to a particular concept [68]. Each SAT indicator was reviewed and coded based on categories derived from the SD impact framework of HEIs (see Figure 1): Core element, assessment target, SD impact area, and impact type. The framework serves as a valid construct for this analysis (see Reference [69]). In addition, the indicators were coded regarding their type (quantitative, quasi-quantitative, and qualitative) and their level of analysis (individual or organizational). The coding for all variables in these categories was binary (1 = it applies; 0 = it does not apply).

First, each indicator was exclusively assigned to one of the five core elements in which activities of SD take place—namely education, research, outreach, campus operations, and campus experiences. Indicators concerning administrative structure and broad-scale policies were assigned to the institutional framework, while indicators addressing assessment and reporting processes were categorized into the "assessment and reporting" category. In addition, indicators addressing the HEI on an institutional level were related to the category "higher education institution". The category "not applicable" includes indicators that do not fit in any of the other categories. Examples for the indicators in these categories are illustrated in Table 2.

Table 2. Examples of indicators classified into (core) elements.

(Core) Element	Examples
Institutional framework	On broad-scale policies and the administrative structure of the HEIs, including, e.g., governance body structure, vision and mission statements, policies for staff and faculty hiring, budget issues, student associations, and development programs for staff and faculty
Education	Teaching, curriculum, and all other activities aiming for the education of students
Research	Research-related activities of the HEIs, e.g., allocation of research funds, transdisciplinary research programs
Outreach	HEI's collaboration efforts with external stakeholders on regional, national, and international level
Campus operations	HEI's environmental management, procurement policies and practices, infrastructure, and workspace-related issues such as safety regulations
Campus experiences	On-campus experiences for students and staff (e.g., student crime) and individual behaviors not related to studying or working (e.g., alcohol consumption)
Assessment and reporting	HEI's assessment and reporting processes that are geared towards the engagement with external stakeholders (e.g., external assurance, reporting cycles, stakeholder identification processes)
Higher education institution	Activities or impacts on the institutional level that cannot be influenced by measures in one of the core elements, e.g., demographic effects on the region through student in-migration

Second, each indicator was reviewed and exclusively categorized regarding its assessment target as a performance, proxy, or impact indicator. Performance indicators are concerned with policies and activities inside the organization (e.g., number of courses with SD content). Proxies are indicators that are able to measure impacts indirectly based on internal data (e.g., GHG emissions for contribution to climate change mitigation) (see Reference [36]), while impact indicators directly measure the impacts on SD outside organizational boundaries.

Third, each proxy and impact indicator was classified into one SD impact area. Indicators that could not be classified were coded as NA. These impact areas include, for example, indicators that address the following topics:

- Economy: Local food purchasing, alumni in the job market;
- Societal challenges: Research ethics, student fees;
- Natural environment: Noise pollution, resource consumption, GHG emissions;
- Policy making: Contribution to public policy development;
- Culture: Cultural dialog, cultural diversity; and
- Demographics: Composition and change of local population, including student and alumni population.

Fourth, the proxy and impact indicators were distinguished regarding the types of impact they measure. Direct impact indicators focus on immediate or short-term effects (e.g., alumni entering the regional job market), while indirect ones focus on intermediate or long-term effects (e.g., changes in environmental conditions).

Finally, the subsample of proxy and impact indicators was classified by type into quantitative (e.g., GHG emissions by weight), quasi-quantitative (e.g., self-rating of outreach efforts), and qualitative (e.g., open questions about contribution to policy making) (see Reference [36]) and also regarding their level of analysis. Indicators on the individual level of analysis address impacts that can be attributed to individual activities or behavior (e.g., alcohol consumption and related impacts on student health), while indicators on the organizational level assess impacts caused by organizational activities (e.g., water consumption and impacts on groundwater) or the HEI itself (e.g., in-migration of students and social problems).

To ensure intercoder reliability, all steps of the coding were executed by two coders (see Reference [70]). The Kappa value of the intercoder reliability was high with 0.91 (see Reference [71]). Differences among the coders were resolved by discussion until consensus was reached.

For the inductive part of the analysis, the authors independently reviewed the descriptions of proxy and impact indicators in each category of the SD impact areas. This process aimed to identify themes for the proxy and impact indicators (based on References [68,72]).

3.3. Analysis of the Coding Matrix

The descriptive statistical analyses were carried out with SPSS [73]. First, the relative frequencies of the indicator distribution among the categories' core elements and assessment target were calculated to comparatively examine the SATs. Second, the sub-sample of proxy and impact indicators was further analyzed by cross-tabulations regarding the categories SD impact area, impact type, and indicator type. Cross-tabulation is a joint frequency distribution that summarizes the categorical data of one group to demonstrate how many cases are present in another [74]. This allows for an analysis of relationships between the different categories in order to identify patterns and trends. All cross-tabulations were tested with the Chi-square test of independence to test the hypothesis that the categorical variables in columns and rows are related. All chi-square values were high and p-values were highly significant (Chi-square values > 32.213 and p-values < 0.001), indicating a highly significant statistical relationship between the variables in the cross-tabulations [75]. The identification of themes of the inductive analysis was supported by the MAXQDA 12 qualitative analysis software [76]. The descriptive part of the analysis is presented in Section 4.1 and the inductive part in Section 4.2.

3.4. Limitations

The research design has limitations inherent to the interpretative nature of qualitative research in terms of reliability and generalizability. To strengthen the validity of the interpretative analysis, the trustworthiness of data and results was assessed in terms of credibility, transferability, and confirmability [77,78]. First, credibility refers to the extent to which the results appear to be acceptable representations of the data. The deductive coding strategy and the inductive generation of themes have yielded consistent results. All deductive coding criteria found representations in the data, thus suggesting that the coding strategy resulted in credible results.

Second, transferability designates the degree to which findings from one study context will apply to other contexts. Transferability was ensured by the purposive sampling approach, aiming to generate a maximum variety of tools to foster a rich comparative assessment [48]. The sample includes not only recently developed tools such as BSIS, but also mature and established tools, such as STAUNCH®. As it is likely that the design of SATs and the understanding of the SD concept vary depending upon specific sociocultural and political contexts, the sample explicitly included SATs from a variety of geographical origins, such as the German self-assessment tool DUK or the Indonesian university ranking UIGM. The findings should thus be applicable to a wide variety of contexts.

Third, enhancing confirmability engenders the active search for potential biases in interpretation of the data. The findings appear consistent with previous studies of SATs in higher education (e.g., References [15,16]). In addition, two coders independently coded the data. Testing for intercoder reliability further strengthened the confirmability of results.

Finally, the nature of the data, i.e., indicators derived from SATs, imposes limitations in terms of the conclusions that can be drawn. While the examination of indicators enables a rich comparative assessment of SATs, it does not allow inferences as to the systemic interrelationships between indicators, and thus also not about the potential of the SATs to drive SD in the HEI context at this level. While sound sustainability assessment is a prerequisite and necessary condition for the improvement of HEIs' impacts on SD, it is not sufficient to judge the extent to which actual improvements materialize. This requires additional analyses that are beyond the scope of this study.

4. Results

The 19 SATs under examination comprised 1134 indicators representing all the tools' capability to assess impacts on SD. The analysis consists of a descriptive part and an inductive examination of major themes.

4.1. Descriptive Analysis

The overall distribution of indicators across the core elements shows a strong focus on the core elements of campus operations (34.48%), and institutional framework (20.90%). The dominance of campus operations can be due to 10 out of the 19 SATs having their largest share of indicators in this core element. Indicators relating to education (16.04%) are also relatively high. All other core elements are covered only by a limited number of indicators and are relatively weakly represented when compared against campus operations, the institutional framework, and education (see Table 3). More than half of the analyzed SATs do not have any indicators on the core elements campus experiences and assessment and reporting, and two SATs do not cover the campus operations and institutional framework elements. The core element of education is addressed by all analyzed SATs. Some of the SATs are specialized, e.g., CSA and PENN have about 70% of their indicators in campus operations and STAUNCH® focuses only on education. It should be noted that the element HEI refers to activities on the institutional level or impacts that are caused by the HEI as institution. This category is only addressed by a few indicators (5.03%).

Table 3. (Core) Elements (in %).

Assessment Tool	Institutional Framework	Education	Research	Outreach	Campus Operations	Campus Experiences	Assessment & Reporting	HEI	NA	Σ
AISHE	23.33	20.00	20.00	20.00	6.67	0.00	10.00	0.00	0.00	100.00
AMAS	44.00	4.00	4.00	8.00	24.00	0.00	12.00	4.00	0.00	100.00
BSIS	7.14	26.19	19.05	18.25	0.79	0.00	0.00	23.02	5.56	100.00
CSA	4.65	6.98	6.98	2.33	72.08	6.98	0.00	0.00	0.00	100.00
CSAF	31.95	5.33	3.54	1.78	48.52	5.92	0.00	1.18	1.78	100.00
D-SiM	8.93	10.71	5.36	1.79	46.43	0.00	0.00	14.29	12.49	100.00
DUK	20.00	30.00	20.00	0.00	20.00	0.00	10.00	0.00	0.00	100.00
GASU	28.16	10.92	6.90	1.72	21.84	1.72	11.49	4.61	12.64	100.00
GMID	20.00	20.00	20.00	40.00	0.00	0.00	0.00	0.00	0.00	100.00
P&P	33.33	11.76	0.00	0.00	50.99	1.96	1.96	0.00	0.00	100.00
PENN	6.06	3.03	9.09	0.00	69.70	12.12	0.00	0.00	0.00	100.00
SAQ	21.94	12.20	9.76	4.88	29.26	9.76	0.00	12.20	0.00	100.00
SCE	23.19	18.84	2.90	0.00	55.07	0.00	0.00	0.00	0.00	100.00
SPT	24.14	6.89	0.00	0.00	68.97	0.00	0.00	0.00	0.00	100.00
STARS	26.48	16.18	4.41	8.82	33.82	0.00	2.94	2.94	4.41	100.00
STAUNCH®	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
TUR	20.00	40.00	33.33	0.00	6.67	0.00	0.00	0.00	0.00	100.00
UIGM	0.00	4.35	7.25	0.00	63.77	1.45	4.35	1.45	17.38	100.00
USAT	30.67	21.33	9.34	8.00	21.33	4.00	0.00	1.33	4.00	100.00
Overall average	20.90	16.04	7.85	5.20	34.48	2.56	2.91	5.03	5.03	100.00

The majority of indicators in the examined SATs assess an HEI's internal activities rather than impacts on SD. Table 4 illustrates the strong focus on performance indicators (69.84%). Some SATs solely assess SD performance, namely DUK, GMID, SAQ, STAUNCH®, TUR, and USAT. Only BSIS and PENN show a distinct focus on addressing impacts outside the organizational boundaries with 81.75% and 60.61% of criteria being either proxy or impact indicators, respectively. Twelve of the reviewed tools make use of proxy indicators (20.55% of the overall sample). Eight SATs offer impact indicators, which comprise only 4.14% of the total indicator sample.

Table 4. Assessment Target (in %).

Assessment Tool	Performance Indicator	Proxy Indicator	Impact Indicator	NA	Σ
AISHE	83.33	0.00	16.67	0.00	100.00
AMAS	84.00	16.00	0.00	0.00	100.00
BSIS	18.25	70.64	11.11	0.00	100.00
CSA	67.44	25.58	6.98	0.00	100.00
CSAF	81.66	16.57	1.18	0.59	100.00
D-SiM	28.56	17.86	14.29	39.29	100.00
DUK	100.00	0.00	0.00	0.00	100.00
GASU	59.77	19.54	4.02	16.67	100.00
GMID	100.00	0.00	0.00	0.00	100.00
P&P	82.35	17.65	0.00	0.00	100.00
PENN	39.39	51.52	9.09	0.00	100.00
SAQ	100.00	0.00	0.00	0.00	100.00
SCE	86.96	13.04	0.00	0.00	100.00
SPT	65.52	17.24	17.24	0.00	100.00
STARS	88.24	7.35	0.00	4.41	100.00
STAUNCH®	100.00	0.00	0.00	0.00	100.00
TUR	100.00	0.00	0.00	0.00	100.00
UIGM	72.47	17.39	0.00	10.14	100.00
USAT	100.00	0.00	0.00	0.00	100.00
Overall average	69.84	20.55	4.14	5.47	100.00

Table 5 shows the characteristics of the indicators that focus on assessing HEIs' impacts on SD. There is a strong focus on proxy indicators that measure impacts in an indirect way, which comprise 83.21% of the indicators that address impacts.

For proxy and impact indicators, the core element most represented is campus operations; 48.21% of the proxy and impact indicators focus on this core element, of which most are proxy indicators. Many of these proxy indicators emphasize assessing GHG emissions and waste generation. Of the indicators, 16.08% address impacts that are caused by the HEI as an organization. The core element assessment and reporting was not addressed because this core element reflects the assessment processes in an HEI rather than the actual impacts.

The proxy and impact indicators address mainly the SD impact areas economy, societal challenges, and natural environment, while policy making, culture, and demographics are seldom considered. Natural environment is the SD impact area with the highest coverage, with 49.30% of proxy and impact indicators assessing impacts in that category. The SD impact areas economy and societal challenges follow with 23.57% and 13.21% of the indicators, respectively. The bulk of the economy proxy indicators stem from the tool BSIS. It is true for any SD impact area that proxy indicators comprise the larger share.

Direct impacts are addressed by almost all proxy and impact indicators (97.14%) and only eight aim at capturing indirect impacts. The indicators assessing indirect impacts are almost exclusively impact indicators.

