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New Insights into Circular Economy and Sustainable Development

Edited by

Viktor Koval, Dzintra Atstaja and Ilona Skačkauskienė

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

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Preface to ”New Insights into Circular Economy and Sustainable Development”

The rational use of natural resources and energy efficiency are considered key parameters for the possibility of an economy’s transition to sustainable development. Decarbonization and energy transition define the requirements for the functioning of the energy economy. The circular economy minimizes the need to use new resources to generate energy while reducing the environmental impact. Consisting of 13 papers written by research experts on a topic of interest, this book reports on the latest research on the circular economy and sustainable innovation. A methodology is presented for analysing scenarios for the introduction of low-carbon technologies in a circular economy, as well as programs related to the reduction of CO_2 emissions through investment in renewable energy sources.

Viktor Koval, Dzintra Atstaja, and Ilona Skačkauskienė
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Article

The "My Electricity" Program as One of the Ways to Reduce CO_2 Emissions in Poland

Piotr Olczak [1,*], Agnieszka Żelazna [2], Dominika Matuszewska [3] and Małgorzata Olek [4]

1 Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Wybickiego St. 7A, 31-261 Kraków, Poland
2 Faculty of Environmental Engineering, Lublin University of Technology, 40B Nadbystrzycka Str., 20-618 Lublin, Poland; a.zelazna@pollub.pl
3 Faculty of Energy and Fuels, AGH University of Science and Technology, 30 Mickiewicza Ave., 30-059 Cracow, Poland; dommat@agh.edu.pl
4 Faculty of Environmental and Power Engineering, Cracow University of Technology, 24 Warszawska, 31-155 Cracow, Poland; molek@pk.edu.pl
* Correspondence: olczak@min-pan.krakow.pl

Abstract: One way to reduce CO_2 emissions is to replace conventional energy sources with renewable ones. In order to encourage prosumers to invest in renewable energy, EU Member States are developing renewable energy subsidy programs. In Poland, in the years 2019–2020, the "My Electricity" program was implemented, co-financing was up to 50% of eligible costs (max PLN 5000, i.e., EUR 1111), and the total cost of the program was 251 million euro. During this period, around 400,000 prosumer installations were created in Poland, including over 220,000 prosumer PV Installations under the My Electricity program. The total power of the installation under the "My Electricity" program was 1.295 GWp with an average installation power of 5.72 kWp. It is estimated that the micro-installations will produce approx. 1.4 TWh of electricity annually. Depending on the replaced source of electricity (coal, gas, mix), in the next 30 years, it will help to avoid 26.2–42.7 million Mg of greenhouse gases calculated as carbon dioxide equivalents (CO_{2eq}). The coefficient of subsidy expenditure from the "My Electricity" program was 194 EUR/kWp, and in the next 30 years, it will be 6.52 EUR/MWh. The investment in PV will save EUR 1550 million, which would have to be incurred for the purchase of CO_2 emission permits.

Keywords: My Electricity; photovoltaic (PV); LCA; carbon dioxide emission; grants; Poland; renewable energy

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1. Introduction

Consequent to population growth and economic development, the demand for energy is constantly growing—the International Energy Agency predicts that the demand for electricity will increase by 30% in 2040, compared with the base year 2016 [1,2]. Unfortunately, attempts to create better living conditions for society involve serious problems related to fossil fuel combustion and its negative environmental impact: climate changes, acid rains, eutrophication, emissions of greenhouse gases (GHG), mercury and other pollutants, etc. [3,4]. Thus, there is also growing public awareness of the urgent need to solve these most pressing environmental problems related to energy production. The consequences of these changes caused the 2015 Paris agreement to limit global warming to well below 2 °C, compared with the pre-industrial era, in order to reduce the risk and damage caused by climate changes [5]. Considering this, the shift from fossil fuels to renewable energy sources seems to be a good and future-proof solution. At the same time, public policy has largely favoured wind and solar technologies for energy production among other technologies using renewable sources (RESs), which contributed to the growth of installations powered by these sources [6–8]. More importantly, many premises indicate that such a climate policy will determine future directions for actions [9–11], where solar energy technologies will have leading importance [12,13]. On the example of the European Union itself, it can be seen how the electricity generation capacity has changed from 1.9 GW to over 133 GW in 2010–2019. The year 2019 alone brought 16.5 GW of new installed capacity in the EU [14]. As a result, the power installed in photovoltaics both in the EU and United Kingdom could generate 5.2% of the final electricity demand (about 150 TWh) at the end of 2019 [15]. The efficiency of photovoltaic systems depends on several factors, including photovoltaic technology and its structure and components used, partial shading, losses related to soiling of the panels, as well as individual environmental factors for different latitudes such as the insolation, temperature, angular losses, etc. [16–18]. Poland, as one of the EU Member States, faces an urgent need to develop new solutions for the energy sector that would be appropriate in terms of environment, technology, and economy [19,20]. This is even more important in the context of the fact that the Polish energy mix is largely based on the use of fossil fuels (mainly coal) as an energy source—in 2020, in Poland, 70.18 TWh was generated from hard coal, while 34.42 TWh was generated from lignite, with total energy generation at the level of 140.56 TWh, which was 49.93% and 34.42%, respectively [21,22]. Data shows that in 2018 in Poland, greenhouse gas emissions were 415.9 million tons of carbon dioxide equivalents (CO_{2eq}) [23]. The high and constantly growing prices of CO_2 emission rights make coal power plants less and less profitable in operation [24,25]. The prices of CO_2 emissions over the last few years are presented in Figure 1.

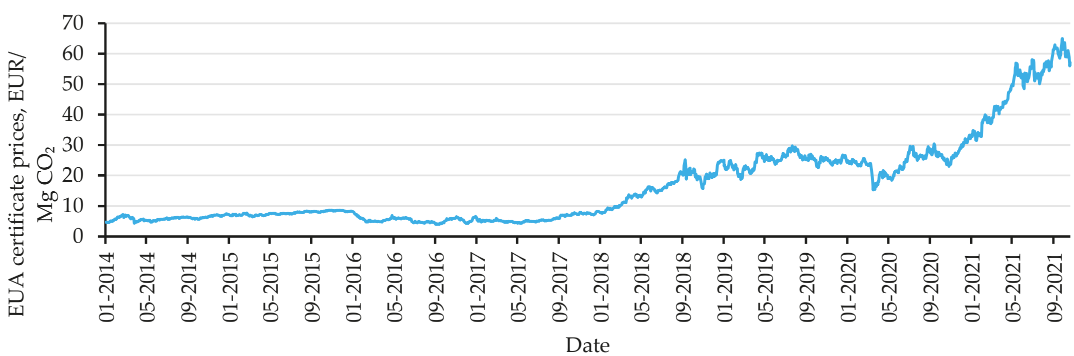


Figure 1. Prices of CO_2 emission allowances in 2014–2021. Authors' study based on [26].

Analysing the current situation on the photovoltaic market in European countries with a temperate climate, Poland, immediately after Germany and The Netherlands, has the largest PV market [27]. With an estimated annual insolation value of 1000 kWh/m^2 [28,29], the Polish photovoltaic sector is the fastest-developed renewable energy sector—with a total capacity of micro-installations of 4075.5 MW (data as of 31 June 2021). Comparing this with the total installed capacity as of 30 June 2017, it indicates almost a 25-fold increase in less than 4 years (Figure 2) [30]. As a result, Poland ranks fifth in terms of creating new PV installation capacities, closely behind Germany, Spain, The Netherlands, and France. Forecasts show that PV installations will continue to be popular in the future, and installed capacity may, with conservative estimates, increase by around 5–7 GWp by 2030 [31] and by around 10–16 GWp by 2040 [32,33].

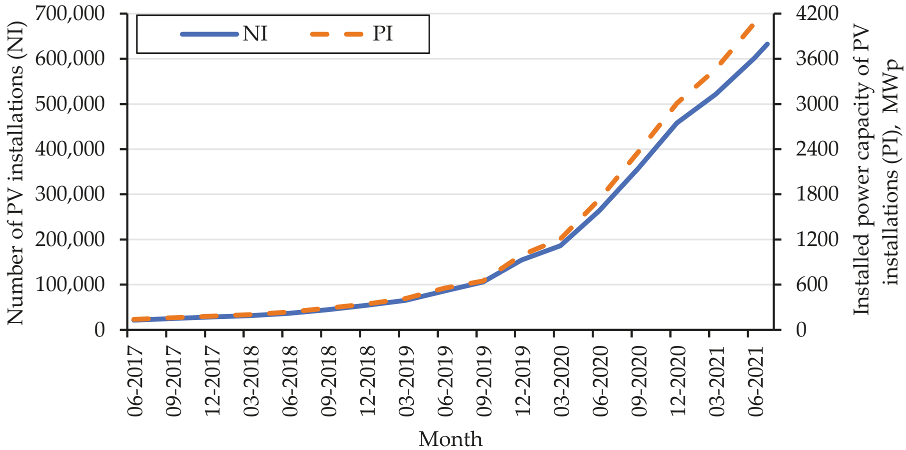


Figure 2. Number of PV installations and installed power capacity of PV installation in Poland. Authors' study based on [30].

The development of photovoltaics both in Poland and the entire EU was possible to a large extent through programs aimed at encouraging investors to invest in solar technologies [6,7]. At the same time, designing a renewable energy policy through various types of support programs, tax breaks, subsidies, is extremely important from the point of view of efficiency, environmental friendliness, as well as social equity [34]. The price effect pushes producers with high marginal costs from the market (which may be influenced by the high costs of carbon certificates in the case of conventional power plants) and a decrease in the wholesale energy price. On the other hand, consumers bear to a large extent hidden costs related to the development of RES since these subsidies are refinanced from taxes. As a result, the allocation of aid funds in RES is extremely important, and it is worth examining whether the mechanisms governing it are not defective, and there are no problems with the appropriate allocation of funds [7,35]. Olczak et al. [36] analysed the allocation of funds for photovoltaic micro-installations in Poland in terms of inequality between voivodeships in terms of their use. In the context of switching from conventional fossil technologies to generation using renewable sources, much is said about reducing GHG emissions during their operation [37]. However, when comparing the difference in GHG emissions between systems using fossil fuels and renewable sources, their operation time should be considered, as well as the entire life cycle, by conducting an appropriate life cycle analysis (LCA) for each of the compared systems [38]. Life cycle assessment (LCA) is a well-known method used to assess the environmental impact of a product or process throughout its entire life cycle (from its manufacture, through operation, to disposal) [39], and consists of four main parts: goal and scope definition, inventory analysis, impact assessment and interpretation [40].

There are numerous studies on PV LCAs in the literature [41–45]. Bracquene et al. [41] discussed how the eco-design of PV can contribute to reducing the environmental impact of photovoltaic panels. Müller et al. [42] conducted an LCA analysis of photovoltaic (PV) systems from sc-Si glass–backsheet and glass–glass modules produced in China, Germany, and the European Union (EU), considering current inventory data. Celik et al. [43] analysed two different structures of perovskite photovoltaic cells using the LCA with cradle-to-grave approach. Bogacka et al. [44] conducted a scenario analysis based on the LCA of the environmental impact of PV recycling. Ansanelli et al. [45] carried out an LCA to assess the environmental performance of a new process for recycling crystalline silicon (c-Si) solar panels at the end of life and to improve the circular economy of recovered materials.

Despite such extensive research linking LCA with PV, in the context of subsidy programs, it seems important to check whether the replacement of fossil fuels by PV will help to avoid emissions (if so, to what extent) in the next 30 years. The novelty of this study is the estimation of the effectiveness of a subsidy program for PV installations, taking into account the LCA analysis—the conclusions obtained as a result of this study may influence the actions of decision makers and support the design of such programs. The authors infer a significant gap as regards checking how the replacement of dirty energy sources by PV in an energy mix such as Poland will affect this transition and avoid emissions.

The paper is structured as follows: Section 2 focuses on presenting the characteristics of the results of the subsidiary program "My Electricity", whose purpose was to partially refinance PV micro-installation in households in Poland. Data as of 14 July 2021 includes over 90% of installations covered by the program as part of the two editions which were carried out in 2019–2020. In Section 3, research methodology is presented, including equations for PV electricity production, the subsidy amount for produced energy, and avoided CO_{2eq} emission. In Section 4, an analysis of the subsidy program is conducted to evaluate the "My Electricity" program as one of the methods of reducing CO_{2eq} emissions in Poland. This was achieved by determining the electricity produced in the first year and over 30 years and the cost of co-financing PV installations for electricity production per 1 MWh. LCA model calculations according to the IPCC GWP 100a method were used to estimate emissions for monocrystalline and polycrystalline PV systems. The unit GWP indicators obtained for hard coal, lignite, natural gas, and the Polish energy mix were used to determine the avoided emissions. Finally, Section 5 concludes the environmental impact of implementing the "My Electricity" program to avoid emissions in Poland over a 30-year perspective.

2. The Results Characteristics of the "My Electricity" Program

The My Electricity program was implemented in the years 2019–2020. The aim of the program was to increase the number of prosumers of PV micro-installations among households in Poland by over 200 thousand. The initial budget of the program was PLN 1 billion (Polish zlotys) at the end of 2020, and the budget was extended to approx. EUR 250 million (EUR 1 = PLN 4.5). According to the data as of 14 July 2021, the amount of funds spent was EUR 251 million; this value covers over 90% of the installations created under the program.

The main convenience for the beneficiaries was a non-returnable subsidy covering 50% of eligible costs up to a maximum of EUR 1111 per installation from the 2–10 kWp range. The eligible costs include the purchase of a new installation and its assembly. The installation is subject to control up to 3 years after the grant is awarded.

In the first round of the program, 28,457 installations were created (with a capacity of 158.4 MWp), i.e., approx. 15% of the total planned pool of installations for 2 years. The average power of the installation was 5.57 kWp, the median was 5.1 kWp, and the average subsidy amount was EUR 1102 (198 EUR/kWp). Detailed results by provinces are presented in Figure 3.