Considering the indicator type, quantitative indicators are the most prevalent (62.50%), followed by quasi-quantitative indicators (19.29%) and qualitative indicators (18.21%). The latter are especially utilized in the subsample of impact indicators.

Table 5. Cross-tabulations of proxy and impact indicators (absolute and relative frequencies).

		Proxy Indicator	Impact Indicator	Total	X^2 [1]
(Core) Elements	Campus Operations	121 (43.21%)	14 (5.00%)	135 (48.21%)	52.20 ***
	Higher Education Institution	33 (11.79%)	12 (4.29%)	45 (16.08%)	
	Outreach	22 (7.85%)	6 (2.15%)	28 (10.00%)	
	Research	22 (7.85%)	1 (0.36%)	23 (8.21%)	
	Education	10 (3.57%)	7 (2.50%)	17 (6.07%)	
	Institutional Framework	13 (4.65%)	2 (0.71%)	15 (5.36%)	
	Campus Experiences	4 (1.43%)	3 (1.07%)	7 (2.50%)	
	Assessment & Reporting	0 (0.00%)	0 (0.00%)	0 (0.00%)	
	NA	8 (2.86%)	2 (0.71%)	10 (3.57%)	
	Total	233 (83.21%)	47 (16.79%)	280 (100.00%)	
SD Impact Areas	Natural Environment	123 (43.94%)	15 (5.36%)	138 (49.30%)	45.87 ***
	Economy	53 (18.93%)	13 (4.64%)	66 (23.57%)	
	Societal Challenges	24 (8.57%)	13 (4.64%)	37 (13.21%)	
	Culture	2 (0.71%)	2 (0.71%)	4 (1.42%)	
	Policy making	2 (0.71%)	1 (0.36%)	3 (1.07%)	
	Demographics	2 (0.71%)	0 (0.00%)	2 (0.71%)	
	NA	27 (9.64%)	3 (1.08%)	30 (10.72%)	
	Total	233 (83.21%)	47 (16.79%)	280 (100.00%)	
Impact Type	Direct	232 (82.85%)	40 (14.29%)	272 (97.14%)	117.93 ***
	Indirect	1 (0.36%)	7 (2.50%)	8 (2.86%)	
	Total	233 (83.21%)	47 (16.79%)	280 (100.00%)	
Indicator Type	Quantitative	162 (57.86%)	13 (4.64%)	175 (62.50%)	107.49 ***
	Quasi-Quantitative	39 (13.93%)	15 (5.36%)	54 (19.29%)	
	Qualitative	32 (11.42%)	19 (6.79%)	51 (18.21%)	
	Total	233 (83.21%)	47 (16.79%)	280 (100.00%)	
Level of analysis	Organizational	211 (75.36%)	32 (11.43%)	243 (86.79%)	68.89 ***
	Individual	22 (7.85%)	15 (5.36%)	37 (13.21%)	
	Total	233 (83.21%)	47 (16.79%)	280 (100.00%)	

[1] Note: The *p*-values indicate the statistical relationship between assessment target (proxy and impact indicator) and the other categories. *** $p < 0.001$.

The level of analysis indicates whether impacts are caused by organizational activities and the HEI as an organization or via individual activities or behavior. Of the subsample of proxy and impact indicators, 86.79% focus on the organizational level of analysis. The share of indicators addressing the individual level is higher among the subsample of impact indicators compared with proxy indicators, where the focus is almost exclusively on the organizational level.

4.2. Inductive Content Analysis

In the inductive content analysis of the subsamples of proxy and impact indicators, major themes within specific SD impact areas were identified (see Table 6). Regarding the SD impact area natural environment, the most addressed themes within the proxy indicators are "Consumption of energy, water and materials", "Emission of GHGs", and "Generation of waste". The impact indicators in this SD impact area address similar themes with the exception of "Effects on conditions (e.g., biodiversity, groundwater)", which presents the largest group of indicators. The indicators in the SD impact area natural environment are almost exclusively tied to campus operations and assess their subject generally in a quantitative way.

The themes most covered by proxy indicators within the SD impact area economy are "Local expenditures", "Research concerning the local economy", and "Local job creation". The impact indicators emphasize "Alumni in the job market" and "Start-ups in the region". Typically, these themes are assessed by quantitative indicators.

The proxy indicators and impact indicators classified into societal challenges are mainly focused on the same themes. They address "Stakeholder engagement and community development", and

"Health and safety issues". The indicators in the theme "Stakeholder engagement and community development" are exclusively linked to outreach.

Proxy as well as impact indicators concerning the SD impact areas policy making, culture, and demographics are very rare. Addressed themes in these areas are: "Contribution to public policy development", "International student exchange", and "In-migration of students".

Table 6. Major themes of proxy and impact indicators.

SD Impact Area	Proxy Indicator	Impact Indicator
Natural Environment	• Consumption of energy, water and materials • Emission of GHGs • Generation of waste	• Effects on conditions (e.g., biodiversity, groundwater) • Generation of waste
Economy	• Local expenditures • Research concerning the local economy • Local job creation	• Alumni in the job market • Start-ups in the region
Societal Challenges	• Stakeholder engagement and community development • Health and safety issues	• Stakeholder engagement and community development • Health and safety issues
Policy making	• Contribution to public policy development	• Contribution to public policy development
Culture	• International student exchange	-
Demographics	• In-migration of students	-

5. Discussion

The research confirms previous studies on SATs (e.g., Reference [15]) in that the vast majority of the analyzed SATs have a strong focus on assessing SD performance in the core element campus operations. Only a small percentage of indicators assess impacts on SD occurring outside the immediate organization. This finding cannot be explained by looking at the timeline of first release of the sampled SATs. Even before impact became a topical issue of discussion, PENN was released in 2000 as one of two examples in the sample with a strong focus on assessing impacts on SD—the other example being the BSIS tool (first issued in 2014). At the same time, relatively new and widely applied SATs such as STARS (first released in 2010 and last updated in 2017) still tend to focus heavily on internal SD performance. Rather, indicators that aim to assess impacts directly are rare across all tools, irrespective of when they were issued.

The literature provides potential explanations for the heavy skew towards performance indicators in the sample. For instance, Reference [16] argued that the assessment of SD impacts involves a high level of complexity, which SATs are not equipped to handle. Closely related to the challenge of capturing a high level of complexity is the question of data availability. The findings suggest that it is important to balance the quality of assessment with the effort and data needed, especially for comprehensive tools that are meant for wide and regular application, such as STARS. The literature on sustainability assessment in adjacent fields also suggests that if SATs are to be widely adopted by HEIs, then they need to enable assessments based on internal data readily available to HEIs [79]. SATs that require additional efforts in data collection (e.g., via alumni surveys) may pose considerable difficulties for their adoption. This is reinforced by the strong focus on proxy indicators in the overall sample and the fact that only a minor share of proxy and impact indicators assesses impacts on an individual level of analysis.

The present research highlights the concrete SD impact areas and themes currently covered by SATs. The sample contains a relatively higher proportion of proxy and impact indicators in SD impact areas, with clearly understood causal pathways from activity to impact, as well as those that can be measured in physical or quantifiable units based on data readily available to HEIs. This is confirmed by the data in the sample. Even for SATs with an overwhelming focus on internal SD performance, there are proxy indicators for impact in the area of campus operations, especially as regards environmental impacts (e.g., consumption of energy, water and materials, GHG emissions, and waste generation). The main focus is on the SD impact areas natural environment, economy, and societal challenges, while policy making, culture, and demographics are rarely considered. In particular, environmental impacts tend to lend themselves to assessment because causal links, e.g., from GHG emissions to climate change, are well understood and easier to assess than many social issues (e.g., impacts of an HEI on local culture) (see Reference [10]).

This means that the SD impact areas addressed by SATs do not necessarily cover the most important impacts of any given HEI. Rather, they focus on indicators that can be measured based on internally available data. In this context, it is notable that only one of the SATs in the sample, namely GASU, requires a materiality assessment or prioritization of SD impact areas. Such exercises are common in corporate SATs or in sustainability assessments (as stated by Reference [80]), which can make it difficult for HEIs to focus their assessment efforts in those SD impact areas where they can make the most substantive contributions to SD.

Some tools acknowledge that impacts may vary between different types of HEIs, e.g., the BSIS tool with its explicit focus on business schools as distinct from universities (see Reference [51]). Other important distinctions might relate to the locality and local socioeconomic importance of HEIs (e.g., in urban or rural contexts) or simply to the size of any given HEI (e.g., in terms of student body and staff). For instance, Hubbard [45] shows that in rural areas, in-migration of students and the resulting cultural and demographic impacts can be a major local concern. Such differences cannot currently be captured by most SATs.

The strong focus on quantitative indicators supports the proposition that impacts, especially indirect ones, are neglected because quantitative assessment is frequently not feasible along complex and poorly understood causal pathways from activity to impact. For example, Hubbard [45] and Yao and Bai [46] provide accounts of how HEIs affect and are affected by student in-migration and internationalization. A capacity for assessing the impacts of internationalization through SATs would be useful for the large number of HEIs that are currently promoting internationalization as part of their strategies [81]. Online learning (e.g., Reference [44]) is another area of high strategic relevance for many HEIs, the direct and indirect impacts of which are currently still poorly understood.

6. Conclusions

The research aims to analyze the ability of SATs to assess impacts of HEIs on SD. In so doing, the study expands upon previous examinations of SATs in higher education, which have largely focused on what HEIs do in support of SD rather than on what they achieve for society, the economy, and the natural environment beyond their organizational boundaries. The research examined 1134 indicators for sustainability assessment derived from 19 SATs explicitly designed for application by HEIs.

While HEIs have increasingly been incorporating SD, their efforts have tended to be compartmentalized and focused on internal operations. It is becoming increasingly imperative that HEIs take a more holistic perspective addressing their system elements and their impacts, in this way, strengthen their contribution to SD. The update of existing indicator-based SATs and the development of new approaches of impact assessment can support HEIs in this endeavor.

Available SATs, to a large extent, are designed to assess specific activities inside the HEI's core elements, and provide external stakeholders only information about the internal engagement with SD. Only a small share of indicators of the examined SATs' aim to assess HEIs' impacts on SD and to a large extent indirectly via internal proxy data. SATs contribute indirectly to SD by raising awareness for SD; however, they tend to neglect the impacts HEIs have outside their organizational boundaries, and therefore, do not fully realize their potential to contribute to SD.

Further research should be carried out, for example on narrative assessments potential to assess impacts of research, where there is increasing consensus that counting citations and bibliometric analysis do not provide an accurate picture of research impacts on SD.

Author Contributions: Conceptualization, F.F.; Methodology, F.F.; Data Curation, F.F. and B.S.; Validation, F.F. and B.S.; Software, F.F. and B.S.; Writing—Original Draft Preparation, F.F. and N.S.; Writing—Review & Editing, R.L. and N.S.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Stephens, J.; Hernandez, M.; Roman, M.; Graham, A.; Scholz, R. Higher Education as a Change Agent for Sustainability in Different Cultures and Contexts. *Int. J. Sustain. High. Educ.* **2008**, *9*, 317–338. [CrossRef]
2. Cortese, A.D. The Critical Role of Higher Education in Creating a Sustainable Future. *Plan. High. Educ.* **2003**, *31*, 15–22.
3. Lozano, R. Incorporation and Institutionalization of Sd into Universities: Breaking through Barriers to Change. *J. Clean. Prod.* **2006**, *14*, 787–796. [CrossRef]
4. UN (United Nations). Declaration of the United Nations Conference on the Human Environment. Available online: http://www.un-documents.net/unchedec.htm (accessed on 27 August 2018).
5. Lozano, R.; Lukman, R.; Lozano, F.J.; Huisingh, D.; Lambrechts, W. Declarations for Sustainability in Higher Education: Becoming Better Leaders, through Addressing the University System. *J. Clean. Prod.* **2013**, *48*, 10–19. [CrossRef]
6. UN (United Nations). Higher Education and Research for Sustainable Development (Hesd). Available online: https://sustainabledevelopment.un.org/partnership/?p=11748 (accessed on 27 August 2018).
7. UN (United Nations). Higher Education Sustainability Initiative (Hesi). Available online: https://sustainabledevelopment.un.org/sdinaction/hesi (accessed on 27 August 2018).
8. Gamage, P.; Sciulli, N. Sustainability Reporting by Australian Universities. *Aust. J. Public Adm.* **2016**, *76*, 187–203. [CrossRef]
9. Lozano, R. A Tool for a Graphical Assessment of Sustainability in Universities (Gasu). *J. Clean. Prod.* **2006**, *14*, 963–972. [CrossRef]
10. Bullock, G.; Wilder, N. The Comprehensiveness of Competing Higher Education Sustainability Assessments. *Int. J. Sustain. High. Educ.* **2016**, *17*, 282–304. [CrossRef]
11. Saadatian, O.; Dola, K.B.; Salleh, E.I.; Tahir, O.M. Identifying Strength and Weakness of Sustainable Higher Educational Assessment Approaches. *Int. J. Bus. Soc. Sci.* **2011**, *2*, 137–146.
12. Gilbert, D.U.; Rasche, A.; Waddock, S. Accountability in a Global Economy: The Emergence of International Accountability Standards. *Bus. Ethics* **2011**, *21*, 23–44. [CrossRef]
13. Shriberg, M. Institutional Assessment Tools for Sustainability in Higher Education. *Int. J. Sustain. High. Educ.* **2002**, *3*, 254–270. [CrossRef]
14. Berzosa, A.; Bernaldo, M.O.; Fernández-Sanchez, G. Sustainability Assessment Tools for Higher Education: An Empirical Comparative Analysis. *J. Clean. Prod.* **2017**, *161*, 812–820. [CrossRef]
15. Fischer, D.; Jenssen, S.; Tappeser, V. Getting an Empirical Hold of Thesustainable University: A Comparative Analysis of Evaluation Frameworks across 12 Contemporary Sustainability Assessment Tools. *Assess. Eval. High. Educ.* **2015**, *40*, 785–800. [CrossRef]
16. Yarime, M.; Tanaka, Y. The Issues and Methodologies in Sustainability Assessment Tools for Higher Education Institutions—A Review of Recent Trends and Future Challenges. *J. Educ. Sustain. Dev.* **2012**, *6*, 63–77. [CrossRef]
17. Findler, F.; Schönherr, N.; Lozano, R.; Reider, D.; Martinuzzi, A. Conceptualizing Sustainable Development Impacts in Higher Education—A Systematic Literature Review. *Int. J. Sustain. High. Educ.*. in press.
18. Vaughter, P.; Wright, T.; McKenzie, M.; Lidstone, L. Greening the Ivory Tower: A Review of Educational Research on Sustainability in Post-Secondary Education. *Sustainability* **2013**, *5*, 2252–2271. [CrossRef]

19. Koehn, P.H.; Uitto, J.I. Evaluating Sustainability Education: Lessons from International Development Experience. *High. Educ.* **2014**, *67*, 621–635. [CrossRef]
20. Lebeau, Y.; Cochrane, A. Rethinking the 'Third Mission': Uk Universities and Regional Engagement in Challenging Times. *Eur. J. High. Educ.* **2015**, *5*, 250–263. [CrossRef]
21. Gupta, H.; Singhal, N. Framework for Embedding Sustainability in Business Schools: A Review. *Vis. J. Bus. Perspect.* **2017**, *21*, 195–203. [CrossRef]
22. Bonaccorsi, A.; Daraio, C.; Geuna, A. Universities in the New Knowledge Landscape: Tensions, Challenges, Change-an Introduction. *Minerva* **2010**, *48*, 1–4. [CrossRef]
23. Caeiro, S.; Jabbour, C.; Leal Filho, W. *Sustainability Assessment Tools in Higher Education Institutions Mapping Trends and Good Practices around the World*; Springer: Cham, Gemany, 2013; p. 432.
24. Ceulemans, K.; Molderez, I.; Van Liedekerke, L. Sustainability Reporting in Higher Education: A Comprehensive Review of the Recent Literature and Paths for Further Research. *J. Clean. Prod.* **2015**, *106*, 127–143. [CrossRef]
25. Dalal-Clayton, B.; Bass, S. *Sustainable Development Strategies: A Resource Book*; Earthscan Publications Ltd.: London, UK, 2002.
26. Daub, C.H. Assessing the Quality of Sustainability Reporting: An Alternative Methodological Approach. *J. Clean. Prod.* **2007**, *15*, 75–85. [CrossRef]
27. Prado-Lorenzo, J.M.; Gallego-Alvarez, I.; Garcia-Sanchez, I.M. Stakeholder Engagement and Corporate Social Responsibility Reporting: The Ownership Structure Effect. *Corp. Soc. Responsib. Environ. Manag.* **2009**, *16*, 94–107. [CrossRef]
28. Ceulemans, K.; Lozano, R.; Alonso-Almeida, M.M. Sustainability Reporting in Higher Education: Interconnecting the Reporting Process and Organisational Change Management for Sustainability. *Sustainability* **2015**, *7*, 8881–8903. [CrossRef]
29. Huber, S.; Bassen, A. Towards a Sustainability Reporting Guideline in Higher Education. *Int. J. Sustain. High. Educ.* **2018**, *19*, 218–232. [CrossRef]
30. Lozano, R.; Llobet, J.; Tideswell, G. The Process of Assessing and Reporting Sustainability at Universities: Preparing the Report of the University of Leeds. *Sostenibilidad, Tecnologia y Humanismo* **2013**, *6*, 85–112.
31. Adams, C.A. Sustainability Reporting and Performance Management in Universities—Challenges and Benefits. *Sustain. Account. Manag. Policy J.* **2013**, *4*, 384–392. [CrossRef]
32. Lambrechts, W. The Contribution of Sustainability Assessment to Policy Development in Higher Education. *Assess. Eval. High. Educ.* **2015**, *40*, 801–816. [CrossRef]
33. Alghamdi, N.; den Heijer, A.; de Jonge, H. Assessment Tools' Indicators for Sustainability in Universities: An Analytical Overview. *Int. J. Sustain. High. Educ.* **2017**, *18*, 84–115. [CrossRef]
34. Ramos, T.B. Development of Regional Sustainability Indicators and the Role of Academia in This Process: The Portuguese Practice. *J. Clean. Prod.* **2009**, *17*, 1101–1115. [CrossRef]
35. Gallopín, G. Indicators and Their Use: Information for Decision Making. In *Sustainability Indicators. Report on the Project on Indicators of Sustainable Development*; Moldan, B., Billharz, S., Eds.; John Wiley and Sons: Chichester, UK, 1997.
36. Jorgensen, A.; Le Bocq, A.; Nazarkina, L.; Hauschild, M. Methodologies for Social Life Cycle Assessment. *Int. J. Life Cycle Assess.* **2008**, *13*, 96–103. [CrossRef]
37. Sayed, A.; Asmuss, M. Benchmarking Tools for Assessing and Tracking Sustainability in Higher Educational Institutions. *Int. J. Sustain. High. Educ.* **2013**, *14*, 449–465. [CrossRef]
38. European Commission. Horizon 2020 Work Program 2014-2015 General Annexes H. Evaluation. Available online: http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-h-esacrit_en.pdf (accessed on 20 July 2018).
39. REF (Research Excellence Framework). What Is the Ref? Available online: http://www.ref.ac.uk/about/whatref/ (accessed on 23 July 2018).
40. EFMD. Efmd Launch Business School Impact System (Bsis). Available online: https://www.efmd.org/efmd-deans-across-frontiers/view/467-efmd-launch-business-school-impact-survey (accessed on 20 July 2018).
41. Maas, K.; Liket, K. Social Impact Measurement: Classification of Methods. In *Environmental Management Accounting and Supply Chain Management*; Burritt, R.L., Schaltegger, S., Bennett, M., Pohjola, T., Csutora, M., Eds.; Springer: Berlin, Gemany, 2011; pp. 171–202.

42. Findler, F.; Schönherr, N.; Martinuzzi, A. Higher Education Institutions as Transformative Agents for a Sustainable Society. In *Chancen Und Grenzen Der Nachhaltigkeitstransformation*; Luks, F., Ed.; Springer Gabler: Wiesbaden, Gemany, 2019.
43. Buckler, C.; Creech, H. *Shaping the Future We Want*; United Nations Educational, Scientific and Cultural Organization: Paris, France, 2014.
44. Versteijlen, M.; Perez Salgado, F.; Janssen Groesbeek, M.; Counotte, A. Pros and Cons of Online Education as a Measure to Reduce Carbon Emissions in Higher Education in the Netherlands. *Curr. Opin. Environ. Sustain.* **2017**, *28*, 80–89. [CrossRef]
45. Hubbard, P. Regulating the Social Impacts of Studentification: A Loughborough Case Study. *Environ. Plan. A* **2008**, *40*, 323–341. [CrossRef]
46. Yao, L.J.; Bai, Y. The Sustainability of Economic and Cultural Impacts of International Students to Regional Australia. *Humanomics* **2008**, *24*, 250–262. [CrossRef]
47. Malina, M.A.; Nørreklit, H.S.O.; Selto, F.H. Lessons Learned: Advantages and Disadvantages of Mixed Method Research. *Qual. Res. Account. Manag.* **2011**, *8*, 59–71. [CrossRef]
48. Teddlie, C.; Tashakkori, A. *Foundations of Mixed Methods Research Integrating Quantitative and Qualitative Approaches in the Social and Behavioral Sciences*, 3rd ed.; SAGE Publications: Los Angeles, CA, USA, 2010; p. 387.
49. Roorda, N.; Rammel, C.; Waara, S.; Fra Paleo, U. Aishe 2.0 Manual: Assessment Instrument for Sustainability in Higher Education. Available online: http://www.eauc.org.uk/theplatform/aishe (accessed on 9 August 2018).
50. Gómez, F.; Sáez-Navarrete, C.; Lioi, S.; Marzuca, V. Adaptable Model for Assessing Sustainability in Higher Education. *J. Clean. Prod.* **2015**, *107*, 475–485. [CrossRef]
51. EFMD Global Network. Bsis Asessment Criteria Guide. Available online: http://www.efmdglobal.org/bsis (accessed on 15 September 2018).
52. Nixon, A. Improving the Campus Sustainability Assessment Process. Bachelor Thesis, Western Michigan University, Kalamazoo, MI, USA, 2002.
53. Cole, L. Assessing Sustainability on Canadian University Campuses: Development of a Campus Sustainability Assessment Framework. Available online: http://neumann.hec.ca/humaniterre/campus_durable/campus_memoire.pdf (accessed on 13 September 2018).
54. Legacy, C. Campus Sustainability: Sustainability Assessment Framework at the University of Waterloo. Available online: http://environment.uwaterloo.ca/research/watgreen/projects/library/w04sustframework.pdf (accessed on 3 September 2018).
55. Waheed, B.; Khan, F.I.; Veitch, B. Developing a Quantitative Tool for Sustainability Assessment of Heis. *Int. J. Sustain. High. Educ.* **2011**, *12*, 355–368. [CrossRef]
56. Deutsche UNESCO-Kommission e.V. Hochschulen Für Eine Nachhaltige Entwicklung: Nachhaltigkeit in Forschung, Lehre Und Betrieb. Available online: https://www.hrk.de/uploads/media/Hochschulen_fuer_eine_nachhaltige_Entwicklung_Feb2012.pdf (accessed on 12 September 2018).
57. Mader, C. Sustainability Process Assessment on Transformative Potentials: The Graz Model for Integrative Development. *J. Clean. Prod.* **2013**, *49*, 54–63. [CrossRef]
58. People & Planet. People & Planet University League. *How Sustainable Is Your University?* Available online: https://peopleandplanet.org/university-league (accessed on 22 October 2018).
59. Penn State Green Destiny Council. Penn State Indicators Report. Steps toward a Sustainable University. Available online: http://www.willamette.edu/~{}nboyce/assessment/PennState.pdf (accessed on 15 October 2018).
60. ULSF (University Leaders for a Sustainable Future). Sustainability Assessment Questionnaire (Saq) for Colleges and Universities. Available online: http://ulsf.org/wp-content/uploads/2015/06/SAQforHigherEd09.pdf (accessed on 12 July 2018).
61. National Wildlife Federation. State of the Campus Environment. Available online: https://www.nwf.org/en/EcoLeaders/Campus-Ecology-Resource-Center/Reports/State-of-the-Campus-Environment (accessed on 14 September 2018).
62. Good Company. Sustainability Assessment of the University of Oregon Based on Good Company's Sustainable Pathways Toolkit. Available online: https://cpfm.uoregon.edu/sites/cpfm2.uoregon.edu/files/sust_assessment_-_sust_pathways_toolkit_0.pdf (accessed on 12 September 2018).

63. AASHE (The Association for the Advancement of Sustainability in Higher Education). Stars Technical Manual. Version 2.1. Available online: https://stars.aashe.org/pages/about/technical-manual.html (accessed on 30 August 2018).
64. Lozano, R. Developing a Tool to Audit Curricula Contributions to Sustainable Development. In *Sustainability at Universities—Opportunities, Challenges and Trends*; Peattie, K., Ed.; Peter Lang Publishing Group: Frankfurt am Main, Germany, 2009; pp. 179–194.
65. Lukman, R.; Krajnc, D.; Glavic, P. University Ranking Using Research, Educational and Environmental Indicators. *J. Clean. Prod.* **2010**, *18*, 619–628. [CrossRef]
66. Greenmetric UI. Ui Greenmetric. Criteria & Indicators. Available online: http://greenmetric.ui.ac.id/criterian-indicator/ (accessed on 22 August 2018).
67. Togo, M.; Lotz-Sisitka, H. *Unit Based Sustainability Assessment Tool. A Resource Book to Complement the Unep Mainstreaming Environment and Sustainability in African Universities Partnership*; Share-Net: Howick, ZA, South Africa, 2009.
68. De Wet, J.; Erasmus, Z. Towards Rigour in Qualitative Analysis. *Qual. Res. J.* **2005**, *5*, 27–40. [CrossRef]
69. Patton, M.Q. *Qualitative Research & Evaluation Methods Integrating Theory and Practice*, 4th ed.; Sage Publications: New York, NY, USA, 2015; p. 806.
70. Seuring, S.; Müller, M. From a Literature Review to a Conceptual Framework for Sustainable Supply Chain Management. *J. Clean. Prod.* **2008**, *16*, 1699–1710. [CrossRef]
71. Tinsley, H.E.A.; Weiss, D.J. Interrater Reliability and Agreement. In *Handbook of Applied Multivariate Statistics and Mathematical Modeling*; Tinsley, H.E.A., Brown, S.D., Eds.; Academic Press: San Diego, CA, USA, 2000; pp. 95–124.
72. Sinkovics, N. Pattern Matching in Qualitative Analysis. In *The Sage Handbook of Qualitative Business and Management Research Methods*; Cassell, C., Cunliffe, A., Grandy, G., Eds.; Sage Publications, Inc.: Thousand Oaks, CA, USA, 2018; pp. 468–485.
73. IBM. Ibm Spss Statistics. Available online: https://www.ibm.com/products/spss-statistics (accessed on 17 October 2018).
74. Singh, K. *Quantitative Social Research Methods*, 1st ed.; SAGE Publications: New Delhi, India, 2007; p. 431.
75. Field, A. *Discovering Statistics Using Ibm Spss Statistics and Sex and Drugs and Rock'n'roll*, 4th ed.; SAGE: Los Angeles, CA, USA, 2013; p. 915.
76. VERBI. Maxdqa—The Art of Data Analysis. Available online: http://www.maxqda.com/ (accessed on 7 October 2018).
77. Flint, D.J.; Woodruff, R.B.; Fisher Gardial, S. Exploring the Phenomenon of Customers' Desired Value Change in a Business-to-Business Context. *J. Mark.* **2002**, *66*, 102–117. [CrossRef]
78. Wallendorf, M.; Belk, R.W. Assessing Trustworthiness in Naturalistic Consumer Research. *Interpret. Consum. Res.* **1989**, 69–84.
79. Gaviglio, A.; Bertocchi, M.; Demartini, E. A Tool for the Sustainability Assessment of Farms: Selection, Adaptation and Use of Indicators for an Italian Case Study. *Resources* **2017**, *6*, 60. [CrossRef]
80. Schönherr, N.; Findler, F.; Martinuzzi, A. Exploring the Interface of Csr and the Sustainable Development Goals. *Trans. Corp.* **2017**, *24*, 33–47. [CrossRef]
81. Bedenlier, S.; Kondakci, Y.; Zawacki-Richter, O. Two Decades of Research into the Internationalization of Higher Education: Major Themes in the Journal of Studies in International Education (1997–2016). *J. Stud. Int. Educ.* **2017**, *22*, 108–135. [CrossRef]

sustainability
MDPI

Essay

About the Triggering of UN Sustainable Development Goals and Regenerative Sustainability in Higher Education