Most installations were built in the Silesian (4039), Masovian (3762), and Lesser Poland (3234) provinces with a total capacity of 61.4 MWp, the least in the Lubuskie (678), Warmian-Masurian (745), West Pomeranian (750) provinces, with a total capacity of 12.6 MWp. Less than 1000 installations were also built in the Podlaskie (781) and Opolskie (816) provinces. The average subsidy amount was PLN 4958 (EUR 890/kWp). The contrast in the number of installations is surprising—voivodeships with the highest number of installations are adjacent to the areas with the lowest number of installations.

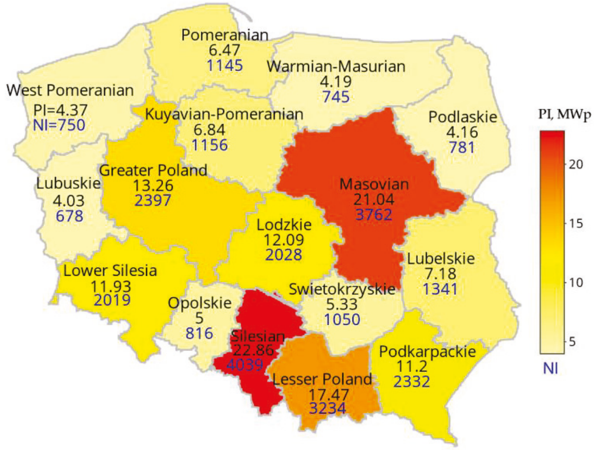


Figure 3. The results of the 1st round of recruitment for the "My Electricity" program (carried out in 2019) number of installations (NI) and power of installations (PI). Authors' study based on [46–48].

As of 14 July 2021, 197.997 installations with a total capacity of 1137 MWp were built in the second round of the program [46]. This is about 8 times more installations than the first round. The average power of the installation is 5.73 kWp (+3% compared with round no. 1 [36]), and the median is 5.25 kWp. The average subsidy amount was EUR 1110 (193 EUR/kWp). Detailed results for individual voivodeships are presented in Figure 4.

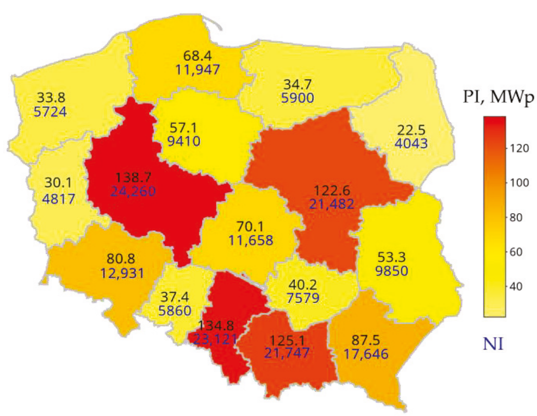


Figure 4. Results of the 2nd round of "My Electricity" recruitment carried out in 2020: number of installations (NI), power of installations (PI).

Most installations were built in the Greater Poland Province (24,260) with a total capacity of 138.7 MWp. Similar values were achieved in the following voivodships: Silesian (23,121) Lesser Poland (21,747) and Masovian (21,482). The fewest installations were built in Podlaskie Province (4043), with a total capacity of 22.5 MWp.

In both rounds of the program, 226,454 installations with a total capacity of 1295 GWp were built. The average power of the installation is 5.72 kWp, and the median power is 5.22 kWp. The average grant amount is EUR 1109 (194 EUR/kWp). Detailed summary results for individual voivodships are presented in Figure 5.

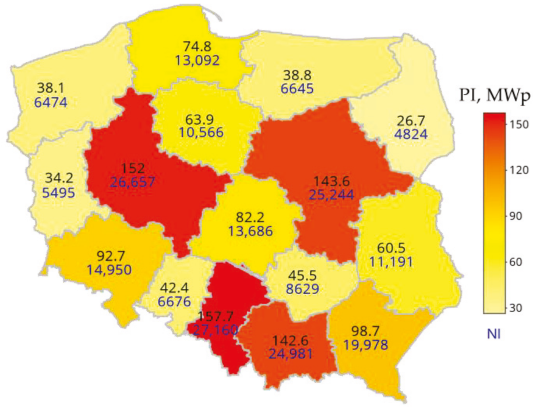


Figure 5. Total results of the 1st and 2nd rounds of the "My Electricity" recruitment carried out in 2019 and 2020: power of installations (PI); number of installations (NI).

In total, in both rounds, most installations were built in the following provinces: Silesian (27,160), Greater Poland (26,657), Masovian (25,244), and Lesser Poland (24,981), with a total capacity of 596 MWp. In the years 2019–2020, the least interest in co-financing photovoltaic installations under the "My Electricity" program was in the Podlaskie Province (4824). The total installed capacity in micro-installations in Podlaskie Province was 26.7 MWp. The differences in power in individual provinces result, from population, urbanisation, insolation of regions [47,48].

It can also be observed that in each province the average installation capacity increased (Figure 6), despite the fact that the subsidy system is the most financially effective at installation capacity close to 2 kWp [48].

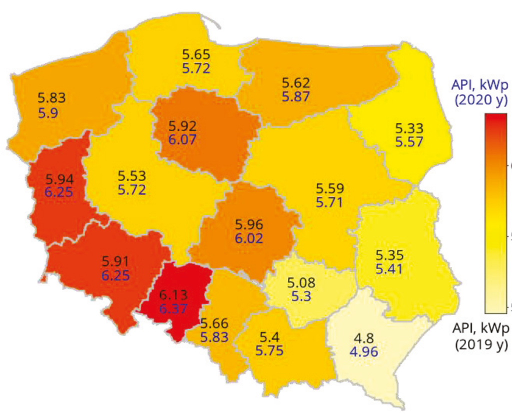


Figure 6. Average installed capacity of installations under the "My Electricity" program (API), in year: 2019 (2019 y), 2020 (2020 y).

According to the weighted power of PV installations created under the "My Electricity" program, determined on the basis of the total power of the installations and geographical coordinates, the centre of Poland was determined to be in the Łódzkie Province—for the place of Łask near Łódź with coordinates 51.61° N and 19.18° E.

3. Research Methodology

The methodology of the presented research was based on the detailed calculation of the possible reduction in carbon dioxide emission. The scope of avoided CO_2 emissions depends mainly on the PV electricity production and the inputs related to the life cycle of examined energy systems, conventional energy sources, or energy mix.

3.1. PV Electricity Production

According to HOMER software, the output of PV panels was calculated with the employment of Equation (1) [49].

$$PPV(\tau) = YPV \cdot FPV \cdot \frac{Gh(\tau)}{GSTC} \cdot (1 + \alpha p \cdot (TC - TSTC)) \tag{1}$$

where

PPV	The power output of photovoltaic panels, kw/kwp;
τ	Hour;
YPV	Rated capacity of the PV array, which implies that its output power under standard test conditions (1 kwp was used), kw/kwp;
FPV	PV-derating factor, 0.90 [50];
G	The available intensity of solar radiation incident on horizontal surface dependent on time, based on MERRA-II database, W/m^2;
$GSTC$	Incident radiation at Standard Test Conditions, 1 kw/m^2;
αp	Temperature coefficient of power, based on [51], %/°C;
TC	PV cell temperature, based on Equation (2), °C;
$TSTC$	PV cell temperature under standard test conditions (25 °C).

Equation (2) presents the PV cell temperature that is the temperature of the surface of the PV installation [52].

$$TC = Ta(\tau) + Gh(\tau) \cdot \frac{TC.NOCT - Ta.NOCT}{G.NOCT} \left(1 - \frac{\eta_c}{ta}\right) \tag{2}$$

where

Ta	Ambient temperature (from MERRA-II), °C;
G	The available intensity of solar radiation incident on surface dependent on time, tilt angle and azimuth angle, W/m^2;
$TC.NOCT$	Nominal operating cell temperature according to [51], °C;
$Ta.NOCT$	The ambient temperature at which the NOCT is defined (20°C);
$G.NOCT$	Solar radiation at which the NOCT is defined (0.8 kW/m^2);
η_C	Temperature efficiency of the PV panel, assumption $\eta_C = \eta_{mp}$, based on [51,53];
ta	Coefficient of transmittance and absorptance, 0.9 [54].

Unit productivity of PV installation arrived at by multiplying the power output of photovoltaic panels and the average efficiency of the inverter and electric installation (Equation (3)).

$$UPVP\ (\tau) = PPV(\tau) \cdot 1\ h \cdot \eta_{inverter} \tag{3}$$

where

$UPVP$	Unit productivity of PV installation, kWh/kWp;
PPV	The power output of photovoltaic panels, kW/kWp;
$\eta_{inverter}$	The average efficiency of the inverter, 0.95 [55].

The value of $UPVP$ was used to calculate the unit electricity production ($YUPVP$) in a photovoltaic installation per year (Equation (4)). Additionally, the annual electricity production from a PV installation ($YPVPI$) is given in Equation (5), 30-years electricity production from a PV installation ($30YPVPI$) including yearly efficiency loss factor is given in Equation (6).

$$YUPVP(year) = \sum_{\tau=1}^{8760} UPVP(\tau, year) \quad (4)$$

where

$YUPVP$ Yearly unit electricity production in PV installation, kWh/kWp/year;
$UPVP$ Unit productivity of PV installation, kWh/kWp.

$$YPVPI(year) = YUPVP(year) \cdot PI \quad (5)$$

where

$YPVPI$ Yearly electricity production in PV installation, MWh/year;
PI The capacity of PV installations per province, MWp.

$$30YPVPI = \sum_{year=1}^{30} YUPVP(year) \cdot (1 - yl \cdot (year - 1)) \cdot PI \quad (6)$$

where

$YPVPI$ Yearly electricity production in PV installation, MWh/year;
PI The capacity of PV installations per province, MWp;
yl Yearly efficiency loss factor, 0.0055 [51].

The value of the subsidy for produced energy (UDPV, euro/MWh) was calculated as follows (Equation (7)):

$$UDPV = \frac{DI}{\sum_{year=1}^{30} YPVPI(year)} \quad (7)$$

where

$YPVPI$ Yearly electricity production in PV installation, MWh/year;
DI Sum of dotation per province, euro.

3.2. Description of Calculation Avoided CO_{2eq} Emission Method

The avoided emission of CO_{2eq} was calculated by the use of the life cycle assessment (LCA) method applied for the standard PV system supported by the "My Electricity" program. The general framework of LCA included in Intergovernmental Standardisation Organisation standards [56] was used to calculate CO_{2eq} released during the lifetime of PV systems, using the cradle-to-grave approach [57]. The aim of the LCA analysis was to compare the emissions from the PV systems to the conventional energy sources dominating the Polish energy market, in particular hard coal, lignite, natural gas, and Polish energy mix, constituting the kinds of energy replaced by photovoltaics, as presented in relevant literature studies [58,59].

System boundaries of the PV systems analysed in the study included the production of 5.72 kWp installation (average power resulting from "My Electricity" program data) together with PV modules (including their market shares) and balance of system (BOS), transportation processes based on market reports including those about local producers and imported parts and servicing (washing, replacement of parts) [60].

The basic assumptions for LCA research were adopted from methodological guidelines and included service life of PV systems equal to 30 years, with partial replacement of inverter, while some elements of BOS such as metal construction for panels had a 60-year lifespan [57,61]. Life cycle inventory was based on the Ecoinvent database and leading producers' data, including the efficiency of monocrystalline panels equal to 20.5% and for polycrystalline panels equal to 17.2%. Adaptation to local conditions was based on "My Electricity" program summary data, region-specific energy yield estimates with an included decrease in panel efficiency described in paragraph 3, and statistical reports on the PV market in Poland, which enabled estimation of transportation distances and kinds of PV panels mounted in 2019 and 2020. According to the market reports, the average share of monocrystalline panels rose from 79.5% in 2019 to 97.65% in 2020, while polycrystalline technology recorded the decrease in share from 20.5% to 2.35% [60,62,63], which was included in the study in accordance to the number of installations built in the analysed years.

The method of CO_{2eq} calculations was Global Warming Potential 2013 (IPCC GWP 100a), enabling calculation of climate change potential on the basis of 204 characterisation factors for specific emissions to air. The life cycle model was built in SimaPro v.8.1 software by PRE Consultants, Amersfoort, The Netherlands, with included Ecoinvent 3.0 database by Ecoinvent Association, Zurich, Switzerland. Sensitivity analysis by the Monte Carlo method was performed with 1000 runs and a confidence interval of 95%. The emissions from energy generation processes were updated to the levels of 2019 and 2020 by the use of modified Ecoinvent unit processes [21,64].

Absolute GHG emission avoidance was calculated in previously mentioned four basic scenarios of energy sources replaced by PV electricity according to Equation adopted by [65].

$$\Delta GHG = \sum_{y=1}^{30} \left(GHG_y^{Repl} - GHG_y^{PV} \right) \quad (8)$$

where

ΔGHG Avoided emissions of greenhouse gases, Mg CO_{2eq};

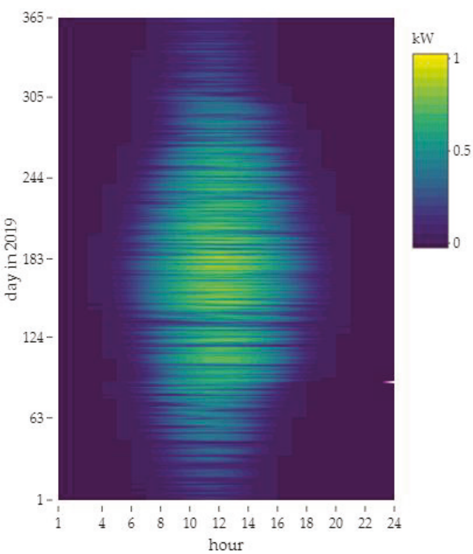
GHG_y^{Repl} GHG emissions of replaced energy source in successive years, Mg CO_{2eq};

GHG_y^{PV} GHG emissions of PV systems built in the My Electricity program in successive years, Mg CO_{2eq}.