Giulia Sonetti [1,*], Martin Brown [2] and Emanuele Naboni [3]

1 Interuniversity Department of Regional & Urban Studies and Planning, Politecnico di Torino and Università di Torino, 10124 Turin, Italy
2 Fairsnape, Lancashire PR3 2LE, UK; fairsnape@gmail.com
3 Institute of Architecture and Technology, School of Architecture, Design and Conservation, Royal Danish Academy of Fine Arts, 1435 Copenhagen, Denmark; emanuele.naboni@kadk.dk
* Correspondence: giulia.sonetti@polito.it; Tel.: +39-348-0575-395

Received: 13 November 2018; Accepted: 2 January 2019; Published: 7 January 2019

Abstract: Humans are at the center of global climate change: The United Nations Sustainable Development Goals (SDGs) are igniting sustainability with proactive, global, social goals, moving us away from the Brundtland paradigm 'do nothing today to compromise tomorrows generation'. This promotes a regenerative shift in the sustainability concept, no longer only considering resources and energy, but also significant human-centric attributes. Despite this, precise ecological and sustainable attitudes have little prognostic value regarding final related individual human behavior. The global cultural challenge, dominated by technological innovations and business imperatives, alongside the mirroring technological fallacy and lack of ethical reasoning, makes the role of small actions, at individual and at academic scale even harder. This paper outlines the context in which universities can collaborate and contribute to triggering sustainability values, attitudes, and behavior within future regenerative societies. This contribution consists in three main areas: the first analyzes the issue of sustainability transitions at the individual scale, where influencing factors and value–behavior links are presented as reviewed from a number of multi and transdisciplinary scholars' works. The second part enlarges the picture to the global dimension, tracing the ideological steps of our current environmental crisis, from the differences in prevailing western and eastern values, tradition, and perspectives, to the technological fallacy and the power of the narratives of changes. Finally, the task of our role as academics in the emerging 'integrative humanities' science is outlined with education promoted as an essential driver in moving from sustainability to regenerative paradigms.

Keywords: education for sustainable development; academic organizational change; transformative learning; behavioral change; SDGs; regenerative approach; university

---

1. Introduction

As reported in the latest Intergovernmental Panel on Climate Change (IPCC) paper, humans are at the center of global climate change: causing anthropogenic climate breakdown, and social factors identified as key to effectively respond to current challenges [1].

The United Nations Sustainable Development Goals (SDGs) are igniting sustainability with proactive, global, social goals, moving us away from the 'do nothing today' Brundtland paradigm and promoting a regenerative shift of the sustainability concept, no longer only considered with resources and energy, but significantly human-centric [2].

The phrase 'sustainable development' has been so abused that it has maybe lost meaning. This gives room for an initial explanation in the societal domination of a particular epistemology, it can be an opportunity to diagnose the present by the past, using a Foucaultian approach [3], often referred as “history of the present” [4].

Using Habermas’ ideas of the system colonizing the lifeworld [5], we agree with Fergus and Rowney when they state that the meaning of sustainable development changed before it could be fully explored through an inclusive and diverse discourse [6]. An inclusive discourse based on the comparison of different epistemological perspectives is therefore the aim of this paper, exploring the ethics of individual and society as a whole having a choice and a responsibility in terms of a new sustainability narrative [7].

Universities can play an important role in this narratives’ shift, triggering new sustainability values, attitudes, and behavior in future regenerative societies [8,9]. However, higher education institutions (HEIs) are often lacking in holistic visions and incentives have a strong anti-transdisciplinary attitude and a tendency for academics and departments to focus on silos approaches in teaching and researching activities [10].

Between these philosophical discourses, global values, and individual attitudes, this contribution aims at highlighting the role of HEIs in a regenerative sustainability transition in four main moments: in the introduction, old and new definition of sustainability are depicted from a policy/abstract level. Then, the second section analyzes the issue of sustainability transitions at the individual scale, where influencing factors and value-behavior links are presented as reviewed from a number of multi and transdisciplinary scholars’ works. The third section enlarges the picture to the global dimension, tracing the ideological steps of our current environmental crisis from the differences in prevailing western and eastern values, tradition, and perspectives, to the technological fallacy and the power of the narratives of changes. Finally, the task of our role as academic in the next revolutionary “integrative humanities” science is outlined, as education is envisaged as an essential element of moving towards regenerative paradigms [11].

1.1. Toward a New Definition of Sustainability

The Brundtland report in the 1980s defined sustainable development as a process that meets todays needs without compromising future generations [12]. Further sustainability definitions stated that sustainability should be intended as a dynamic equilibrium within humans and ecosystem [13,14]. The regenerative paradigm pushes forward the positive balance, aiming for restoring environments and communities, and to enable conditions for regenerative growth [15–17], and sustainability efficiency [18]. In this paradigm shift, Figure 1, not only technological solutions, but also humanistic and ecological values are embraced [19,20].

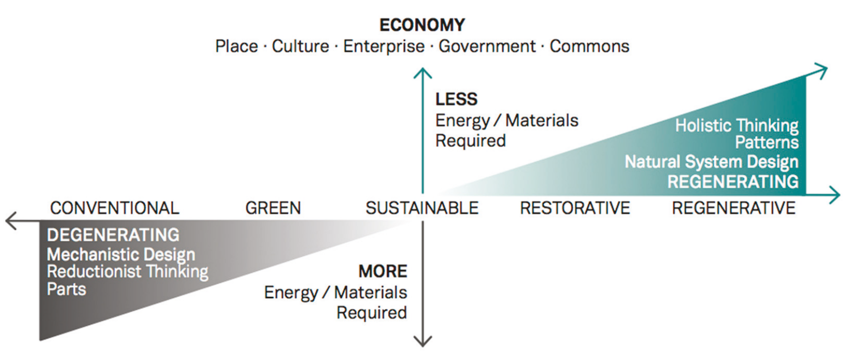


Figure 1. Stages of development, from conventional to the regenerative economy according to [19].

This shift has recently been witnessed in a new normal at legislative and governmental levels: while in the Paris Agreement (December 2015) 197 countries agreed to reduce any increase in global warming to “well below 2 °C above pre-industrial levels” [21], with an aspiration to cap temperatures at 1.5 °C. The latest Intergovernmental Panel on Climate Change (IPCC) report (October 2018) stressed the importance of demand-side measures to achieve consistent pathways toward global CO_2 mitigation [22].

Hence, humans are at the center of global climate change: their actions cause anthropogenic climate change, and social change is key to effectively respond to climate change [23–25]. Potential synergies and trade-offs between 1.5 °C mitigation pathways and different sustainable development (SD) individual dimensions are an emerging field of research: in Section 5.4, the IPCC 2018 report assesses interactions between individual mitigation measures with other societal objectives. The same adaptation strategy is supporting the sustainable development goals (SGDs) call for behavioral change and institutional capacity, as social learning strengthen is key for longer-term changes [26–28].

The SDGs have the potential for igniting sustainability with proactive, global, social goals, moving us away from the do nothing today Brundtland paradigm toward a regenerative paradigm [29,30]: the regenerative sustainability is indeed defined as the one enabling social and ecological systems to maintain a healthy state and to evolve [31]. Its key related topics (place, energy, carbon, water, resources, wellbeing, equity, education) are synoptically displayed in Table 1.

Table 1. Regenerative sustainability key topics. Reproduced from to [31].

Key Topics	Vision	State of Art	Gap
Place	Earth as a community, not a commodity	Regenerative approaches departing from the recognition that each place is a unique dynamic entity.	To evolve towards a harmony between people and space in which the human activity generates zero net waste and uses renewable resources to assure sustainable development for current and future generations. To restore the connection of people to nature and to the planet.
Energy	Local/renewable ownership and management	Focus on renewable energy production, energy efficient construction, and green goods and services industries (green economy) and less on the role of energy for the ecosystem restoration.	To move from a green economy to a balanced economy this implies the preservation and restore of the planet's health. Energy as part of a coherent restoration approach aiming to increase the quality of the ecosystem contributing at the same time to sustainable economic growth.
Carbon	Carbon working with natural systems	Strategies oriented to the remediation of the damage caused to the environment (e.g., revegetation).	Strategies oriented to the restoration of the damaged ecosystems, comprehending activities aimed at the increase of carbon stocks and the reduction of the emissions of carbon dioxide, which would contribute for slowing the process of climate change.
Water	Building and cities to participate in water cycles, local watersheds	Buildings and sealed areas prevents the functioning of the water cycle. Approaches dealing with water as if the human owns it.	Innovative approaches in which cities incorporate natural cycles in the way they are built, function, and grow. Develop urban concepts that mimic nature as a requirement for a balance and healthy life. Transform the human relationship with water, which implies the respect of its natural processes.
Resources	Local, accessible, and low-cost resources and building responsibility of managing the commons	Resources exist for human use. Management of resources based on an economic rationality: damage to the ecosystem can be compensated through a monetary payment.	Policies based on the idea that it is impossible to compensate damages; so, damages have to be avoided. Resources are to be maintained for the future generations, which implies a responsible public management and an increasing participation of the society on the collective choices.
Wellbeing	Happiness that con-tributes to individual, community, and/or global well-being without exploiting other people, the environment, or future generations	"Instant" happiness instigated by the consumer society that sustains the idea that more goods means higher individual and collective well-being, without considering the social and environmental impacts of their production and distribution.	Sustainable well-being as an opportunity to enhance quality of life and contribute to individual, community, and society well-being. Wellbeing from acknowledging that human are part of a living system and a damaged planet impacts negatively on the health of people and communities, today and for the future (a biophilic approach towards the well-being of the earth). The well-being of society as being interconnected to the achieved well-being of the planet.
Equity	All voices shall be heard; equity beyond human community	Groups with economic power that exert lobby activities near governments guarantee for themselves economic and environmental advantages over the society without considering the depletion of the planet's resources.	To share the well-being between present people and future people, generating an intergenerational fairness in allocating resources between current competing interests.
Education	Bottom–up cultures/initiatives (permaculture, urban gardening, local currencies, urban pioneer movement, placemaking)	Top–bottom approaches to deal with imbalances and damages in nature.	Bottom–up approaches which give voice to different sectors and interests of the society, and creates a forum for the promotion of a proactive collaboration to foster restoration actions, involving those affected in the process of change. Education for eco-literacy as a precursor of public participation.

1.2. Regenerative Behaviors

Following the conceptual framework outlined above, regenerative behaviors are introduced as additional, positive behaviors, intentional or otherwise, created through regenerative sustainability interventions [31]. We focus on social aspects of decision making considering that some of the challenges related to sustainable development are social in their core identity [32,33]. They are social regarding the motivations towards our consumption, the configuration in which we shape the institutes and companies we interact with and the behavioral assumptions behind many of the strategies and interventions for the transition to better consumption and production pathways [34–36]. Indeed, eloquent collective changes start with individual transformation.

Emerging theories, like the "Theory U" by Otto Schirmer [37], are social field theory that makes visible the source from which we operate—i.e., individuals, as teams, as organizations, and as larger systems—and the impact depending on which source we are operating from: [38].

Our feelings will affect our actions towards climate change issues [39]. While negative feelings can reinforce adaptation [40], positive feelings may be counterproductive in terms of protective attitudes [41]: people are more willing to take action for climate change when they are directly affected and concerned [42], and when they can be rewarded somehow from their actions [43].

For many years, policies have presumed that humans make a decision and act in logical and foreseeable ways; however, in reality, how and why we (as individuals, communities, and entities) behave is due to the confluence of many factors. For instance, individual conduct is extremely entrenched with our social circumstances, formal settings, religious and cultural rules, together with many contingent mental dynamics [44–46].