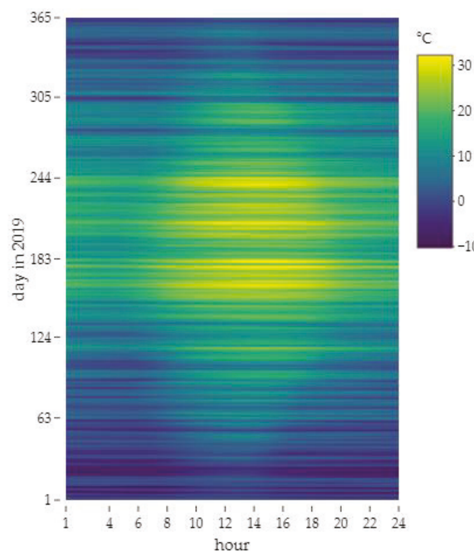
4. Results

4.1. Results of PV Electricity Production

Based on MERRA-II data for the town of Łask near Łódź, a map chart of the intensity of solar radiation falling on the horizontal plane and a map chart of the outside temperature were drawn, as shown in Figure 7.



(**a**)



(**b**)

Figure 7. Weather data for the centre of Poland according to the weighted power of photovoltaic installations created under the "My Electricity" program, data for 2019: (**a**) solar radiation intensity on the horizontal plane; (**b**) outdoor temperature.

Similar data from the MERRA-II website were collected for all province capitals in Poland. Based on the data on the intensity of solar radiation and the outside temperature, detailed calculations of electricity productivity were made using Equations (1)–(5). There is no archived information on the arrangement of the panels in the databases relating to the "My Electricity" program, and therefore, it cannot be assumed that all installations are located in terms of ensuring maximum energy gains per year. The calculations used data on the total annual intensity of solar radiation registered on the horizontal plane (insolation).

The calculation results for each province in Poland in terms of insolation, yearly unit production electricity from PV (YUPVP), and the average annual temperature are presented in Table 1.

Table 1. Insolation, yearly electricity productivity, and yearly average temperature outside per province. Authors' study based on [66].

Province	Insolation (Yearly Sum of Gh)	YUPVP (First Year)	YUPVP′	Yearly Average Ta
	kWh/m^2/year	kWh/kWp/year	kWh/kWp/year	°C
Lower Silesia	1253.9	1099.88	1036.6	9.93
Kuyavian-Pomeranian	1185.7	1040.45	979.8	9.44
Lubelskie	1219.2	1070.71	1010.6	9.35
Lubuskie	1179.4	1033.60	973.6	10.09
Łódzkie	1222.0	1072.05	1011.2	9.67
Lesser Poland	1257.0	1104.32	1042.5	9.36
Masovian	1206.2	1058.02	998.2	9.46
Opolskie	1250.5	1096.62	1033.7	9.86
Podkarpackie	1241.5	1090.58	1029.2	9.42
Podlaskie	1176.9	1035.67	977.1	8.34
Pomeranian	1229.8	1083.12	1025.7	9.60
Silesian	1251.4	1099.54	1038.3	9.37
Świętokrzyskie	1232.3	1082.70	1022.0	9.33
Warmian-Masurian	1164.5	1025.71	967.9	8.32
Greater Poland	1210.9	1061.72	1000.0	10.00
West Pomeranian	1230.5	1075.29	1016.2	10.58

YUPVP′—yearly electricity production directly from MERRA-II database [66].

The highest value of insolation in relation to m^2 of the panel area per year was obtained for the Lesser Poland Province, as 1257 kWh. Additionally, the highest productivity was found for the Lesser Poland Province (1104.32 kWh/kWp/year), and the lowest for the Warmian-Masurian Province (1025.71 kWh/kWp/year). The obtained values of yearly electricity production (YUPVP) were similar to the results presented by MERRA-II (YUPVP′). The convergence of values was greater than 99% (difference YUPVP and YUPVP′ < 1%).

On the basis of Formulas (5) and (6), electricity productivity was calculated in the first year and over 30 years. Based on information on the amount of co-financing for each province (DI), the cost of co-financing electricity production was calculated per 1 MWh. The results are presented in Table 2.

In the perspective of 30 years, the production of 1 MWh of energy from PV was subsidised in the amount of approximately 6.52 EUR on the national scale. The highest amount was co-financed for installations in the Podkarpackie Province (7.46 EUR/MWh), and the lowest in the Opolskie Province (5.78 EUR/MWh). The differences in the amount of co-financing result from weather conditions, as well as the average size of installations in individual provinces.

Table 2. Globally electricity production and dotation per MWh per province.

Province	PI MWp	YPVPI (First Year) GWh	Σ30 Years YPVPI TWh	DI mln EUR	UDPV EUR/MWh
Lower Silesia	92.7	102.0	2.81	16.59	5.89
Kuyavian-Pomeranian	63.9	66.5	1.84	11.72	6.38
Lubelskie	60.5	64.8	1.79	12.41	6.94
Lubuskie	34.2	35.3	0.97	6.10	6.25
Łódzkie	82.2	88.2	2.43	15.18	6.24
Lesser Poland	142.6	157.4	4.35	27.73	6.38
Masovian	143.6	151.9	4.19	28.00	6.68
Opolskie	42.4	46.4	1.28	7.41	5.78
Podkarpackie	98.7	107.6	2.97	22.16	7.46
Podlaskie	26.7	27.6	0.76	5.35	7.01
Pomeranian	74.8	81.1	2.24	14.52	6.49
Silesian	157.7	173.4	4.79	30.14	6.30
Świętokrzyskie	45.5	49.3	1.36	9.57	7.04
Warmian-Masurian	38.8	39.8	1.10	7.37	6.70
Greater Poland	152.0	161.4	4.45	29.57	6.64
West Pomeranian	38.1	41.0	1.13	7.18	6.34
sum (*mean)	1294.3	1393.6	38.47	250.98	6.52*

4.2. Results of Calculations Avoided CO_{2eq} Emission

Results of LCA model calculations according to the IPCC GWP 100a method showed that the main elements influencing environmental burden in the climate change category are connected with the production of PV systems. Calculation of basic scenarios for monocrystalline and polycrystalline PV systems of 5.72 kW_p resulted in estimated emissions of 9421.43 kg CO_{2eq} and 8744.99 kg CO_{2eq}, respectively. Over 82% of these values related to PV panels, while 12% corresponded to BOS and 5% to the servicing. Other unit processes such as transport and installing were characterised by relatively small shares within 1%, which is also reported in related previous studies [67]. These basic values were then differentiated between provinces on the basis of changing transportation distances, kinds of technology used in 2019 and 2020, as well as systems' productivity. The results of individually calculated emissions per functional unit (1 kWh of energy generated by system) and over a 30-year perspective used in the study are presented in Table 3 and Figure 8.

Table 3. Results of GWP indicator calculation: S-GWP—GWP indicator calculated for a PV system of 5.72 kWp, kg CO_{2eq}; P-GWP—GWP indicator calculated for installations built during 2019 and 2020 in provinces, Mg CO_{2eq}; FU-GWP—GWP per functional unit, Mg CO_{2eq}/kWh.

Province	S-GWP kg CO_{2eq}	P-GWP Mg CO_{2eq}	FU-GWP kg CO_{2eq}/kWh
Lower Silesia	9390.0	152,176.7	0.0542
Kuyavian-Pomeranian	9390.7	104,906.6	0.0570
Lubelskie	9392.2	99,340.1	0.0555
Lubuskie	9390.0	56,142.9	0.0579
Łódzkie	9389.3	134,929.5	0.0555
Lesser Poland	9391.4	234,129.0	0.0538
Masovian	9391.4	235,770.8	0.0563
Opolskie	9390.7	69,609.4	0.0544
Podkarpackie	9389.3	162,013.8	0.0546
Podlaskie	9392.2	43,841.0	0.0577
Pomeranian	9390.7	122,801.5	0.0548
Silesian	9390.7	258,901.0	0.0541
Świętokrzyskie	9391.4	74,704.5	0.0549
Warmian-Masurian	9391.4	63,704.1	0.0579
Greater Poland	9390.7	249,543.1	0.0561
West Pomeranian	9389.3	62,540.3	0.0553

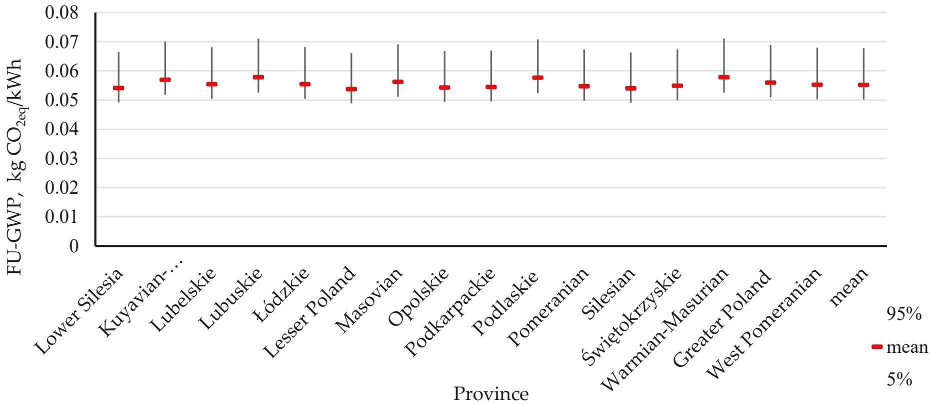


Figure 8. Monte Carlo results of FU-GWP calculated for the provinces with a confidence interval of 90%.

As can be inferred, FU-GWP differs between provinces, first on the basis of various productivity of PV installation and then transport distances. The correlation between yearly electricity productivity can be observed on the base of Table 1 since the provinces such as Lower Silesia, Opolskie, Silesian, characterised by the highest productivity represent the lowest FU-GWP indicators. The outcomes of calculations are comparable to previous studies on PV systems working in temperate climate conditions [67–69], and smaller FU-GWP indicators result from the higher efficiencies of the analysed PV panels. At the same time, the calculated emission rate is similar to the literature results of the carbon emission rate for PV installations working under similar solar irradiation (1222 kWh/m^2/year, Germany), equal to 55 g CO_{2eq}/kWh [70].

Calculation of avoided emission ΔGHG, Mg CO_{2eq}, was based on unit GWP indicators obtained for hard coal (0.966 kg CO_{2eq}/kWh), lignite (1.164 kg CO_{2eq}/kWh), natural gas (0.738 kg CO_{2eq}/kWh), and Polish energy mix called MIX PL (0.804 kg CO_{2eq}/kWh) compared with the data in Table 4 [21,64,71].

According to the data in Table 4 and Figure 9, provinces with the highest number of installations (Lesser Poland, Masovian, Greater Poland, Silesian) contribute to the highest possible reduction in CO_{2eq} emission. The level of CO_{2eq} avoided emission depends on the energy source replaced. The final effects of the "My Electricity" program in accordance with climate change are, therefore, hard to precisely estimate since CO_{2eq} avoided emission is correlated with the predictions on shares of energy sources in the Polish market.

Comparison of the obtained results with previous studies on the existing support programs and their environmental impacts over the world show the potential of carbon emission avoidance determined by local conditions and the scope of calculations. One of the main factors can be defined as the characteristics of grid electricity (energy mix) determining both emission avoidance potential and energy payback time. Thus, in fossil-fuel-based countries, the support programs of photovoltaic technology have the potential to contribute to GHG reduction, while in countries with a high share of RES, such as the study by [58,72] using the example of Brazil, the policy should be more carefully defined, in spite of the fact that calculated GHG emissions from photovoltaics can be reduced by the use of PV panel manufactured in low-carbon economics. Still, in some case studies assessing PV distributed generation projects (1255.2 kWp) in the same country, the estimated environmental advantage is nearing 0.48 kg CO_{2eq}/kWh and 19,900 Mg CO_{2eq} over the project lifetime of 25 years [73].

Table 4. ΔGHG, Mg CO_{2eq}, calculated for provinces in Poland in 30 years perspective on the basis of individual GWP differences for the energy sources considered to be replaced, kg CO_{2eq}/kWh.

Province	Hard Coal	Lignite	Natural Gas	MIX PL	Hard Coal	Lignite	Natural Gas	MIX PL
	kg CO_{2eq}/kWh				10^3 Mg CO_{2eq}			
Lower Silesia	0.912	1.110	0.683	0.750	2562.1	3119.6	1920.5	2107.1
Kuyavian-Pomeranian	0.909	1.107	0.681	0.747	1672.4	2037.4	1252.3	1374.5
Lubelskie	0.910	1.109	0.682	0.749	1629.7	1984.8	1221.0	1339.8
Lubuskie	0.908	1.106	0.680	0.746	880.8	1073.2	659.3	723.7
Łódzkie	0.910	1.109	0.682	0.748	2212.3	2694.4	1657.4	1818.8
Lesser Poland	0.912	1.110	0.684	0.750	3967.7	4830.7	2974.4	3263.3
Masovian	0.910	1.108	0.681	0.748	3811.5	4642.7	2854.8	3133.0
Opolskie	0.912	1.110	0.683	0.750	1166.8	1420.7	874.5	959.5
Podkarpackie	0.911	1.110	0.683	0.749	2706.8	3296.0	2028.6	2225.9
Podlaskie	0.908	1.107	0.680	0.746	690.3	841.0	516.7	567.2
Pomeranian	0.911	1.109	0.683	0.749	2040.9	2485.3	1529.4	1678.2
Silesian	0.912	1.110	0.684	0.750	4368.0	5318.2	3274.2	3592.3
Świętokrzyskie	0.911	1.109	0.683	0.749	1239.0	1508.8	928.4	1018.7
Warmian-Masurian	0.908	1.106	0.680	0.746	998.8	1217.0	747.7	820.7
Greater Poland	0.910	1.108	0.682	0.748	4048.9	4931.7	3032.8	3328.3
West Pomeranian	0.911	1.109	0.682	0.749	1029.0	1253.1	770.9	846.0
ΔGHG, 10^6 Mg CO_{2eq}					35.025	42.655	26.243	28.797

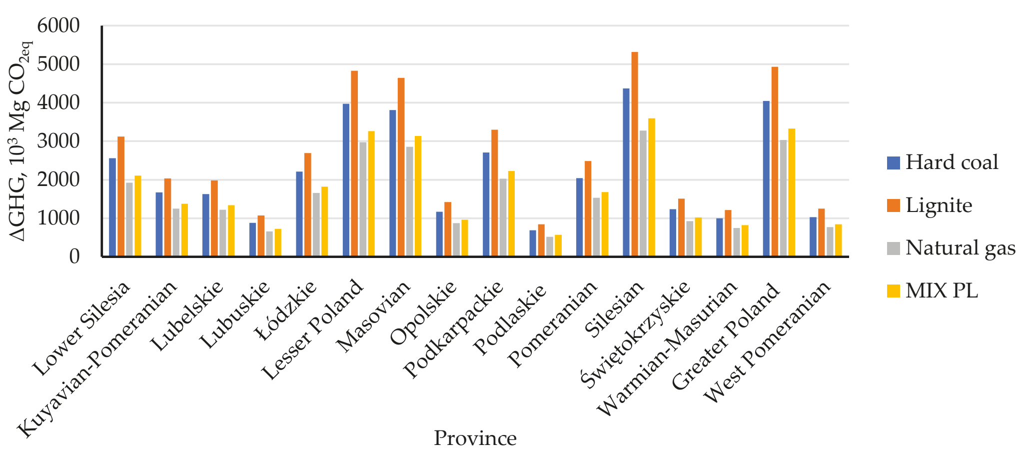


Figure 9. ΔGHG, 10^3 Mg CO_{2eq} in four scenarios of replaced energy source.

According to data presented in [73] on the basics of household cases, many legislative and financial supports need to be implemented to ensure financial accessibility of novel technologies to domestic consumers and to encourage them to participate in balancing local energy demand and supply. A similar trend can be observed in this study, where the fast development of the PV market was stimulated by financial aspects. As presented in [73], average implicit abatement subsidy varies between countries and was estimated as 137–170 USD/1 Mg CO_{2eq} (116–145 EUR/1 Mg CO_{2eq}) for Germany, with avoidance potential 0.521 kg CO_{2eq}/kWh [74]. It should be noted that higher avoidance potential in this study results from the energy mix and close to 0.748 kg CO_{2eq}/kWh. Assuming that the energy produced from burning hard coal is replaced by energy from photovoltaics, the savings will amount to 35 million tons of CO_2. With the current prices of CO_2 emission allowances of around EUR 50 (Figure 1), the "My Electricity" program will save EUR 1550 million with an expenditure of EUR 251 million. Taking into account the total installation costs of 1010 EUR/kWp [75,76], they are still lower than the costs of CO_2 emission rights over 30 years.

5. Conclusions

In the years 2019–2020, the Polish government offered prosumers a program of co-financing PV installations called "My Electricity". The amount of the subsidy was up to max. 50% of eligible costs, up to a maximum amount of PLN 5000 (EUR 1111). In the assumed period, more than half of the photovoltaic micro-installations established in Poland received funding under the "My Electricity" program. The total cost of the subsidy program was EUR 251 million. Currently, the program continues as part of the third round from July 2021 with changed conditions, including a reduced maximum grant amount of EUR 667 for installations.

The average power of PV micro-installations with co-financing is 5.72 kWp. Most installations were built in the very industrialised Silesian Province (27,160), the lowest in the Podlaskie Province (4824). In total, installations with a total capacity of 1295 MWp were created under the "My Electricity" program. With the productivity of PV installations at the level of 1025–1104 kWh/kWp/year (differentiated by region), these installations will contribute to the production of approx. 38 TWh of green energy over 30 years.

It is broadly recognised that PV systems can be treated as a source of green energy. The environmental effects of the "My Electricity" program implementation in Poland, measured by the avoided CO_{2eq} emissions based on the IPCC GWP 100a indicator, are highly positive in light of the fact that the Polish power industry is still largely based on fossil fuels. The detailed LCA analysis of the installations allowed for the determination of CO_{2eq} emissions at the average level of 9390.7 kg per system, while the average CO_{2eq} emission per functional unit was 0.056 kg CO_{2eq}/kWh, which corresponds to the Central European conditions of insolation. The particular indicators are influenced by the type of technology and location of the system, as stated in this study. Future analysis should consider the relationship between the size of the system and the CO_{2eq} emissions to show the areas with the greatest effectiveness of support.

According to the analysis, while reducing the carbon footprint of energy units by 92–95%, PV systems built in the "My Electricity" program can contribute to the avoidance of 26–42·10^6 Mg of greenhouse gas emission in 30 years of life cycle perspective. This, together with the analysed economic aspects, leads to the conclusion that the use of this type of financial instrument is fully justified, in particular in the case of stimulating the development of energy markets with a large share of conventional energy sources.

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Article

Analysis of Selected Service Industries in Terms of the Use of Photovoltaics before and during the COVID-19 Pandemic

Sylwester Kaczmarzewski [1,*], Dominika Matuszewska [2] and Maciej Sołtysik [3]

[1] Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Wybickiego St. 7A, 31-261 Cracow, Poland
[2] Department of Thermal and Fluid Flow Machines, Faculty of Energy and Fuels, AGH University of Science and Technology, 30 Mickiewicza Ave., 30-059 Cracow, Poland; dommat@agh.edu.pl
[3] Faculty of Electrical Engineering, Częstochowa University of Technology, Dąbrowskiego St. 69, 42-201 Częstochowa, Poland; maciej.soltysik@pcz.pl
* Correspondence: skaczmarzewski@min-pan.krakow.pl

Abstract: Previous analyses of the PV market (and the impact of the pandemic on it) have focused on the market as a whole. The literature does not contain analyses of selected services sectors (e.g., catering, hotel services) in terms of the use of photovoltaics. There are no studies that would show in which segments the demand profile for electricity most closely matches the production from photovoltaic installations (not to mention the impact of the pandemic). The authors analyzed selected service sectors (catering and hotel) in terms of the use of photovoltaics before and during the COVID-19 pandemic. The paper proposes a comparative methodology for the use of photovoltaics for self-consumption, including statistical analyses and calculations of the self-consumption index for representatives of various selected services sectors. The highest value of the self-consumption ratio at the level of 52% was shown for cafes and restaurants (during the pandemic). Surprisingly, in the pandemic, the self-consumption rate increased for restaurants and cafes for the same size of installations (compared to pre-pandemic times).

Keywords: photovoltaic (PV); renewable energy source (RES); solar photovoltaic; self-consumption; COVID-19; Poland; energy consumption

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1. Introduction

The rapid economic and population development causes that the demand for electricity in the world is growing year by year [1]. The International Energy Agency (IEA) provides forecasts in which the increase in electricity demand is estimated at 30% in 2040 compared to the base year 2016 [2]. At the same time, the challenges of climate change and global warming are led to the energy sector transformation. There is a large shift from fossil fuel-based systems to clean technologies and an economy based on sustainable resources [3,4]. Even though more and more countries in the world are promoting policies based mainly on the use of sustainable energy sources as factors mitigating climate change, ensuring energy security and sustainable economic development [5–8], the cost of producing electricity from renewable sources is still higher than from fossil fuels [9,10]. As a result, it is consumers who pay the highest price for green electricity [11]. There are more and more proposals on the market aimed at better management of energy and lowering its prices—especially the one from renewable sources, these include, among others, initiatives such as the creation of energy cooperatives on the capacity market, which would use the potential of renewable energy sources in rural areas [12], the idea of unlimited use of the low voltage grid by electricity consumers, producers prosumers [13], energy storage systems from renewable energy sources [14,15] or even properly designed subsidy support systems for RES [16]. At the same time, solar (as well as wind) technologies are largely favored among other technologies that use renewable energy sources, which significantly affects the development of installations supplied from these sources [17,18]. The use of solar technologies for the production of electricity is associated with their undoubted advantages, including scalability, no need for heavy support infrastructure and availability in remote locations, etc. [19]. It is also important that these systems do not have any moving parts, they do not require significant maintenance with relatively long service lives and, during use, do not pollute the air or water [20,21]. Research shows that among individual customers, solar energy is valued higher than electricity generated from other sources [22], while the very idea of self-sufficiency and the possibility of active participation in the energy transformation positively influences investments in solar technologies [23,24]. Taking into account the growing prices of electricity for end-users, with the simultaneous decline in the prices of photovoltaic systems, a significant increase in interest in this type of technology is observed [25]. Despite these undoubted advantages of solar technologies and strong pressure from the European Union to eliminate units fired by coal and switch to clean, renewable sources [26,27], it should be realized that solar technologies are sensitive not only to the solar radiation level but also to average air temperatures, seasonal and weather changes [28]. These factors can significantly affect the power grids [29]. With the observed significant increase in installed solar power not only in Europe but also in the world [30,31], there is more and more discussion about the problems (such as the duck curve) that accompany this increase [32,33]. The imbalance between the intermittent supply, sensitivity to weather conditions and the volatile profile of demand for electricity begins to raise serious concerns about the load and, consequently, the reliability of the power grid [34]. There was the idea of using traditional backup generators (powered by fossil fuels) to prevent the threat of imbalance risks, but it runs counter to the goal of a clean energy transition and has been criticized for polluting the environment [35]. Alternatively, attention is paid to the energy demand response (DR) as a way of balancing the power grid [36,37] or increasing the auto-consumption ratio, which would largely (or fully) cover the demand, depending on the PV load and production level [38]. The COVID pandemic also had a significant impact on the entire energy industry [39]—including the PV industry, which was not resistant to these perturbations and the entire industrial chain felt the effects of the pandemic, which resulted in a short-term increase in production costs [40]. At the same time, Zhang H. et al. [41] show that the risk of slowdown in solar PV deployment due to COVID-19 can be mitigated through comprehensive incentive strategies.

As shown in the literature, there are many analyses of these problems related to PV installations, however, the authors see a large gap regarding the lack of analyses of selected segments in terms of the use of photovoltaics. There are no studies that clearly show that the demand profile for electricity in the selected segment corresponds to the production from PV installations, thus making the self-consumption rate very high. There are no indications of this type of behavior in research papers, not to mention the impact of the COVID-19 pandemic on these phenomena. As shown in Figures 1 and 2, the literature can find the amount of new PV capacity installed in individual segments and forecasts regarding their growth, however, the authors see a lack of in-depth analyses of individual segments. For this reason, the authors decided to analyze selected service industries for their use before and during the COVID-19 pandemic.

Figure 1 shows shares of solar PV net capacity additions by application segment in 2013–2022 (however, until May 2021, this estimate is based on the reported data, and after May 2021 on the forecast). IEA estimated that global solar PV capacity additions are expected to reach nearly 117 GW in 2021 in the main case. In the years 2020–2022, an increase in new installed capacity is expected in all application segments, with the largest share of new installed capacity still being observed for utility-scale projects [42]. Interestingly, comparing this data with [43], where it was stated that in 2020 138 gigawatts of new PV capacity was installed, it can be assumed that these values are underestimated.

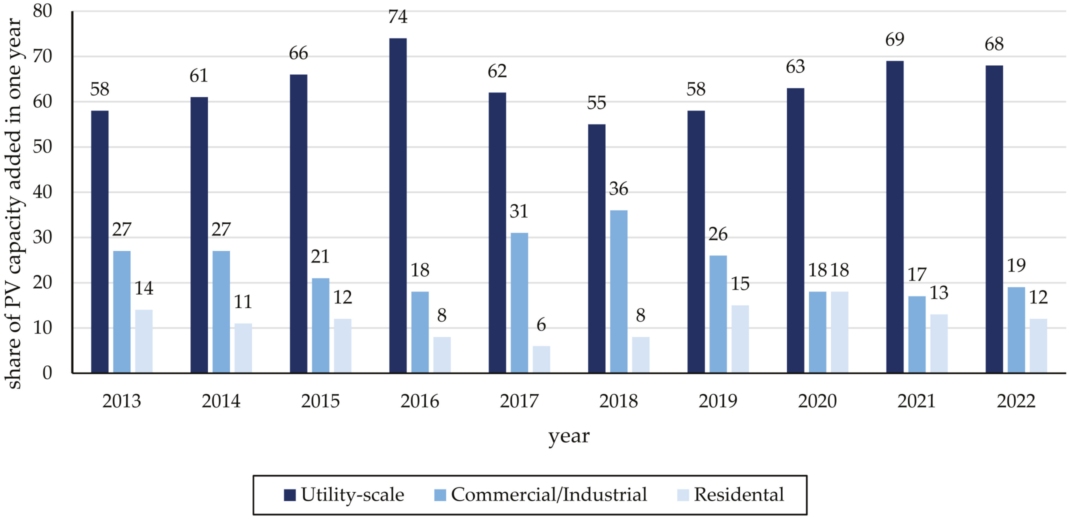


Figure 1. Shares of PV net capacity additions by application segment, 2013–2022. Based on [38].