A recurrent outcome from behavioral and attitudinal surveys is that people are increasingly caring towards the planet and concerned about the need for an ecologically sound lifestyle [47,48]. However, values and attitudes may not always be mirrored by actual actions and choices. This is not only related to sustainability: our practices, instincts, and wish for comfort and opportunities challenge much even with our best intents and trusted views. This gap is well recognized in behavioral and cognitive science, and it unlocks concerns regarding the confidence we have on surveys and qualitative information-based policies aiming at behavioral changes [49–51].

Nevertheless, the need for a focus on human values, attitudes, and behaviors to establish the basis for a sustainability transition is urgent [33,52,53]. Even if the drivers vary, this remains the case both at individuals' level and at public/private entity level. Higher education institutions, as education providers, have a crucial role in cultivating sustainability awareness and values within in future generations of citizens, entrepreneurs, and policy makers [8,54,55].

1.3. Between the Individual and Global Dimensions

Although the topic of individual ecological shift is well researched and debated, people sometimes can feel powerless in applying their principles in capitalist systems. However, individual inner self-observation and awareness can create the basis for a collective change in a social, economic, and environmental sustainability [56–59].

The evolution of economic thought can be regarded as a system moving from traditional ego-system awareness (something we still teach today at business schools around the world) to a new stage of awareness, an "eco-system awareness" focusing on the well-being of not only a few but the well-being of all [60–62].

The EGO-ECO-SEVA scheme illustrates these three worldviews [63–65]. The path from EGO to ECO to SEVA begins by stepping up from our EGO dimension, realizing the connectedness of all ECO spheres, arriving to a SEVA position for a life on earth via a regenerative approach. The regenerative sustainability shift therefore requires a radical turn of our worldview, from a mechanistic to ecological one [15].

2. Individual Dimension

According to Leiserowitz et al., "Values are abstract ideals, such as freedom, equality, and sustainability. They often evoke emotional reactions and are typically expressed in terms of good or bad, better or worse, desirability or avoidance. Values define or direct us to goals, frame our attitudes, and provide standards against which the behavior of individuals and societies can be judged.

Attitudes refer to the evaluation of a specific object, quality, or behavior as good or bad, positive or negative. Attitudes often derive from and reflect abstract values. Finally, behavior refers to concrete decisions and actions taken by individuals and groups, which are often rooted in underlying values and attitudes" (p. 414, [33]).

All these converge progressively toward a proper value system: a set of values assumed by an individual or a society inducing the conduct of (often unaware) associates [5,66]. We rank our decisions with judgment categories that can become private, shared, monetary, civil, or religious based. Our values make us who we are and whom we want to appear to be and eventually who others see in us: collectively, they are the driving factors that can change the relationship between us and ourselves, us and society and us with the ecosystem in which we live [67,68]. There is much investigation that confirms how personal well-being, curiosity, empathy, kindness, and non-materialistic values are linked with more sustainable behaviors [59,69,70]. Sustainability thus really condenses into nurturing and allying values, beliefs, and behaviors with ecological stewardship and with collective responsibility. Through our everyday choices, we can choose either to improve or weaken the planet, our society, and commercial wealth. Emerging from these, global attitudes toward the Millennium Declaration Values are envisaged in freedom and democracy, fairness, solidarity, acceptance, respect for nature, and shared responsibility [71]. A study by Pappas defines 'individual sustainability' as follows:

> Sustainable individuals are characterized by creating harmony, interconnection, and relatively high levels of self-awareness in their values, thoughts, behaviors, and actions as well as cultivating continued individual growth in their physical, emotional, social, philosophical, and intellectual abilities. Individual sustainability includes possessing a well-developed and demonstrated value system that acknowledges the importance and interconnectedness of all global biological and social systems, and our appropriate place within them. (p. 12, [72])

A number of research projects comment that people with self-enhancing, money-oriented goals and values concentrating on accomplishments, wealth, control, prestige and image have more adverse attitudes to the environment, and are less expected to be moved into eco-friendly behaviors [73]. The conclusions presented in the work of Lavelle et al. [74] show the heterogeneity and richness of ecological behaviors [73,75]: according to studies by Martinsson et al. [76], (infra)structural and cultural factors are found to be a significant aspect in shaping behavioral change. This means that working upon strategies tailor-made for a specific target of people can be far more effective than promoting general policies for sustainable consumption [77]. Moreover, from a social cognitive perspective [78] it has been found that personal agency (as the ability to deliberately select, perform, and achieve personal intentions and desires) is crucial to obtain visible results in sustainable behavioral change. From an environmental psychology point of view, positive circumstantial conditions and ecological self-efficacy, visible outcomes are stressed to foster an individual's expectations and more stimulating goals. The work by Shapiro et al. [79] explores mindfulness practices at schools as useful tools to help illuminate one's values, to learn how to think more impartially, so that students can experience and understand attitudes that may be truer and responsive to real intentions. According to Rosenberg [80], mindfulness training can help to become more attentive of believed processes and so more critical when receiving an external narrative/influence. This approach can also be found in the INDICARE model [55]. As a sustainability assessment framework, it aims at stimulating the sustainability debate in higher education, suggesting a more holistic approach emphasizing the interconnectedness of human–nature relationships, combined with meditative workouts that help the transformative process both at individual and institutional level.

Inspired by biophilic ideas, transformative learning theories, and participatory evaluation, INDICARE is an evaluation framework that seeks an eco-centric and integrative approach toward our inner being, the earth and its communities Outlines proposed by [81] also draw from transformative learning concepts and propose key competencies including: "*Gestaltungskompetenz*" [82,83]; heads, hands, and heart tools [84]; values, knowing, skills, understanding [85–87]; and a few others [88].

3. The Global Dimension

In the previous paragraph, sustainability values, attitudes and behaviors are tracked, mirroring the culture, as socially transmitted behavior. Here we explore the connection of the local focus on sustainability transition to a wider value dimension, sense of responsibility and identity given by a new alternative culture (as, quoting Clyde Kluckhohn, it would not have been be fish who discovered the existence of water [89]). The individual dimension is not enough to understand real opportunities for the desired paradigm shift. A third part of this essay attempts to depict, from a higher level of "*Weltanschauung*", why we need to observe the meta-culture of change against current narratives of positivism and technology fallacies.

3.1. Values Beyond Sustainable Development

Sustainable development, at its most theoretical level, highlights the values of economic development, environmental, and social thriving. Whilst this three pillars model has been generally accepted, it is now clear that tough trade-offs between these values, conflicting value promises, and main concerns are rarely openly or debated, leading to increased misinterpretation, intensified disagreement, and confusion.

Integrated sustainability values strategy aims to reconcile these constructively. Considering the language of the UN General Assembly, the World Summit on Sustainable Development, the Earth Charter, and the Global Scenario Group, values for sustainable development include 'freedom, equality, unity, tolerance, regard for nature, and joint responsibility'. More specific and practical translation of these aspirations were posed to echo more specific actions for achieving a global peace, equitable development, diffuse human rights, African protection, and so forth. It was through this lens that the United Nations in 2015 took the very ambitious step of setting its 17 Sustainability Development Goals (SDGs).

The 17 SDGs address social and economic development whilst incorporating poverty, hunger, health, gender equality, water, sanitation, education, climate change, energy, environment, and social justice issues. They differed from their forerunners—the eight UN Millennium Development Goals (MDGs) set in 2000—in crucial ways. Their focus was on social issues in developing countries and success was limited to areas such as impacting poverty, HIV and malaria. In setting the SDGs, the most extensive global consultation in history was launched to gauge opinion on what they should include, embracing governments, international organizations, academia, civil society, businesses, and individuals around the world. With the world's population set to exceed 8.5 billion by 2030, growing demands on resources will in turn heighten risks of insecurity, poverty, and disadvantage. The rapid advances in digital technology and artificial intelligence brings to light new risks and impacts the way we work. As Spangenberg [90] warns, the SDGs can be seen re found to be weak on 'agency', since public administrations have limited duties on reporting and achievements, while business or consumers almost none (which is why success of SDGs is seen to be through the private, not public sector).

SDGs have made a big effort on compromise and discussion among nations and rights. However, being so wide they can just focus on a single state and impact, overlooking the burdens and in the end allowing contemporary counterproductive drivers. In order to allow positive interaction between the different targets, the means of implementation must set legally binding guidelines and criteria for all important stakeholders and entities (importantly including business), for ruling the market second equity principles, for a transparent governance of the public–private partnership instead of deregulation, and for a stronger role of public bodies and citizens and all main civil society assemblies.

The attitudes pursuing the values carried by SDGs should address the root causes of the inequalities and climate breakdown we live in. This requires behaviors taking more radical steps than corporate social responsibility (CSR) reports or the frequent intellectual exercises of greenwashing. For success with the SDGs, we need to go to the roots of our analysis, be visionary in willing change and stop defending the status quo, individually and as a society.

But what is at the root for change?

3.2. Three Main Narratives of Change

While SDGs condense the values and bring attitudes for radical change in society and ourselves towards sustainability, three main narratives of this change are taking place, as envisaged by Sörlin and here redrawn in more general terms.

3.2.1. The Anthropocene "Weltanschauung"

One such narrative of change is the Anthropocene "*Weltanschauung*", a German word for a fundamental concept of German philosophy and epistemology referring to a wide world perception.

In the case of Anthropocene, it defines the radical new phase of earth history that begun when human activities started to have a significant global impact on the Earth's geology and ecosystems. In the words of the eminent geographers and sociologists, we need to start thinking in revolutionary terms about the opportunities to impact this earth with a regenerative switch [91–93].

Jason suggests we live in the 'age of capital,' the Capitalocene [94], seen as arrangement of control, profit, and re/production as the essence of life. The troubled binary relationship of human/nature is one cause of our reluctance to consider human organizations—in addition to capitalism—as part of nature [95]. Societal post-war transformations must be viewed also in the light of how they work into procedures of power, capital, and nature established four centuries earlier, which have at their bases values such as the scientific progress and anthropocentrism.

Such values misled humanity in the believing of possessing an intellectual culture very far from giving us a better knowledge of our life conditions, since our relationship with our cultural instruments is strongly mediated by technology [96]. In other words, we are prisoners of the culture (as a mix of values, attitudes, and behaviors) we produced, and we live in, like fish in a stream of water. However, unlike other species, we are also able to see where we are heading.

While the meta-culture is usually a very difficult operation, being wide, branched, and enveloping, we, as members of the academic sector and elements delivering culture, must reflect upon this issue and be aware of the power of this narrative. Ethics and values lie at the very heart of the SDGs and can be seen as a vision for how we want to share the earth's resources among the whole of humanity. We now are aware that earth's resources are finite and that the human population is on track to reach approximately 10 billion by the middle of this century. Ethically, it is hard to argue that any one individual has more or less right to development than any other person on earth. For not exceeding planetary boundaries while increasing social justice [97–99], we need to be well-informed and develop brave imagination, responsible reflexivity, and a market with a sense of direction [100]. The last centuries' myths demonstrated that laws of economic motion produce intentional inequality, and that is why it is an incredibly exciting time to redesign the economy so that we meet the needs of all within the means of the planet. Drawing from the Kluckhohn fishes' metaphor, we must imagine to proceed in the counter stream [68] and observe how the 'dominion' of man over nature finds its root very far, and show its limit with all the clarity of natural disaster and diffused unhappiness of individuals.

3.2.2. The 'Extended Now' and the Right to Development

The second great transformative narrative is the directionality of this change [97]. In the book "*Regimes d'historicité*" [101], Francois Hartog describes the years after 1989 as a period when time had lost track, since the past and future appear of no importance in a system destroyed in its inner values. Before 1789, the past strongly informed the current life. Between 1789 and 1989, the fascination with the future. According to Hartog, our time is trapped between fears and senses, of one of emptiness, against a scenario where the earth ecosystem is devastated by a market still running as it was created in the initial capitalism. The 'extended now' is a well detected phenomenon, but we can still influence and heal the future, with narratives of positive change (for example through resilience) and improving the environment through principles of regenerative sustainability [14].

A regenerative sustainability shift allows for profound personal, societal, and global renewal, likened to the deeply religious, but perhaps heretical, sense that Franciscans claimed as the spiritual independence of all parts of nature. Fairness, equality, respect between humans and all other natural components are revolutionary values proposed by St. Francis. His belief in the value of humility, not merely for the individual but for man as a species, set up a form of democracy of all God's creatures, putting human beings in a system of equality. It is perhaps regrettable that our current science and technology are so entangled with a certain Christian/western arrogance towards nature, that any solution from here alone cannot be trusted [102].

That concept of domination over nature re-emerged fiercely between 1500 and 1600 and was enshrined in Western culture until recently, where our values allow investing in more and more technological power than political wisdom (the vested interests became stronger than public ones), giving authority to lineal causal planning instead of holistic approaches, giving privilege to arrogance and not to scientific understanding of complexity, prioritizing the short-term, instead of the long-term strategic vision [103,104].

3.2.3. The New Epistemology for Transdisciplinarity

The third great transformative narrative is the epistemological widening of the domain of knowledge, that is often the tool called into action for the big climate change challenge. Recent research is composed of specialists of multifaceted analysis, dealing with what Ronald Barnett called "supercomplexity" [105,106]. A new epistemology is needed above all in the places of knowledge transfer and sharing.

Great utopias like the Tommaso Campanella "*La città del sole*" or the "New Atlantis" by Francis Bacon have generated a mentality that is technically possible [107,108], regardless of a duty of respect for the created world that has been "entrusted to man's responsibility for its conservation and the maintenance of its beauty". The perspectives and promises of the socio-technical system in which we are still immersed are retraceable also in the discourses of the great intellectuals of the 17th century ([109], p. 168).