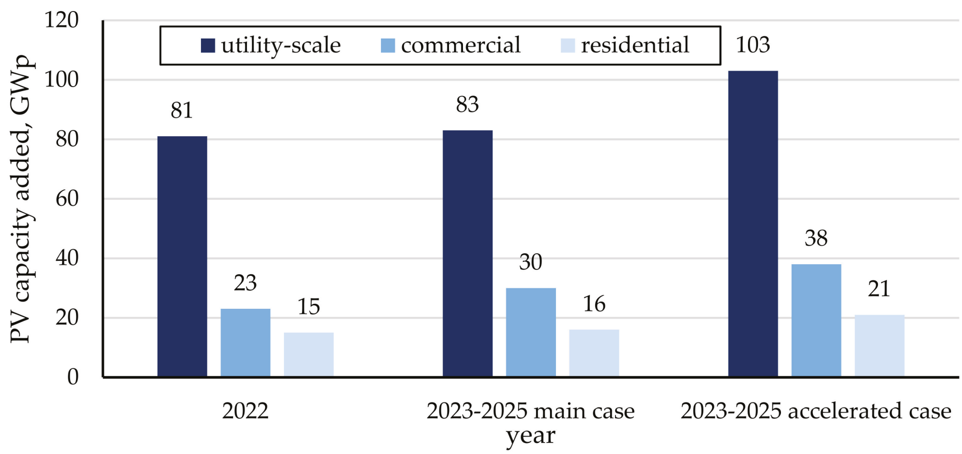


Figure 2. Average global annual capacity additions in main and accelerated cases, 2023–2025. Based on [38].

Figure 2 shows the average global annual capacity additions in main and accelerated cases, 2023-2025. Continued political support and cost reduction are projected to drive further solar expansion beyond 2022. The distributed solar segment is expected to grow in 2023–2025 as a result of the global economic recovery, which will positively impact the faster adoption of commercial and residential systems. The potential for total PV in the accelerated case compared with the main case is significantly higher—it is estimated that in the years 2023–2025 the annual capacity increase may reach 165 GW on average [42]. There are many studies on the impact of self-consumption from PV installations in the literature. McKenna et al. [44] analyzed the self-consumption of photovoltaic systems in a smart grid demonstration project in the residential sector in the United Kingdom. Tongsopit S. et al. [38] analyzed the feasibility of self-consumption chemists for four customer groups from an economic point of view in Thailand. Mateo C. et al. [45] analyzed the impact of shaping the consumption policy on the distribution networks with which the prosumers are connected. Pedrero J. et al. [46] analyzed the economics of self-consumption from PV installations for an industrial park and showed that greater economic benefits come from shared self-consumption. Fachrizal R. and Munkhammar J. [47] reported an increase in self-consumption from PV systems installed in apartment buildings thanks to the use of an intelligent charging system for electric vehicles.

As shown in Figures 1 and 2 in the literature, there are estimates of the increase in installed power in given application segments, however, there are no in-depth analyses of PV installations within a given sector, for example, in which order and in which industries it is best to invest in PV systems (e.g., whether it is better to invest in PV first in the hotel industry, or maybe in the catering industry, etc.) so that the profits and the self-consumption rate are as high as possible. From the point of view of the policy of supporting PV installations, as well as business decisions for investors, this gap seems to be a significant problem, so far not noticeable in research. The novelty of this publication is a proposed comparative methodology of various segments in the service industry in terms of the use of photovoltaics for the production of electricity for own use. In addition, it was analyzed how these factors are changing due to the impact of the COVID-19 pandemic.

The paper is structured as follows: Section 2 describes research objects, data sources and scope of work; Section 3 provides the rationale for the selected research methodology along with its description; Section 4 describes the results of the analyses and discussion and finally, the conclusions can be found in Section 5.

2. Research Objects, Data Sources and Scope of Work

The article analyzes anonymized data on the electricity consumption of customers from the C12 group running a business in the gastronomy and hotel industry. Hourly resolution data were provided by one of the Distribution Network Operators.

The research objects were in the south-west of Poland and were:

- Three cafes, conventionally marked with the symbols "C1", "C2" and "C3";
- Four hotels, conventionally marked with the symbols "H1", "H2", "H3", "H4";
- Seven restaurants marked with the symbols "R1", "R2", "R3", "R4", "R5", "R6" and "R7".

For the purposes of analyzing the insolation conditions in terms of the productivity of potential photovoltaic installations, the conditions in the vicinity of the capital of the Opolskie Voivodeship were assumed as the geometric center of gravity of the analyzed enterprises' distribution. The location of the Opolskie Voivodeship and the value of available solar radiation in relation to other regions of Poland are shown in Figure 3. The insolation data in the analyzed period were a set of hourly data of horizontal radiation values downloaded from the website [48]. Horizontal radiation is the sum of direct and diffused solar radiation. The above-mentioned data were extracted from the ERA5 database on an hourly basis.

Using statistical methods, the degree of similarity of the electricity consumption profiles in the analyzed enterprises was determined according to:

- The profile of power demand in the National Power System,
- The value of horizontal insolation and (as a derivative) of electricity production profiles from potential photovoltaic installations in the analyzed cases of enterprises, with the degree of self-consumption of the produced energy.

The calculation process was carried out in the RStudio environment (RStudio: Boston, MA, USA) on the hourly data of energy consumption in enterprises (Figures 4–10), hourly power demand in the National Power System (Figure 11a) and solar radiation conditions (Figure 11b).

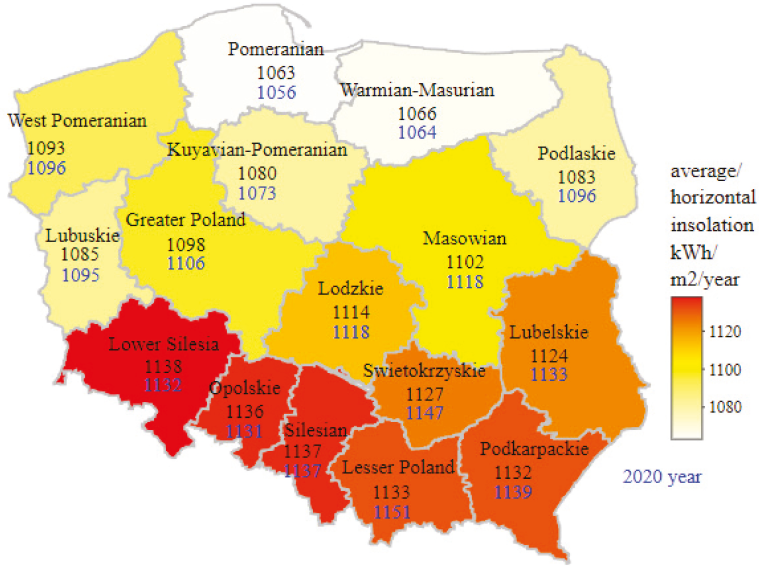


Figure 3. Horizontal insolation in Poland (for horizontal surfaces) for years: 2010–2019 (numbers in black) and 2020 (numbers in blue). Source: own study based on references [48].

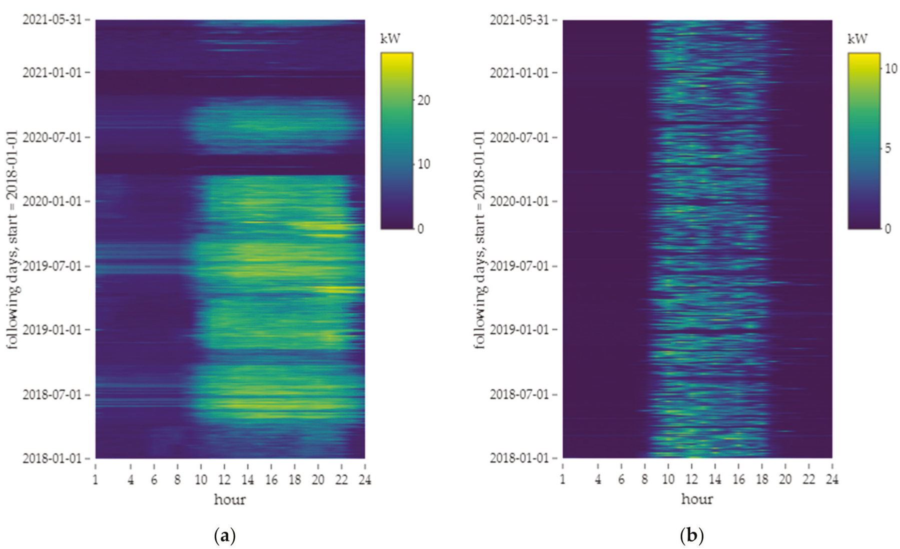
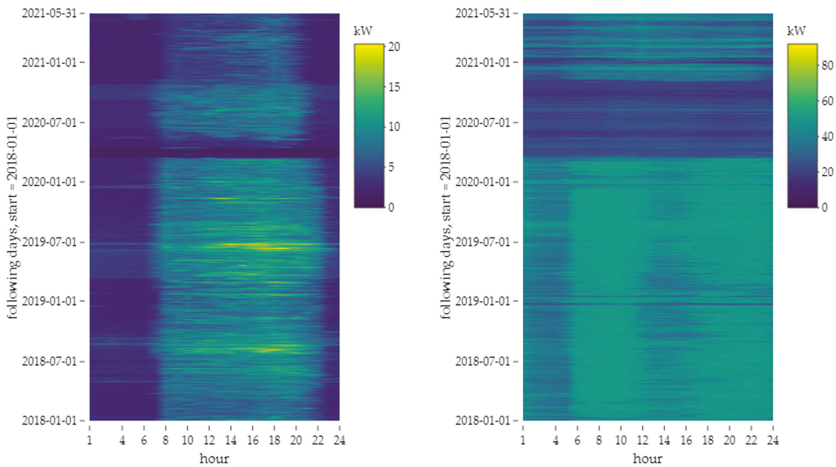


Figure 4. Course of hourly electricity consumption for the analyzed case study: (**a**) C1, (**b**) C2. Source: own study.

The analysis in Figures 4–10 shows the existence of certain differences in the course of the variability of hourly electricity consumption also within individual industries. These differences result, among others, from the characteristics and working hours of individual enterprises.

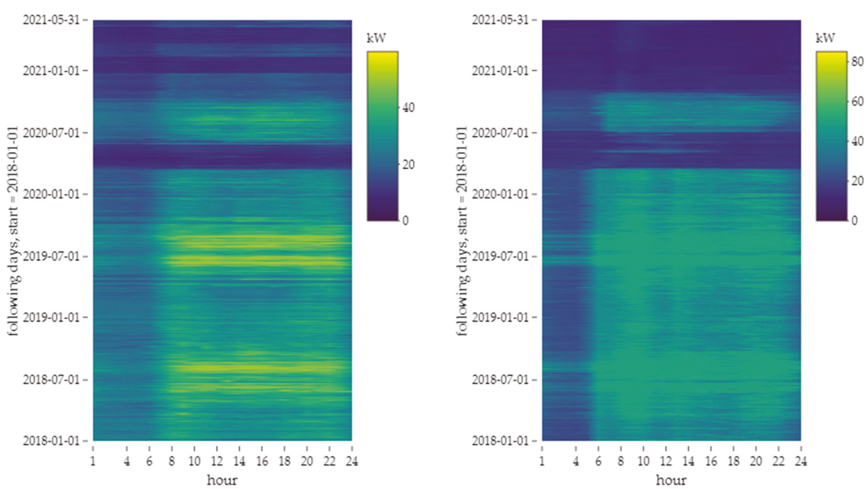
The horizontal blue bars indicate low electricity consumption on off-peak days, which is especially noticeable in C1, H2, R2 and R5. The work pattern adopted in other cases of enterprises results in the maintenance of a stable level of electricity consumption on a weekly basis, which is particularly visible in the case of C2 and R3.

The impact of restrictions introduced during the COVID-19 pandemic waves is particularly interesting. In all cases, except C2, the first lockdown in March 2020 is visible. The impact of the second lockdown in November 2020–January 2021, encompassing the "national quarantine" period, is visible in cases C1, C3, H3, R1–R5. However, in the cases of C1, H2, H3, R1–R5, the devastating effect of restriction is noticeable. A significant reduction in their activities is visible throughout the period from the second to the third wave of the COVID-19 pandemic.



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

Figure 5. Course of hourly electricity consumption for the analyzed case study: (**a**) C3, (**b**) H1. Source: own study.



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

Figure 6. Course of hourly electricity consumption for the analyzed case study: (**a**) H2, (**b**) H3. Source: own study.

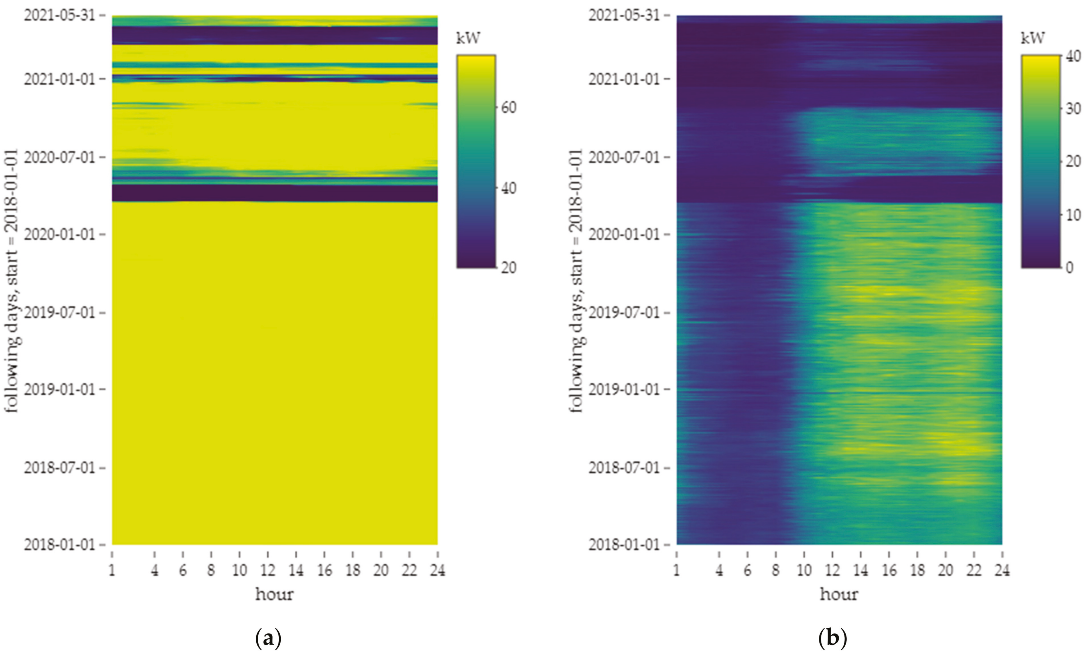


Figure 7. Course of hourly electricity consumption for the analyzed case study: (**a**) H4, (**b**) R1. Source: own study.

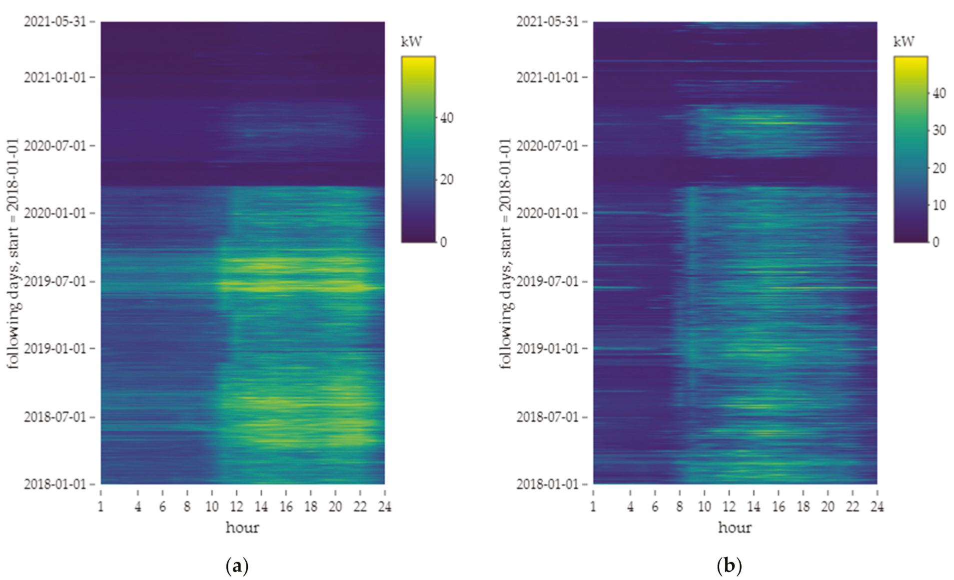


Figure 8. Course of hourly electricity consumption for the analyzed case study: (**a**) R2, (**b**) R3. Source: own study.

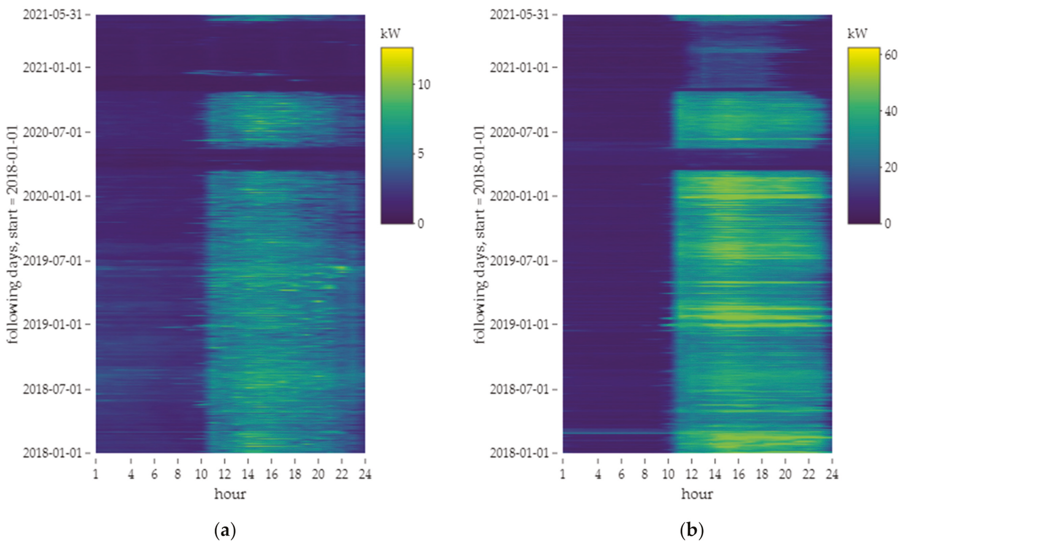


Figure 9. Course of hourly electricity consumption for the analyzed case study: (**a**) R4, (**b**) R5. Source: own study.

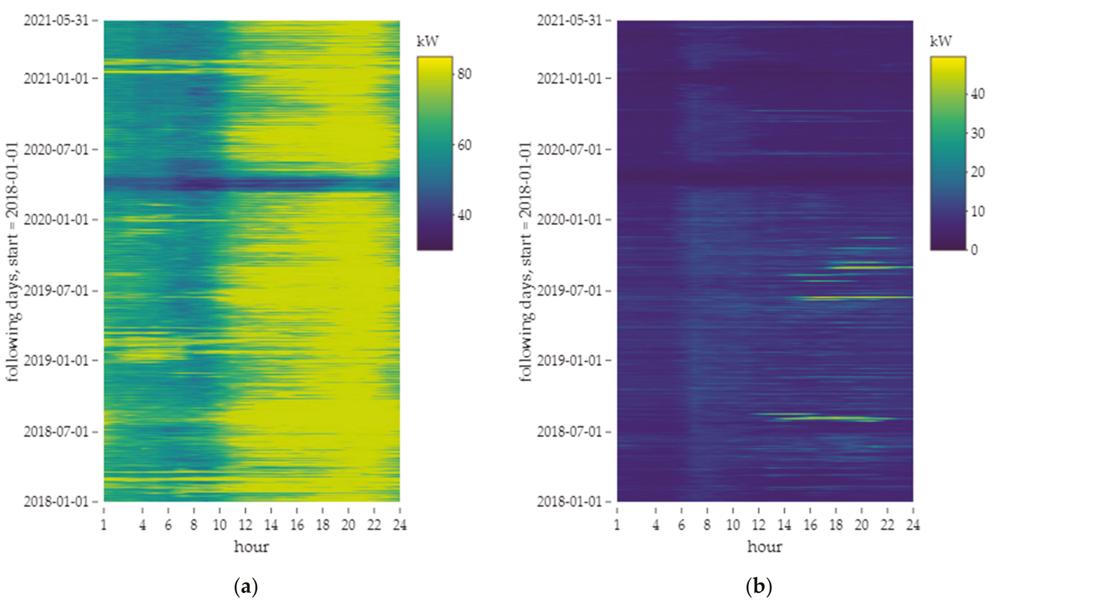
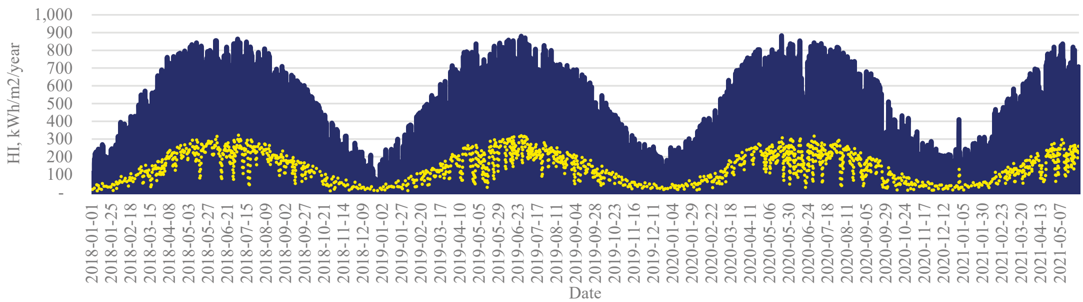
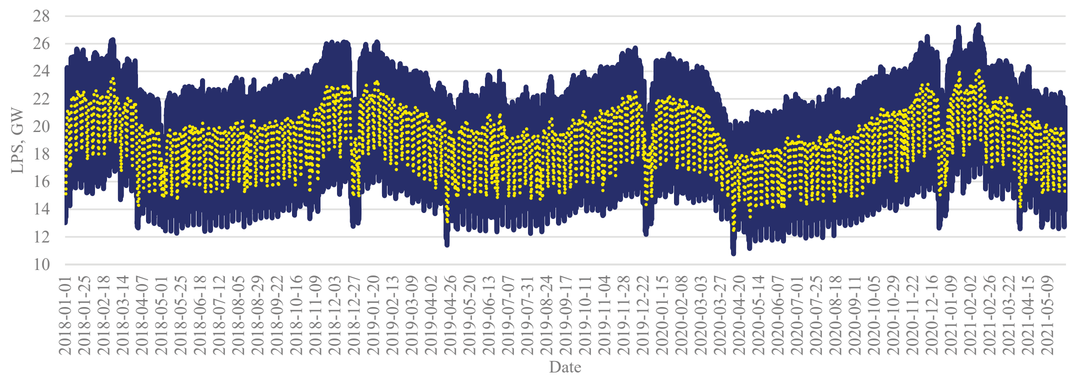


Figure 10. Course of hourly electricity consumption for the analyzed case study: (**a**) R6, (**b**) R7. Source: own study.



(**a**)



(**b**)

Figure 11. Course of hourly electricity consumption for the analyzed case study: (**a**) Horizontal Insolation, kWh/m^2/year (**b**) Load of Power System, GW. Source: own study.

3. Research Methods

3.1. Determinants of the Selection of the Research Period

As mentioned in Section 2, electricity consumption data were available for enterprises operating in the catering and hotel industry for the period from 1 January 2018 to 31 May 2021.

However, the authors were particularly interested in the impact of the COVID-19 pandemic on changing the characteristics of electricity consumption in the analyzed sectors of the economy.

The World Health Organization (WHO) on 14 January 2020 issued a warning against the spread of SARS-COV-2, and then, on 30 January 2020, assessed that the spread of the new pathogen poses a threat to public health of international scope. Ultimately, on 11 March, WHO declared SARS-CoV-2 to be a pandemic [49].

The unprecedented scale of subsequent restrictions imposed by governments as part of counteracting the development of the pandemic in subsequent waves of COVID-19, significantly restricting the freedom to perform previously routine everyday activities, has left its mark, especially on sectors related to people-to-people contacts. The forced change in the behavior of society, especially during the first wave in March and April 2020, from the energy point of view, caused problems in maintaining grid stability and adjusting the volume of energy production to unpredictably fluctuating demand. Thus, the black swan in the form of the new coronavirus pandemic has caused operational and financial difficulties for energy companies [50].

The restrictions regulated by legislation introduced during the pandemic waves, obviously influencing the freedom of everyday activities, influenced the amount of electricity demand in industries related to gastronomy, tourism or broadly understood entertainment (where there was a large concentration of people in closed spaces). However, the impact of behavioral changes in society in the face of growing negative moods is intuitively difficult to determine [51].

Therefore, for a detailed analysis, the time from 5 March 2020 to 31 May 2021 was assumed as a disturbed pandemic period. This is the period starting from the day following 4 March 2020, in which the first case of SARS-COV2 infection was diagnosed in Poland—the so-called "patient zero" [49]. This date was adopted as the limit of the change in the public awareness of the nature of the problem from global to national, which could have caused a spontaneous change in behavior, regardless of the restrictions introduced later.

On the other hand, the reference point was the same period in the previous years, that is, the interval from 5 March 2018 to 31 May 2019.

3.2. The Course of the Development of the COVID-19 Pandemic in Poland

- 4 March 2020—the first reported case of COVID-19 in Poland.
- 13 March 2020—announcement of the state of epidemic threat. Restricting the activities of restaurants and cafes only to the fulfillment of take-away or delivery orders.
- 20 March 2020—introduction of an epidemic state.
- 25 March 2020—no movement allowed except in special cases.
- 1 April 2020—hotel operations are limited to serving medical staff, people under quarantine and on business trips.
- 20 April 2020—1st stage of lifting restrictions—permission to travel for recreational purposes.
- 4 May 2020—2nd stage of lifting restrictions—allowing hotels to operate under the sanitary regime while restricting the activities of hotel restaurants to serving meals to rooms. Opening of shopping centers (without opening food court zones).
- 18 May 2020—3rd stage of lifting restrictions—opening restaurants, cafes and gastronomic spaces in shopping centers, maintaining the sanitary regime and the distance between tables.
- 30 May 2020—full opening of hotels along with the stationary operation of hotel restaurants. Admission to the organization of receptions for up to 150 people.
- 6 June 2020—swimming pools and hotel gyms are approved for use.
- 24 June 2020—lifting of restrictions in the event industry (fairs, conferences).
- 8 August 2020—regionalization of restrictions. Division into yellow and red zones (19 poviats, e.g., reducing the number of people in restaurants).
- 17 October 2020—covering part of the area of operation of the analyzed enterprises with the red zone—limiting the stationary activity of gastronomic establishments to 6–21 h and take-out orders after 9 p.m.
- 24 October 2020—the entire country will be restricted in the red zone. Suspension of the restaurant's stationary activities—only take-away and delivery services are allowed.
- 7 November 2020—hotel operations are limited to receiving guests on business trips. Restriction of the functioning of shopping malls (only stores with basic necessities).
- 27 November 2020—the "responsibility" stage—opening of stores in shopping malls.
- 28 December 2020—"national quarantine"—closure of hotels, including for business purposes. Restricting the functioning of shopping malls to the purchase of basic items.
- 1 February 2021—full opening of shopping malls.
- 12 February 2021—all hotels are allowed to operate in the sanitary regime.
- 13 March 2021—restriction of hotel operations to 50% of places and serving meals only to rooms.
- 20 March 2021—partial lockdown across the country—hotel closure, except for employee hotels and business trips.
- 14 April 2021—closing of shopping malls.
- 4 May 2021—opening of shopping malls and cultural facilities.

- 8 May 2021—opening of hotels with max 50% occupancy.
- 15 May 2021—gastronomy—admission (apart from take-away service) to open restaurant gardens.
- 29 May 2021—opening of the restaurant for indoor service at 50% occupancy, maintaining the distance between the tables and the sanitary regime.
- 13 June 2021—allowing the sale and consumption of meals in cinemas, theaters, events and cultural institutions.
- 26 June 2021—increasing customer limits to 75% in hotels and restaurants. Limits do not apply to vaccinated persons.