A key to that future utopia, a non-place, cannot be found in human nature: the key must in a revolutionary relationship between human culture and nature. The true utopia is our modernity, our techno-scientific vision of the world was that of Descartes, connecting that of the Renaissance alchemists and the research groups of our laboratories. This utopia is an intentional narrative accountable for the prevailing and furious alterations to the terrestrial landscape up to today's ecological and individual/phycological crisis. The contemporary rise of fundamentalists can be intended as a way to recover a sort of identity from the past, where the society has lost all its norms and values (*anomia*), and broke down all its social structures (*atomia*) [110,111], and seeks for a new epistemology.

The epistemological widening of the domain of knowledge is often the tool called into action for this big "supercomplexity" challenge of sustainability, embracing social, economic, and environmental issues in uncertain and unpredictable ways [106]. A new epistemology is needed in the knowledge transfer and sharing, communicating values of openness, boldness, community engagement, accessibility, and that should give to students occasions to learn how to solve societal challenges through experience

Such a new transdisciplinary epistemology should teach how to listen to many points of view and embrace uncertainty. The branch of integrative humanities emerged for understanding of such contemporary complexity and against the supremacy of any functionalist rhetoric as another symbolical turning point for this movement.

Aldo Leopold [112] can be viewed as a tipping point for such change in thinking: "We abuse the land because we regard it as a commodity belonging to us. When we see the land as a community to which we belong we may begin to use it with love and respect" (p. 373, [113]). Other attempts to articulate the *zeitgeist* of regenerative sustainability can be seen in Henry David Thoreau's Walden [114], in the rewilding of the land called for by George Monbiot [115], in Rachel Carson's 1967 "Silent Spring" [116] and in Brown's "FutuREstorative" [14], as well as in the recent "Doughnut Economics" from Kate Raworth [96].

This awareness brought the discourse to the third part of this paper, exploring the task of our role as academics in regenerative and revolutionary 'integrative humanities' science, with education outlined as an essential element for moving from sustainability to regenerative paradigms.

4. The Role of University

A "Great Transformation", in the words of Karl Polanyi, is needed to reorganize our knowledge, our education and our markets [117]. Drawing from Arendt's claim, science must now arise as a matter of political debate [118].

An essential element for this shift education [88,112,119]. This means rethinking, from a "change in education" to an "education for change" [120]. Eco-literacy in this sense may be the new seed to plant in future generations moving towards a collaborative, cooperative, and responsible approach [121–123].

4.1. The Importance of Words and Practices in Sustainability Education

Universities may take the responsibility of injecting behavioral change in future citizens and decision makers, considering the "acting", the "going", as a form of responsibility itself [124]. Communication is crucial since responsibility arises first by making all sustainability actions visible, and by creating a common language for sustainability, since a language deficit brings an attention deficit [125].

As suggested in the international literature, to act in an integrated lens is essential to develop a proper sustainability plan [126–128]. The University could, and should be the place of value transition, proceeding with coordinated actions on two fronts: implementing sustainability education, stressing its potential and in practicing what it preaches the classroom.

Transition theories also focus on the process of change [129] and transition (such as enroll in a new university, moving, getting a new job, or retiring). University-based policy initiatives could leverage into these 'moments of change' that characterize each new academic year.

The University can ultimately be an actor in society, being the place to reflect upon the relationship between the *tecnè* (*τέχνη*), our know-how on how cultural instruments should be used, and the *ethos* (*ἦθος*), the value system that should be able to control it. With integrative humanities support [130], a future university can overcome disciplinary silos, merging Social Science and Humanities (SSH) and Science, Technology, Engineering and Mathematics (STEM) in a problem-based knowledge transfer and co-creation systems [131–133].

The change in the teaching/research system requires interdisciplinary studies to replace the conventional lecture, or course-based education: more open (including external, green, and biophilic) spaces providing place for cooperation, interactions, workshops, co-study and greater academic recognition for qualitative studies will be needed [134,135]

In addition, any education agenda for regenerative sustainability will need to rethink the scientific mindset and tools to enable change curriculum networks at all levels of education, from kindergarten to university, in vocational training schools and in business. The educational system should strengthen the bonds between nature, biophilic design, biodiversity, buildings, and other ecosystems which have impacts on us as humans [31,136,137]. Citizens will take an important task working with experts and researchers from the academia and other research institutions and organizations to understand the scientific effects of climate change [138].

4.2. Four Practicable SDGs Recommended for Implementation in Higher Education Institutions

As practical examples of implementation, we propose four actions per each of the issues envisaged in Leiserowitz [33,139,140] as current barriers for behavioral change. For each issue, a specific university action is proposed:

1. SDG 4: Individuals (and the institutions they are affiliated with) can claim they do not have the time or background knowledge, or skills, or they do not think their single act may be effective. The university should offer courses for students, administrative staff, and professors regarding sustainable behaviors and their social, economic, and environmental impacts while suggesting practical tips for a wiser energy and resource consumption both at work and at home.
2. SDG 17: People will claim for physical obstacles to reach sustainability goals inside the university: the lack of an eco-friendly mobility infrastructure, or technology for renewable energy production, laws allowing a more flexible purchase of goods selected upon green criteria, elevated cost for the 'greener' choice. The coalition of national universities for sustainability may be the collector of single intentions to ask energy providers for lower renewable energy costs, or national governments for more flexible rules for green purchases.
3. SDG 12: Even when not acknowledged, habit and routine are strong barriers for people and institutions willing to change their behaviors. Even the simple disposing of recyclable waste, or switching off lights when exiting the office, can require time to change habits. However, recent evidence suggests that we act irrationally very often and that a stringent law in response to a shocking event can change the habits from one day to another.

The introduction of the smoking ban inside public buildings, hard punishment for drunk driving, mandatory seat belts, are all cases of single behaviors that saw a relatively quick change. Aside from this top–down strategy, the concept of 'bounded rationality' has been proposed by psychological economics claiming that logical decision-making is frequently imperfect for lack of time, or for the high number of alternatives that leads to postponement [141]. This 'paradox of choice' can be intensified when dealing with the complexity of defining green behavior. In this case, the university may support new habits taking the responsibility of selecting, with the help of in-house environmental experts, the products and the consumption behavioral path that are scientifically found more sustainable, thus inducing a 'forced' but informed new greener, choice.

4. SDG 13: As also argued by Shove [142], the complexity of sustainable behavior cannot be tackled just by placing independent driving features, such as value systems and organization settings, into simple causal models. Behavioral change is reciprocally encouraging. Dynamic and visible management cared by a dedicated unit in universities may foster the making of positive feedback loops, essential to support and accelerate the impact of a single behavioral change. A more active approach that considers not users, but humans as part of the set-up they live and work in, is also encouraged by the theory-U [37] for the co-creation of values. Shove's 'three elements model' (material—meanings-procedures) highlights the value of little gestures that can be easily promoted and performed by universities: for instance, providing physical items that allow or make easy a green behavior (such as waste points collections or energy consumption displays). A prosumer strategy put in place by communication offices in universities may profit of the co-creation with students and professors of a self-tailor-made strategy for effective sustainability communication, and increased wellbeing of all. Prosumer in the same institutions may easily identify a key field of action where the university can improve its environmental footprint—both in campus operations (estate management, procurement, etc.), and in teaching, research, and public impact—identify methods to communicate objectives to target audiences and enable individual communications projects to contribute towards a coordinated student engagement campaign.

5. Conclusions

Humans are at the center of global climate breakdown: The United Nations Sustainable Development Goals (SDGs) have ignited sustainability with proactive, global, social goals, moving us away from the 'do nothing today to compromise tomorrow's generation'. This Brundtland paradigm promotes a regenerative shift in the sustainability concept, no longer only considering resources and energy, but also the significant human-centric attributes. Despite this, precise ecological and sustainable attitudes have little prognostic value regarding final related individual human behavior. The global cultural contest, dominated by technological innovations, anthropocentric imperatives, the mirroring technological fallacy and the oblivion of ethical reasoning, makes the role of small actions, both at individual and academic scale even harder. To outline the context in which universities can collaborate to trigger sustainability values, attitudes, and behavior in future regenerated societies, this contribution is articulated in three main parts.

The first part analyzes the issue of sustainability transitions at the individual scale, where influencing factors and value-behavior links are presented as reviewed from a number of multi and transdisciplinary scholars' works. Structural and cultural factors are found to be a noteworthy part in behavioral change shaping. This means that working upon strategies tailor-made for specific target of people is far more effective than promoting general policies for sustainable consumption. Moreover, personal agency (as the ability to deliberately select, perform, and achieve personal intentions and desires) is crucial to obtain visible results in sustainable behavioral change. Mindfulness practices are found to be very useful tools to help illuminate one's values, to learn how to think more impartially, so that students can re-experience and gather attitudes that may be truer and respondent to real intentions. Mindfulness training can also help us to become witnesses of our mind processes, and thus more critical when receiving an external narrative/influence/desire.

The second part enlarges the picture to the global dimension, tracking the ideological steps of our current environmental crisis from the differences in prevailing western and eastern values, tradition, and perspectives, to the technological fallacy and the power of the narratives of changes. The heretical and revolutionary figure of St. Francis, recalled by the last Pope encyclic, breaks the attitudes of domination, derived from Genesis, with his belief in the value of humility, not merely for the individual but for man as a species, setting up a sort of democracy of all God's creatures.

The epistemological widening of the domain of knowledge is often a tool called into action for the big "supercomplexity" challenge of sustainability. A new epistemology is needed above all in the places of knowledge transfer and sharing like the university of the future, that should communicate values of openness, boldness, community engagement, accessibility, and that should give to students occasions to learn how to solve societal challenges by experiencing them in the streets. A new transdisciplinary epistemology should teach to listen to many points of view and embrace uncertainty. The branch of integrative humanities emerged precisely for the quest for much more authoritative and suitable understanding of such contemporary complexity and against the supremacy of the functionalist rhetoric.

This awareness brought the discourse to the third part of the paper, exploring the task of our role as academics in the revolutionary 'integrative humanities' science, as education is outlined as an essential element for moving from sustainability to regenerative paradigms.

Eventually, universities may take the societal role of injecting behavioral change in future citizens and decision makers, considering the 'acting', the 'going', as a form of responsibility itself.

Scaling up from the individual shift towards sustainability into a global shift must address the issue of responsibility. We may cite Edgar Morin in the beginning of his book [143]: "I felt in touch with the heritage of the planet, animated by the religion of what unites, from the rejection of what he refuses; animated by an infinite solidarity" ([143], p. 1). The aspiration and the intent of a planetary humanism offers the values, attitudes, and behavior not only as origin and purpose of complex thought, but also as a concrete journey of individual and global regeneration for exiting the crises of our time.

As suggested in the international literature, to act in an integrated optic is essential to develop an effectively-communicated sustainability plan. The University could, and should, be the place of value transition, proceeding with coordinated actions on two tracks: one, by implementing sustainability education, stressing the potential it has to orientate the civic sense; the other, for practicing what it preaches in its classrooms, by profiting of the transition moment of students enrolling or new staff hiring, experiencing concrete sustainable practices take place in the daily campus operations.

Author Contributions: G.S. is the main researcher. E.N. shaped the paper contents according to the aim of the RESTORE COST action in which this research spread out. M.B. contributed in respect to regenerative sustainability and refined the writing style.

Funding: This research received no external funding but the APC was funded by the COST Action CA16114 'RESTORE: Rethinking Sustainability towards a Regenerative Economy'. More information can be found at www.eurestore.eu/.

Acknowledgments: The authors acknowledge the great influence in structuring this article after attending enlightening seminars by Francesco Remotti, Viriato Soromenho-Marques, Joachim Spangenberg, Sverker Sörlin, Sebastian Thomas, Dario Padovan, Andrea Bonaccorsi, Carlo Olmo, and the lovely conversation with Didac Ferrer-Balas, Julie Newman, and Davis Bookhart. Interesting aspects emerged while participating in the COST Action CA16114 "RESTORE: Rethinking Sustainability towards a Regenerative Economy", the COST Action TD1408 "INTREPID: Interdisciplinarity in research programming and funding cycles", and the H2020 funded project SHAPE-ENERGY "Social Sciences and Humanities for Advancing Policy in European Energy".