3.3. A Research Method Choice

The aim of the research was to determine the impact of the electricity consumption profile in the analyzed groups of service enterprises on the cooperation with the National Power System and potential photovoltaic sources. For this reason, the research method was searched for in the group of statistical correlation tests.

Choosing the right statistical test and checking the fulfillment of its assumptions is extremely important from the point of view of the credibility and correctness of the interpretation of the results. The tests of the normality of the distribution are specific tests examining the compliance of a given distribution with the normal distribution—the most frequently used in statistics because many features have a distribution similar to it. The assumption that the distribution is normal is often required in the case of parametric statistical tests. Non-parametric tests, on the other hand, are free from such assumptions [52].

The value of the Pearson's correlation score as a measure of the linear relationship between two variables, however, may be underestimated when there is a dependence between the variables, but the relationship is not linear. It may or may not give erroneous values and lead to a misinterpretation of the results if the assumptions about the normality of the distribution are not met.

After initial identification of the lack of a linear relationship between the analyzed variables, higher values in the Spearman's Rho test were expected as a better measure of the degree of correlation of the analyzed variables. The use of non-parametric methods independent of the distribution of the analyzed variables is more convenient from the point of view of meeting the applicability conditions of parametric statistical procedures. Spearman's Rho can be treated similarly to Pearson's linear correlation coefficient, that is, in terms of the percentage of explained variation, with the difference that Spearman's Rho is calculated based on ranks.

As part of the implementation of this study, tests of interdependencies between the variables were carried out using the most intuitive in interpretation parametric test of Pearson's r-correlation and its non-parametric counterpart based on the ranks of the Spearman, the use of which appears to be more adequate [53].

3.4. The Course of the Research Process

3.4.1. Stage "0"

Along with the approximation of the natural conditions (insolation conditions in Poland—Figures 3 and 11a) and market conditions (the course of the variability of power demand in the National Power System—Figure 11b), the general characteristics of electricity consumption in the analyzed enterprises were outlined throughout the entire period of the obtained data. For this purpose, the variability courses of the analyzed variables were determined (Figures 4–11).

The course of the research process is described by a schematic and conceptual flowchart (Figure 12).

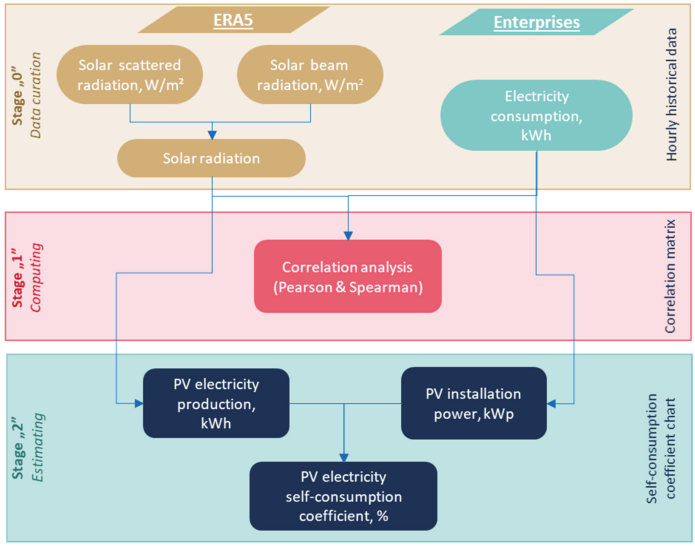


Figure 12. Schematic and conceptual flowchart of the research process. Source: own study.

The analyses in the next part were carried out by dividing them into the period before the outbreak of the COVID-19 pandemic in Poland and in the pandemic period. In the beginning, descriptive statistics of the analyzed variables (in pre-pandemic and pandemic periods) were determined using the "stats" library of the RStudio environment and presented in tabular form (Tables 1 and 2).

Table 1. Descriptive statistics of the analyzed variables for analyzed research objects and insolation and loads of power systems before the COVID-19 pandemic period.

	C1	C2	C3	H1	H2	H3	H4	R1	R2	R3	R4	R5	R6	R7	HI	LPS
Unit	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh/ m^2/year	GW
Min.	0.37	0.01	0.56	20.34	0.96	18.54	17.25	4.40	2.63	4.84	0.47	0.85	11.22	1.64	0	11.40
1st Qu.	3.23	0.06	3.23	37.80	24.15	34.29	118.05	8.94	15.50	8.34	2.27	5.49	60.12	6.57	0	16.68
Median	7.58	0.14	6.23	44.82	28.98	41.72	137.32	21.68	21.49	11.62	3.19	19.91	68.61	7.79	10.53	19.60
Mean	8.81	0.93	6.15	45.64	29.38	40.36	143.87	19.17	23.39	12.95	3.73	18.66	69.89	8.26	143.58	19.38
3rd Qu.	14.22	1.01	8.17	52.56	33.6	47.12	166.51	26.95	29.82	16.17	4.99	29.24	78.28	9.32	238.78	21.88
Max.	27.31	10.27	19.91	91.98	56.10	71.96	285.94	38.40	56.97	43.21	12.63	60.72	115.23	47.72	863.48	26.58
Skewness	0.44	2.46	0.42	0.36	0.51	(0.24)	0.71	−0.16	0.68	1.20	0.78	0.37	0.40	4.41	1.43	−0.06
Kurtosis	1.88	8.95	2.48	2.72	3.09	2.48	3.30	1.54	2.55	4.53	2.83	1.91	3.04	49.62	3.91	2.01
Variance	35.8	2.86	8.41	101.05	45.66	98.61	1223.93	80.96	79.81	33.37	2.95	168.58	150.99	7.39	44,517.58	9892.66
SD	5.98	1.69	2.90	10.05	6.76	9.93	34.98	9.00	8.93	5.78	1.72	12.98	12.29	2.72	210.99	3.14

Source: own study.

Table 2. Descriptive statistics of the analyzed variables for analyzed research objects and insolation and loads of power systems during the COVID-19 pandemic.

	C1	C2	C3	H1	H2	H3	H4	R1	R2	R3	R4	R5	R6	R7	HI	LPS
Unit	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh/ m^2/year	GW
Min.	0.26	0.01	0.98	8.55	3.24	9.99	8.70	0.57	1.66	2.41	0.38	2.50	16.74	1.58	0	10.77
1st Qu.	0.70	0.04	2.17	20.77	10.08	12.06	36.90	2.43	3.13	3.81	0.83	4.38	54.06	4.36	0	16.41
Median	2.12	0.14	3.56	24.12	13.92	14.98	70.20	4.09	4.63	4.84	1.12	6.58	62.04	5.17	10.28	19.07
Mean	3.41	0.85	3.95	26.24	16.01	18.38	67.23	6.51	5.57	6.76	1.75	11.45	64.21	5.53	138.52	19.03
3rd Qu.	4.14	1.01	5.15	31.00	19.86	21.58	94.05	8.68	7.24	7.97	1.80	14.82	74.13	6.29	216.73	21.45
Max.	19.57	8.80	13.57	63.99	43.38	53.15	178.65	32.90	36.38	49.88	10.32	51.11	114.39	18.41	882.83	27.37
Skewness	1.65	2.51	0.93	0.97	1.07	1.35	(0.03)	1.39	1.98	2.29	2.00	1.37	0.36	1.35	1.51	0.08
Kurtosis	5.06	9.22	3.39	3.60	3.44	3.76	2.12	4.01	10.18	10.30	6.74	3.64	2.76	5.98	4.19	2.22
Variance	13.10	2.43	4.48	62.19	51.05	74.09	1172.12	37.66	11.85	20.35	2.23	101.76	181.69	3.08	42,847.07	10,680.73
SD	3.62	1.56	2.12	7.89	7.14	8.61	34.24	6.14	3.44	4.51	1.49	10.09	13.48	1.75	207	3.27

Source: own study.

3.4.2. Stage "1"

The article is an attempt to transfer the determined dependencies diagnosed on the basis of a relatively small sample of case studies to the entire industry. Due to the fact that the aim of the study is to obtain knowledge and formulate conclusions about the analyzed groups of service enterprises, despite the relatively small number of their representatives, an analysis of the intergroup correlation was carried out, the product of which is the r-Pearson and non-linear Rho-Spearman correlation matrices for individual general case studies (Figures 13–16).

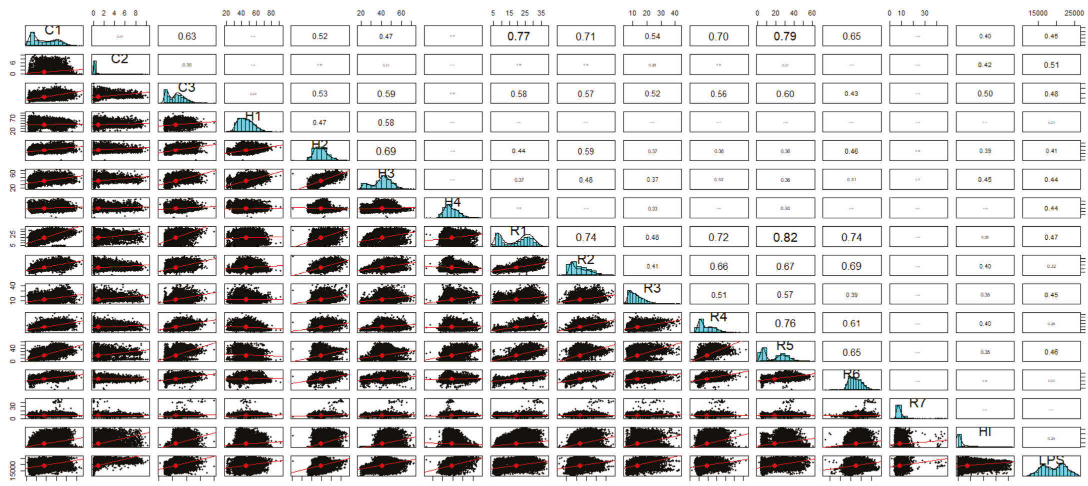


Figure 13. Correlation matrix with Pearson's correlation coefficients between analyzed case studies for the pre-pandemic period. Source: own study.

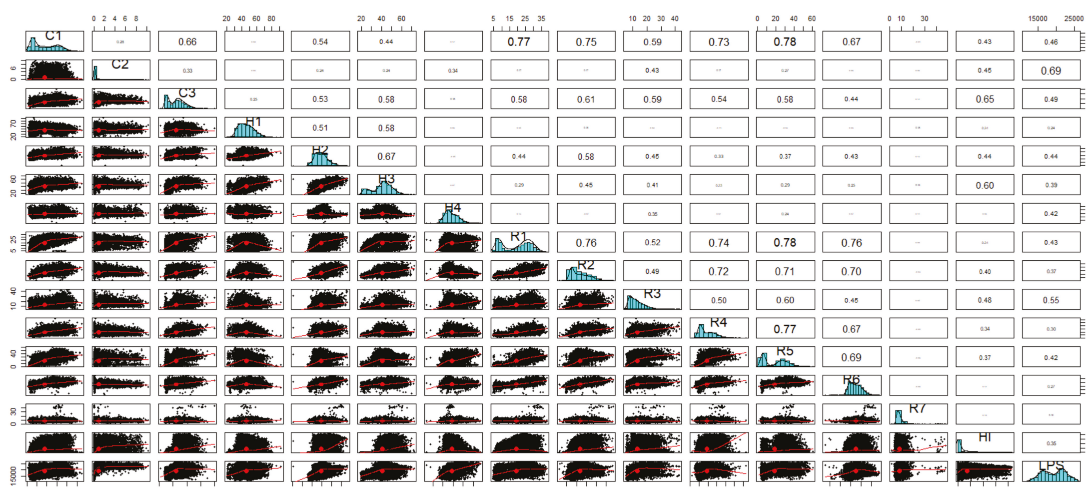


Figure 14. Correlation matrix with Spearman's correlation coefficients between analyzed case studies for pre-pandemic period. Source: own study.

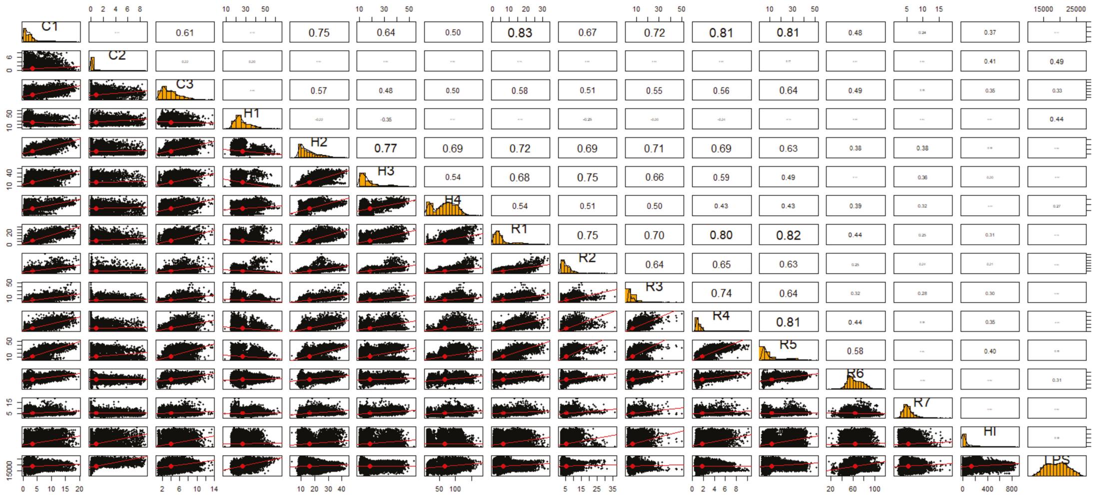


Figure 15. Correlation matrix with Pearson's correlation coefficients between analyzed case studies for pandemic period. Source: own study.