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IPCC. *Global Warming of 1.5 °C*; IPCC: Geneva, Switzerland, 2018.
2. Flückiger, Y.; Seth, N. Sustainable Development Goals: SDG indicators need crowdsourcing. *Nature* **2016**, *531*, 448. [CrossRef] [PubMed]
3. Wickham, G.; Kendall, G. *Using Foucault's Methods*; SAGE Publications, Ltd.: London, UK, 1999.
4. Foucault, M. *The Order of Things*; Routledge: Abingdon-on-Thames, UK, 2005.
5. Habermas, J. *The Theory of Communicative Action*; Beacon Press: Boston, MA, USA, 1984; Volume 2.
6. Fergus, A.H.T.; Rowney, J.I.A. Sustainable development: Lost meaning and opportunity? *J. Bus. Ethics* **2005**, *60*, 17–27. [CrossRef]
7. Fergus, A.H.T.; Rowney, J.I.A. Sustainable development: Epistemological frameworks & an ethic of choice. *J. Bus. Ethics* **2005**, *57*, 197–207.
8. Ferrer-Balas, D.; Buckland, H.; de Mingo, M. Explorations on the University's role in society for sustainable development through a systems transition approach. Case-study of the Technical University of Catalonia (UPC). *J. Clean. Prod.* **2009**, *17*, 1075–1085. [CrossRef]
9. Sonetti, G.; Lombardi, P.; Chelleri, L. True Green and Sustainable University Campuses? Toward a Clusters Approach. *Sustainability* **2016**, *8*, 83. [CrossRef]
10. Lozano, R.; Lukman, R.; Lozano, F.J.; Huisingh, D.; Lambrechts, W. Declarations for sustainability in higher education: Becoming better leaders, through addressing the university system. *J. Clean. Prod.* **2013**, *48*, 10–19. [CrossRef]
11. Mader, C.; Scott, G.; Abdul Razak, D. Effective change management, governance and policy for sustainability transformation in higher education. *Sustain. Account. Manag. Policy J.* **2013**, *4*, 264–284. [CrossRef]
12. Brandon, P.S.; Lombardi, P. *Evaluating Sustainable Development in the Built Environment*; John Wiley & Sons: Hoboken, NJ, USA, 2010.
13. Sarrica, M.; Richter, M.; Thomas, S.; Graham, I.; Mazzara, B.M. Social approaches to energy transition cases in rural Italy, Indonesia and Australia: Iterative methodologies and participatory epistemologies. *Energy Res. Soc. Sci.* **2018**, *45*, 287–296. [CrossRef]
14. Brown, M. *FutuREstorative: Working towards a New Sustainability*, 1st ed.; RIBA Publishing: London, UK, 2016.
15. Sonetti, G.; Naboni, E.; Brown, M. Exploring the Potentials of ICT Tools for Human-Centric Regenerative Design. *Sustainability* **2018**, *10*, 1217. [CrossRef]
16. Schuetze, T.; Chelleri, L. Urban Sustainability Versus Green-Washing—Fallacy and Reality of Urban Regeneration in Downtown Seoul. *Sustainability* **2015**, *8*, 33. [CrossRef]

17. Klein, J.T. Reprint of "Discourses of transdisciplinarity: Looking back to the future". *Futures* **2015**, *65*, 10–16. [CrossRef]
18. Giovannini, E. *L'utopia Sostenibile*; Laterza: Roma, Italy, 2018.
19. Fullerton, J. *Regenerative Capitalism*; Capital Institute: Greenwich, CT, USA, 2015.
20. Dias, B.D. Beyond Sustainability–Biophilic and Regenerative Design in Architecture. *Eur. Sci. J.* **2015**, 11, ISSN: 1857–7881 (Print) e - ISSN 1857–7431.
21. Rogelj, J.; Den Elzen, M.; Höhne, N.; Fransen, T.; Fekete, H.; Winkler, H.; Schaeffer, R.; Sha, F.; Riahi, K.; Meinshausen, M. Paris Agreement climate proposals need a boost to keep warming well below 2 C. *Nature* **2016**, *534*, 631–639. [CrossRef] [PubMed]
22. Barr, S.; Shaw, G.; Coles, T. Times for (Un)sustainability? Challenges and opportunities for developing behaviour change policy. A case-study of consumers at home and away. *Glob. Environ. Chang.* **2011**, *21*, 1234–1244. [CrossRef]
23. Vlek, C.; Steg, L. Human Behavior and Environmental Sustainability: Problems, Driving Forces, and Research Topics. *J. Soc. Issues* **2007**, *63*, 1–19. [CrossRef]
24. Reid, W.V.; Chen, D.; Goldfarb, L.; Hackmann, H.; Lee, Y.T.; Mokhele, K.; Ostrom, E.; Raivio, K.; Rockström, J.; Schellnhuber, H.J.; et al. Earth System Science for Global Sustainability: Grand Challenges. *Science* **2010**, *330*, 916–917. [CrossRef] [PubMed]
25. Dietz, R.; O'Neill, D. *Enough Is Enough: Building a Sustainable Economy in a World of Finite Resources*; Routledge: Abingdon-on-Thames, UK, 2013.
26. Henly-Shepard, S.; Gray, S.A.; Cox, L.J. The use of participatory modeling to promote social learning and facilitate community disaster planning. *Environ. Sci. Policy* **2015**, *45*, 109–122. [CrossRef]
27. Ensor, J.; Harvey, B. Social learning and climate change adaptation: Evidence for international development practice. *Wiley Interdiscip. Rev. Clim. Chang.* **2015**, *6*, 509–522. [CrossRef]
28. Johannessen, Ã.; Hahn, T. Social learning towards a more adaptive paradigm? Reducing flood risk in Kristianstad municipality, Sweden. *Glob. Environ. Chang.* **2013**, *23*, 372–381. [CrossRef]
29. ISSC; UNESCO. *World Social Science Report 2013: Changing Global Environments*, 1st ed.; United Nations Educational, Scientific and Cultural Organization (UNESCO): Paris, France; The International Social Science Council (ISSC): Paris, France; Organisation for Economic Co-Operation and Development (OECD): Paris, France, 2013; OECD ISBN 978-92-64-20340-2 (print) ISBN 978-92-64-20341-9 (PDF) UNESCO ISBN 978-92-3-104254-6 (PDF and Print). [CrossRef]
30. Brandi, C. Safeguarding the earth system as a priority for sustainable development and global ethics: The need for an earth system SDG. *J. Glob. Ethics* **2015**, *11*, 32–36. [CrossRef]
31. Restore, C.A.C. *Sustainability, Restorative to Regenerative*; Brown, M., Haselsteiner, E., Aproó, D., Kopeva, D., Egla, L., Pulkkinen, K.-L., Vula Rizvanolli, B., Eds.; RESTORE Wo.: Wien, Austria, 2018.
32. Dempsey, N.; Bramley, G.; Power, S.; Brown, C. The social dimension of sustainable development: Defining urban social sustainability. *Sustain. Dev.* **2011**, *19*, 289–300. [CrossRef]
33. Kates, R.W.; Parris, T.M.; Leiserowitz, A.A. What is sustainable development? Goals, indicators, values, and practice. *Environment* **2005**, *47*, 8–21.
34. Jackson, T. Motivating sustainable consumption. *Sustain. Dev. Res. Netw.* **2005**, *29*, 30.
35. Soron, D. Sustainability, self-identity and the sociology of consumption. *Sustain. Dev.* **2010**, *18*, 172–181. [CrossRef]
36. Fuchs, D.A.; Lorek, S. Sustainable consumption governance: A history of promises and failures. *J. Consum. Policy* **2005**, *28*, 261–288. [CrossRef]
37. Scharmer, C.O. *Theory U: Learning from the Future as It Emerges*; Berrett-Koehler Publishers: Oakland, CA, USA, 2009.
38. Scharmer, O. *The Essentials of Theory U: Core Principles and Applications*; Berrett-Koehler Publishers: Oakland, CA, USA, 2018.
39. Brosch, T.; Patel, M.K.; Sander, D. Affective influences on energy-related decisions and behaviors. *Front. Energy Res.* **2014**, *2*, 11. [CrossRef]
40. Kerstholt, J.; Duijnhoven, H.; Paton, D. Flooding in The Netherlands: How people's interpretation of personal, social and institutional resources influence flooding preparedness. *Int. J. Disaster Risk Reduct.* **2017**, *24*, 52–57. [CrossRef]

41. Lefevre, A.; Chapman, M. *Behavioural Economics and Financial Consumer Protection*; OECD Working Papers on Finance, Insurance and Private Pensions, No. 42; OECD Publishing: Paris, France, 2017. [CrossRef]
42. Verplanken, B.; Roy, D. "My worries are rational, climate change is not": Habitual ecological worrying is an adaptive response. *PLoS ONE* **2013**, *8*, e74708. [CrossRef] [PubMed]
43. Taufik, D.; Bolderdijk, J.W.; Steg, L. Going green? The relative importance of feelings over calculation in driving environmental intent in the Netherlands and the United States. *Energy Res. Soc. Sci.* **2016**, *22*, 52–62. [CrossRef]
44. Masini, A.; Menichetti, E. The impact of behavioural factors in the renewable energy investment decision making process: Conceptual framework and empirical findings. *Energy Policy* **2012**, *40*, 28–38. [CrossRef]
45. McKenzie-Mohr, D. *Fostering Sustainable Behavior: An Introduction to Community-Based Social Marketing*; New Society Publishers: Gabriola Island, BC, Canada, 2013.
46. Blok, V.; Wesselink, R.; Studynka, O.; Kemp, R. Encouraging sustainability in the workplace: A survey on the pro-environmental behaviour of university employees. *J. Clean. Prod.* **2015**, *106*, 55–67. [CrossRef]
47. Kollmuss, A.; Agyeman, J. Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environ. Educ. Res.* **2002**, *8*, 239–260. [CrossRef]
48. Kaiser, F.G.; Wölfing, S.; Fuhrer, U. Environmental attitude and ecological behaviour. *J. Environ. Psychol.* **1999**, *19*, 1–19. [CrossRef]
49. Blake, J. Overcoming the 'value-action gap' in environmental policy: Tensions between national policy and local experience. *Local Environ.* **1999**, *4*, 257–278. [CrossRef]
50. Kuo, F.; Young, M. A study of the intention–action gap in knowledge sharing practices. *J. Am. Soc. Inf. Sci. Technol.* **2008**, *59*, 1224–1237. [CrossRef]
51. Rhodes, R.E.; de Bruijn, G. How big is the physical activity intention–behaviour gap? A meta-analysis using the action control framework. *Br. J. Health Psychol.* **2013**, *18*, 296–309. [CrossRef] [PubMed]
52. Segalas, J.; Ferrer-Balas, D.; Mulder, K.F. What do engineering students learn in sustainability courses? The effect of the pedagogical approach. *J. Clean. Prod.* **2010**, *18*, 275–284. [CrossRef]
53. Feola, G.; Nunes, R. Success and failure of grassroots innovations for addressing climate change: The case of the Transition Movement. *Glob. Environ. Chang.* **2014**, *24*, 232–250. [CrossRef]
54. Leal Filho, W.; Manolas, E.; Pace, P. The future we want: Key issues on sustainable development in higher education after Rio and the UN decade of education for sustainable development. *Int. J. Sustain. High. Educ.* **2015**, *16*, 112–129. [CrossRef]
55. Disterheft, A.; Caeiro, S.S.; Leal Filho, W.; Azeiteiro, U.M. The INDICARE-model–measuring and caring about participation in higher education's sustainability assessment. *Ecol. Indic.* **2016**, *63*, 172–186. [CrossRef]
56. Allen, M.W.; Hung Ng, S.; Wilson, M. A functional approach to instrumental and terminal values and the value-attitude-behaviour system of consumer choice. *Eur. J. Mark.* **2002**, *36*, 111–135. [CrossRef]
57. Maio, G.R.; Olson, J.M. Value—Attitude-behaviour relations: The moderating role of attitude functions. *Br. J. Soc. Psychol.* **1994**, *33*, 301–312. [CrossRef]
58. Dembkowski, S.; Hanmer-Lloyd, S. The environmental value-attitude-system model: A framework to guide the understanding of environmentally-conscious consumer behaviour. *J. Mark. Manag.* **1994**, *10*, 593–603. [CrossRef]
59. Ericson, T.; Kjønstad, B.G.; Barstad, A. Mindfulness and sustainability. *Ecol. Econ.* **2014**, *104*, 73–79. [CrossRef]
60. Pred, A. Production, family, and free-time projects: A time-geographic perspective on the individual and societal change in nineteenth-century US cities. *J. Hist. Geogr.* **1981**, *7*, 3–36. [CrossRef]
61. Watkins, K.E.; Marsick, V.J. *Sculpting the Learning Organization: Lessons in the Art and Science of Systemic Change*; ERIC, Jossey-Bass Inc.: San Francisco, CA, USA, 1993.
62. Andersen, R.; Newman, J.F. Societal and individual determinants of medical care utilization in the United States. *Milbank Mem. Fund Q. Health Soc.* **1973**, 95–124. [CrossRef]
63. Carew, A.L.; Mitchell, C.A. Teaching sustainability as a contested concept: Capitalizing on variation in engineering educators' conceptions of environmental, social and economic sustainability. *J. Clean. Prod.* **2008**, *16*, 105–115. [CrossRef]
64. Tejedor, G.; Segalàs, J.; Rosas-Casals, M. Transdisciplinarity in higher education for sustainability: How discourses are approached in engineering education. *J. Clean. Prod.* **2018**, *175*, 29–37. [CrossRef]
65. Leiserowitz, A.A.; Kates, R.W.; Parris, T.M. Sustainability values, attitudes, and behaviors: A review of multinational and global trends. *Annu. Rev. Environ. Resour.* **2006**, *31*, 413–444. [CrossRef]

66. Parsons, T.; Shils, E.A.; Smelser, N.J. *Toward a General Theory of Action: Theoretical Foundations for the Social Sciences*; Transaction Publishers: Piscataway, NJ, USA, 1965.
67. Mèunch, R.; Münch, R.; Smelser, N.J. *Theory of Culture*; Univ of California Press: Oakland, CA, USA, 1992; Volume 2.
68. Remotti, F. *Contro L'identità*; Gius. Laterza & Figli Spa: Bari, Italy, 2012.
69. Czap, N.V.; Czap, H.J.; Lynne, G.D.; Burbach, M.E. Walk in my shoes: Nudging for empathy conservation. *Ecol. Econ.* **2015**, *118*, 147–158. [CrossRef]
70. Scherer, B.; Waistell, J. Incorporating mindfulness: Questioning capitalism. *J. Manag. Spiritual. Relig.* **2018**, *15*, 123–140. [CrossRef]
71. Mearns, R.; Norton, A. *The Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World*; The World Bank: Washington, DC, USA, 2009.
72. Pappas, J.B.; Pappas, E.C. The sustainable personality: Values and behaviors in individual sustainability. *Int. J. High. Educ.* **2014**, *4*, 12. [CrossRef]
73. Whitmarsh, L.; O'Neill, S. Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. *J. Environ. Psychol.* **2010**, *30*, 305–314. [CrossRef]
74. Lavelle, M.J.; Rau, H.; Fahy, F. Different shades of green? Unpacking habitual and occasional pro-environmental behavior. *Glob. Environ. Chang.* **2015**, *35*, 368–378. [CrossRef]
75. Karlin, B.; Davis, N.; Sanguinetti, A.; Gamble, K.; Kirkby, D.; Stokols, D. Dimensions of Conservation: Exploring Differences Among Energy Behaviors. *Environ. Behav.* **2012**, *46*, 423–452. [CrossRef]
76. Martinsson, J.; Lundqvist, L.J.; Sundström, A. Energy saving in Swedish households. The (relative) importance of environmental attitudes. *Energy Policy* **2011**, *39*, 5182–5191. [CrossRef]
77. Fahy, F.; Doyle, R.; Rau, H.; Davies, A.R.; Pape, J. Situating sustainable consumption in a policy context. In *Challenging Consumption*; ROUTLEDGE in Association with GSE Research; ROUTLEDGE: Abingdon-on-Thames, UK, 2014; Volume 19, pp. 19–35. Available online: https://www.researchgate.net/publication/258811315_Situating_sustainable_consumption_in_a_policy_context (accessed on 7 January 2019).
78. Sawitri, D.R.; Hadiyanto, H.; Hadi, S.P. Pro-environmental Behavior from a SocialCognitive Theory Perspective. *Procedia Environ. Sci.* **2015**, *23*, 27–33. [CrossRef]
79. Shapiro, S.L.; Bootzin, R.R.; Figueredo, A.J.; Lopez, A.M.; Schwartz, G.E. The efficacy of mindfulness-based stress reduction in the treatment of sleep disturbance in women with breast cancer. An exploratory study. *J. Psychosom. Res.* **2003**, *54*, 85–91. [CrossRef]
80. Rosenberg, E.L. Mindfulness and consumerism. *Psychol. Consum. Cult. Struggl.* **2004**, 107–125.
81. Wiek, A.; Withycombe, L.; Redman, C.L. Key competencies in sustainability: A reference framework for academic program development. *Sustain. Sci.* **2011**, *6*, 203–218. [CrossRef]
82. De Haan, G. The BLK '21'programme in Germany: A 'Gestaltungskompetenz'-based model for Education for Sustainable Development. *Environ. Educ. Res.* **2006**, *12*, 19–32. [CrossRef]
83. Barth, M.; Rieckmann, M. Academic staff development as a catalyst for curriculum change towards education for sustainable development: An output perspective. *J. Clean. Prod.* **2012**, *26*, 28–36. [CrossRef]
84. Sipos, Y.; Battisti, B.; Grimm, K. Achieving transformative sustainability learning: Engaging head, hands and heart. *Int. J. Sustain. High. Educ.* **2008**, *9*, 68–86. [CrossRef]
85. Parkin, S. Contexts and drivers for operationalizing sustainable development. In *Proceedings of the ICE-Civil Engineering*; Thomas Telford: London, UK, 2000; Volume 138, pp. 9–15.
86. Sterling, S. Learning for resilience, or the resilient learner? Towards a necessary reconciliation in a paradigm of sustainable education. *Environ. Educ. Res.* **2010**, *16*, 511–528. [CrossRef]
87. Segalàs, J.; Ferrer-Balas, D.; Svanström, M.; Lundqvist, U.; Mulder, K.F. What has to be learnt for sustainability? A comparison of bachelor engineering education competences at three European universities. *Sustain. Sci.* **2009**, *4*, 17–27. [CrossRef]
88. Steiner, G.; Posch, A. Higher education for sustainability by means of transdisciplinary case studies: An innovative approach for solving complex, real-world problems. *J. Clean. Prod.* **2006**, *14*, 877–890. [CrossRef]
89. Kluckhohn, C. *Culture and Behavior*; Free Press Glencoe: Oxford, UK, 1962.
90. Spangenberg, J.H. Hot air or comprehensive progress? A critical assessment of the SDGs. *Sustain. Dev.* **2017**, *25*, 311–321. [CrossRef]

91. Steffen, W.; Crutzen, P.J.; McNeill, J.R. The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature. *Ambio* **2007**, *36*, 614–621. [CrossRef]
92. Chelleri, L.; Waters, J.J.; Olazabal, M.; Minucci, G. Resilience trade-offs: Addressing multiple scales and temporal aspects of urban resilience. *Environ. Urban.* **2015**, *27*, 181–198. [CrossRef]
93. Steffen, W.; Persson, Å.; Deutsch, L.; Zalasiewicz, J.; Williams, M.; Richardson, K.; Crumley, C.; Crutzen, P.; Folke, C.; Gordon, L.; et al. The Anthropocene: From Global Change to Planetary Stewardship. *Ambio* **2011**, *40*, 739–761. [CrossRef]
94. Moore, J.W. The Capitalocene, Part I: On the nature and origins of our ecological crisis. *J. Peasant Stud.* **2017**, *44*, 594–630. [CrossRef]
95. Shove, E.; Walker, G. CAUTION! Transitions ahead: Politics, practice, and sustainable transition management. *Environ. Plan. A* **2007**, *39*, 763–770. [CrossRef]
96. Weber, M. *Wissenschaft als Beruf: 1917–1919; Politik als Beruf: 1919*; Mohr Siebeck: Heidelberg, Germany, 1992; Volume 17.
97. Rockstrom, J.; Steffen, W.; Noone, K.; Persson, A.; Chapin, F.S.; Lambin, E.F.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; et al. A safe operating space for humanity. *Nature* **2009**, *461*, 472–475. [CrossRef] [PubMed]
98. Raworth, K. *Doughnut Economics: Seven Ways to Think like a 21st-Century Economist*; Chelsea Green Publishing: White River Junction, VT, USA, 2017.
99. Sörlin, S. Reform and responsibility—The climate of history in times of transformation. *Hist. Tidsskr.* **2018**, *97*, 7–23. [CrossRef]
100. Eriksen, T.H. *Globalization: The Key Concepts*; A&C Black: London, UK, 2014.
101. Hartog, F. *Régimes D'historicité. Présentisme et Expériences*; Le Seuil: Paris, France, 2014.
102. Francis, P. *Laudato Si: On Care for Our Common Home*; Our Sunday Visitor: Huntington, IN, USA, 2015.
103. Peters, T. Nature as measure: The biomimicry guild. *Archit. Des.* **2011**, *81*, 44–47. [CrossRef]
104. Du Plessis, C. Towards a regenerative paradigm for the built environment. *Build. Res. Inf.* **2012**, *40*, 7–22. [CrossRef]
105. Barnett, R. University knowledge in an age of supercomplexity. *High. Educ.* **2000**, *40*, 409–422. [CrossRef]
106. Barnett, R. Supercomplexity and the curriculum. *Stud. High. Educ.* **2000**, *25*, 255–265. [CrossRef]
107. Campanella, T. *La Città del Sole*; Newton Compton Editori: Roma, Italy, 2012.
108. Bacon, F. *New Atlantis and the Great Instauration*; John Wiley & Sons: Hoboken, NJ, USA, 2016.
109. Descartes, R. *Discourse on Method; and, Meditations on First Philosophy*; Hackett Pub Co Inc.: Indianapolis, IN, USA, 1993.
110. Galtung, J. Cultural violence. *J. Peace Res.* **1990**, *27*, 291–305. [CrossRef]
111. Galtung, J. Violence, peace, and peace research. *J. Peace Res.* **1969**, *6*, 167–191. [CrossRef]
112. Knapp, C.E. The "I-thou" relationship, place-based education, and Aldo Leopold. *J. Exp. Educ.* **2005**, *27*, 277.
113. Silvius, J.E.; Holtzman, L.T. Leopold Appealed to Conscience. *Bioscience* **2006**, *56*, 373. [CrossRef]
114. Thoreau, H.D. *Walden*; Lyndon Shanley, J., Ed.; Princeton University Press: Princeton, NJ, USA, 1971.
115. Monbiot, G. *Feral: Rewilding the Land, the Sea, and Human Life*; University of Chicago Press: Chicago, IL, USA, 2014.
116. Carson, R. *Silent Spring*; Houghton Mifflin Harcourt: Boston, MA, USA, 2002.
117. Polanyi, K.; MacIver, R.M. *The Great Transformation*; Beacon Press Boston: Boston, MA, USA, 1944; Volume 2.
118. Arendt, H.; Kohn, J. *Between Past and Future: Eight Exercises in Political Thought*; Penguin: London, UK, 2006.
119. Bousquet, F.; Barreteau, O.; d'Aquino, P.; Etienne, M.; Boissau, S.; Aubert, S.; Le Page, C.; Babin, D.; Castella, J.C.; Janssen, M. *Complexity and Ecosystem Management: The Theory and Practice of Multi-Agent Approaches*; Cheltenham: Glos, UK, 2002.
120. Ferrer-Balas, D.; Lozano, R.; Huisingh, D.; Buckland, H.; Ysern, P.; Zilahy, G. Going beyond the rhetoric: System-wide changes in universities for sustainable societies. *J. Clean. Prod.* **2010**, *18*, 607–610. [CrossRef]
121. Lozano, R.; Ceulemans, K.; Seatter, C.S. Teaching organisational change management for sustainability: Designing and delivering a course at the University of Leeds to better prepare future sustainability change agents. *J. Clean. Prod.* **2014**. [CrossRef]
122. Venetoulis, J. Assessing the ecological impact of a university: The ecological footprint for the University of Redlands. *Int. J. Sustain. High. Educ.* **2001**, *2*, 180–197. [CrossRef]

123. Lombardi, P.; Sonetti, G. *News from the Front of Sustainable University Campuses*; Edizioni Nuova Cultura: Roma, Italy, 2017.
124. Weber, M. *La Politica Come Professione*; Armando Editore: Roma, Italy, 1997.
125. Macfarlane, R. *Landmarks*; Penguin: London, UK, 2015.
126. Bentivegna, V.; Curwell, S.; Deakin, M.; Lombardi, P.; Mitchell, G.; Nijkamp, P. A vision and methodology for integrated sustainable urban development: BEQUEST. *Build. Res. Inf.* **2002**, *30*, 83–94. [CrossRef]
127. Bosher, L. Built-in resilience through disaster risk reduction: Operational issues. *Build. Res. Inf.* **2014**, *4*, 240–254. [CrossRef]
128. Mugerauer, R. Toward a theory of integrated urban ecology: Complementing Pickett et al. *Ecol. Soc.* **2010**, *15*, 31. [CrossRef]
129. Prochaska, J.O.; DiClemente, C.C. Transtheoretical therapy: Toward a more integrative model of change. *Psychother. Theory Res. Pract.* **1982**, *19*, 276. [CrossRef]
130. Available online: https://shapeenergy.eu/ (accessed on 1 October 2018).
131. Sovacool, B.K. What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda. *Energy Res. Soc. Sci.* **2014**, *1*, 1–29. [CrossRef]
132. Arrobbio, O.; Sonetti, G.; Foulds, C. *The SHAPE ENERGY Horizon 2020 Sandpits: Key Findings*; SHAPE ENERGY: Cambridge, UK, 2018.
133. Bonaccorsi, A. Towards an Epistemic Approach to Evaluation in SSH. In *The Evaluation of Research in Social Sciences and Humanities*; Springer: New York, NY, USA, 2018; pp. 1–29.
134. Lang, D.J.; Wiek, A.; Bergmann, M.; Stauffacher, M.; Martens, P.; Moll, P.; Swilling, M.; Thomas, C.J. Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustain. Sci.* **2012**, *7*, 25–43. [CrossRef]
135. Thomas, S.; Richter, M.; Lestari, W.; Prabawaningtyas, S.; Anggoro, Y.; Kuntoadji, I. Transdisciplinary research methods in community energy development and governance in Indonesia: Insights for sustainability science. *Energy Res. Soc. Sci.* **2018**, *45*, 184–194. [CrossRef]
136. Available online: https://gaiaeducation.org/news/ecological-design-education/ (accessed on 8 November 2018).
137. Available online: http://www.intrepid-cost.eu/ (accessed on 8 November 2018).
138. Available online: https://www.seattletimes.com/pacific-nw-magazine/the-school-of-regenerative-design-will-teach-what-mclennan-design-preaches/ (accessed on 8 November 2018).
139. Leiserowitz, A.A. American risk perceptions: Is climate change dangerous? *Risk Anal. Int. J.* **2005**, *25*, 1433–1442. [CrossRef] [PubMed]
140. Leiserowitz, A. Climate change risk perception and policy preferences: The role of affect, imagery, and values. *Clim. Chang.* **2006**, *77*, 45–72. [CrossRef]
141. Simon, H.A. *Models of Bounded Rationality: Empirically Grounded Economic Reason*; MIT Press: Cambridge, MA, USA, 1997; Volume 3.
142. Shove, E. Beyond the ABC: Climate change policy and theories of social change. *Environ. Plan. A* **2010**, *42*, 1273–1285. [CrossRef]
143. Morin, E. La voie. In *Pour L'avenir L'humanite*; Fayard/Pluriel: Paris, France, 2011.

MDPI
St. Alban-Anlage 66
4052 Basel
Switzerland
Tel. +41 61 683 77 34
Fax +41 61 302 89 18
www.mdpi.com

Sustainability Editorial Office
E-mail: sustainability@mdpi.com
www.mdpi.com/journal/sustainability

MDPI
St. Alban-Anlage 66
4052 Basel
Switzerland

Tel: +41 61 683 77 34
Fax: +41 61 302 89 18

www.mdpi.com

ISBN 978-3-03921-905-6