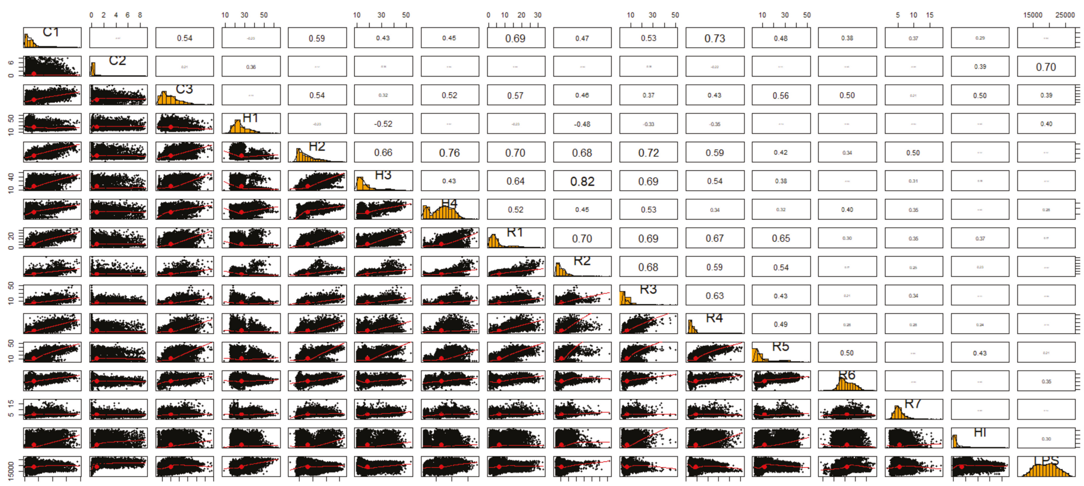


Figure 16. Correlation matrix with Spearman's correlation coefficients between analyzed case studies for the pandemic period. Source: own study.

The correlation analysis of the electricity consumption profiles of the analyzed enterprises was carried out in relation to:

- The power demand profile in the National Power System to determine the impact of these groups of enterprises on the power grid stability. The partial aim of the study is to determine whether these economic sectors contribute to the electricity peak demand in the national network, still covered in Polish conditions by high-emission conventional sources. The positive correlation justifies the environmental effectiveness of PV using in case studies.

- The electricity production profiles of potential PV sources with their productivity defined in simplification only on the basis of historical insolation conditions for the considered locations.

Higher correlation coefficients between electricity consumption profiles in enterprises and insolation, and thus also the potential production of electricity from photovoltaics, result in a greater potential self-consumption coefficient of this electricity.

Therefore, in the first stage of the research process, correlation analysis was performed to avoid unnecessary in-depth self-consumption analysis. Only when the correlation analysis reveals the existence of a relationship between the variables, it is reasonable to test the degree of self-consumption of PV electricity.

The correlation matrices were organized in such a way as to investigate how the electricity generation profiles of a potential RES source fit into the electricity consumption profiles in individual research objects to cover their own energy needs. Thus, the study deals with an increase in environmental efficiency as a result of the reduction of the emissions of national energy, based mainly on fossil fuels as a result of the use of own photovoltaic sources to cover their own electricity demand. Then, the correlation matrices between the individual electricity consumption profiles in the relevant case studies at pre-pandemic and pandemic periods were determined using the "pairs.panels" function from the "psych" library of the RStudio environment. The correlation between the case studies was carried out in order to assess their representativeness, including the research results and conclusions drawn on their basis in relation to the industries they represent.

3.4.3. Stage "2"

Finally, the degree of self-consumption of electricity produced in potential photovoltaic sources was determined and the averaged values of the degree of auto-consumption in individual enterprises were presented.

Based on hourly historical data:

- Electricity consumption in individual case studies,
- Value of available solar radiation available in these locations in a correspondence hour

We estimated:

1. The size of the PV installation expressed in kWp based on the average annual electricity consumption. The analyzed sub-periods (before and in the pandemic) covered 10,872 h. In consequence, the sum of 10,872 h was multiplied in the research by the quotient (8760/10,872) to specify average yearly electricity consumption (demand) levels in analyzed case studies.
2. Hourly electricity production from PV installations estimated on the basis of Equation (1).

$$Ep_{PV} = \frac{Y_{EC}}{1000} * HI_h * \eta * \frac{1}{1000} \quad (1)$$

where:

Ep_{PV}—electricity produced by the *PV* installation on an hourly basis, kWh
Y_{EC}—*PV* installation power, kWp (average annual electricity demand, kWh)
HI_h—horizontal insolation on an hourly basis, kWh/m^2/year
η—efficiency factor of the components of the *PV* installation, assumed η = 0.9

The value of the self-consumption electricity was estimated on an hourly basis based on Equation (2). These values were determined for the period from 5 March to 31 May of the following year (10,872 h).

$$Esc_{PV} = \begin{cases} H_{EC}\ if: H_{EC} < Ep_{PV} \\ Ep_{PV}\ if: H_{EC} \geq Ep_{PV} \end{cases} \quad (2)$$

where:

Esc_{PV}—hourly consumption of *PV* produced electricity, kWh
Ep_{PV}—hourly *PV* electricity production, kWh

H_{EC}—hourly electricity consumption, kWh

The averaged value of the self-consumption coefficient was determined (Equation (3)) as the quotient of the sums of self-consumed and potentially produced electricity in 8760 consecutive hours (Equation (4)).

$$HSCc = \frac{Esc_{PV}}{Ep_{PV}} * 100\% \tag{3}$$

where:

Hsc_{PV}—hourly PV electricity self-consumption coefficient, %

$$SCc = \frac{\sum_1^{8760} Esc_{PV}}{\sum_1^{8760} Ep_{PV}} * 100\% \tag{4}$$

where:

SCc—annual average PV electricity self-consumtion coefficient, %

The specified research sub-periods covered the period from 5 March 2020 to 31 May 2021 (10,872 h) and the corresponding period in 2018/2019. In order not to disturb the analysis on an annual basis, due to the two-stage occurrence of the spring season in the analyzed sub-periods (2112 h), averaged values of the self-consumption coefficient were determined for the next 2112 observations of moving average values from the previous 8760 h. This shift removes the impact of seasonal variability while using the full knowledge of the analyzed sub-periods. The course of the variability of the coefficient is shown in the Section 4.5.

With a low power of the installation, the self-consumption of the produced energy will occur practically always [54] while with the rescaling of the installation, the degree of self-consumption of electricity decreases and, at the same time, the self-sufficiency increases [18,55]. Apart from the power of the installation, the very degree of correlation of the profile course, while maintaining the conditions for which they were determined, remains approximately constant.

4. Results of Numerical Analysis of Research Objects

4.1. Descriptive Statistics of the Analyzed Variables

The values of descriptive statistics show the character of the empirical distribution of the analyzed variables. Table 1 presents descriptive statistics as well as measures of dispersion and shape of distribution of the analyzed variables in the pre-pandemic period (Table 1) and during the COVID-19 pandemic (Table 2).

In the pre-pandemic period, the variables show a relatively high similarity of empirical distributions to the normal distribution. In the case of variables H2, R4 and R6, the values of descriptive statistics and the parameters of the shape of empirical distributions of these variables prove their significant normality. This is confirmed by the graphical analysis of the histograms (Figures 13–16).

During the pandemic, in research objects of C1, C2, H3, R1, R2, R3, R4 and R5 cases, the average value of hourly electricity consumption is higher than the median, and therefore more observations are on the left-hand side of the average value, which indicates the right-hand value asymmetry of the empirical distribution. The concentration of the empirical distribution (kurtosis) for only three cases of H4, R6 and LPS is below 3, which means that they are platocurtic distributions, and the values of the variable are less concentrated than with the normal distribution. In the case of six variables, it is close to the 3 value typical for the normal distribution. The cases of the H6 and LPS variables show the greatest similarity to the normal distribution, but their empirical distributions, intuitively, do not meet the normality criteria.

In the case of insolation conditions in the location of the analyzed case studies during a pandemic, the distribution of the variable is of course similar to the pre-pandemic period, due to the numerous occurrences of zero and close to zero values, it shows a strong left-hand asymmetry. Literature sources confirm that the empirical distribution of horizontal insolation does not show similarity to the normal distribution and is best approximated by the beta distribution [56–58]. Sources also indicate that for some seasons and latitudes, the empirical distribution may approximate the Weibull distribution [59,60] commonly used for wind speed analysis, as well as the log-normal [61] or gamma [58,61] distribution.

Therefore, the use of the Pearson linear correlation method for all variables may be associated with the incorrect determination of the value of the correlation coefficient and lead to erroneous conclusions. Therefore, the nonlinear rho-Spearman correlation method was used as an alternative, although less intuitive in interpretation.

4.2. Analysis of the Correlation between the Cases of Enterprises and with Regard to Sunlight Conditions and the Course of Power Demand in the National Power System

The partial goal of the research was to determine the power and nature of the relationship between the course of electricity demand in the analyzed groups of enterprises and:

- The course of power demand in the National Power System in order to determine the global impact of the considered groups of enterprises on the stability of the distribution network.
- Variability of insolation conditions, and thus determining the potential of cooperation of enterprises from the analyzed sectors with the photovoltaic installation.

The analysis of correlation carried out between the profiles of individual enterprises may turn out to be valuable for determining the degree of similarity and representativeness of the analyzed enterprises, and thus the legitimacy of making a conclusion about the sector on the basis of a relatively small sample.

4.3. Pre-Pandemic Period

To facilitate the interpretation and readability of the matrix, the functionality of the "pairs.panels" function ("psych" RStudio library) was used, which differentiates the font size of the given values of correlation coefficients depending on their size. For absolute values close to 1 (full correlation), the font has a target size, and for values tending to zero (no correlation) the font is fading out.

When analyzing the results included in the Pearson and Spearman correlation matrices in the pre-pandemic period (Figures 13 and 14) and the values of correlation coefficients collected in tabular form (Tables 3 and 4), it should be stated that the highest degree of similarity (relationships) is shown by the restaurants marked R1 and R5, for which the r-Pearson correlation coefficient was 0.82, which should be interpreted as the existence of a strong linear correlation. Spearman's rho coefficient was slightly lower, that is, 0.78. Similarly, the cases of R1, R2, R4, R5 and R6 showed a strong almost linear relationship, as the values of both statistics here are over 0.7. Hotels H2 and H4 and cafes C1 and C3 show a slightly lower value, but which can already be interpreted as the average strength of correlation. In the linear Pearson correlation to the power demand profile in the National Power System, only the C2 café case showed a value above 0.5 (average correlation), although most enterprises achieved values above 0.4 (moderate correlation). It is worth noting, however, that Spearman's rho-statistic showed the existence of a much stronger non-linear relationship in the case of C3 cafes with the Spearman correlation coefficient at the level of 0.69 and 0.55 for the R3 restaurant.

With regard to the insolation conditions, and thus the productivity of a potential PV installation, the highest value of non-linear correlation at the level of 0.65 was achieved by the case of the C3 café. The H3 hotel recorded a slightly worse result (0.60).

Table 3. The values of correlation coefficients between hourly electricity consumption and load of Power System. Description of colors: Green = positive. Red = negative. Ascending order: from light (near zero) to dark (near 1) color.

		C1	C2	C3	H1	H2	H3	H4	R1	R2	R3	R4	R5	R6	R7
before COVID-19	r-Pearson	0.45	0.51	0.48	0.23	0.41	0.44	0.44	0.47	0.32	0.45	0.28	0.46	0.23	0.12
	rho-Spearman	0.46	0.69	0.49	0.24	0.44	0.39	0.42	0.43	0.37	0.55	0.3	0.42	0.27	0.16
during COVID-19	r-Pearson	0.11	0.49	0.33	0.44	0.08	(0.02)	0.27	0.14	0.03	0.04	(0.01)	0.19	0.31	0.09
	rho-Spearman	0.09	0.70	0.39	0.4	0.12	(0.12)	0.28	0.17	(0.02)	(0.06)	(0.14)	0.21	0.35	0.13

Source: own study.

Table 4. The values of the correlation coefficients between hourly electricity consumption and horizontal insolation. Description of colors: Green = positive. Red = negative. Ascending order: from light (near zero) to dark (near 1) color.

		C1	C2	C3	H1	H2	H3	H4	R1	R2	R3	R4	R5	R6	R7
before COVID-19	r-Pearson	0.40	0.42	0.50	0.11	0.39	0.45	(0.05)	0.28	0.40	0.35	0.40	0.35	0.16	0.05
	rho-Spearman	0.43	0.45	0.65	0.24	0.44	0.60	0.06	0.24	0.40	0.48	0.34	0.37	0.12	0.10
during COVID-19	r-Pearson	0.37	0.41	0.35	0.01	0.19	0.20	(0.01)	0.31	0.21	0.30	0.35	0.40	0.04	0.04
	rho-Spearman	0.29	0.39	0.50	0.05	0.12	0.19	0.05	0.37	0.23	0.11	0.24	0.43	0.05	0.08

Source: own study.

4.4. COVID-19 Pandemic Period

Analyzing the results presented in the Pearson and Spearman correlation matrices for the pandemic period (Figures 15 and 16) and the values of correlation coefficients collected in tabular form (Tables 3 and 4), it should be noted that in relation to the period before the pandemic, a slight increase in the number of significant relationships between the variables was noted. The highest value of the correlation coefficient occurred again in the case of the R1 and R5 restaurants in the Pearson linear correlation (0.82), as well as R4-R5 (0.81) and R1-R4 (0.80). The dependencies identified by the Spearman's rho test were much weaker—a maximum of 0.70 in the case of the R1-R2 pair. Next in terms of the strength of the relationship is the pair of hotels H2-H3 (r = 0.77) and H2-H4 (rho = 0.76). It is worth noting the negative Spearman correlation between H1-H3 at −0.52. The C1–C3 cafes again showed an average correlation at the level of r = 0.61 and rho = 0.54.

In the linear Pearson correlation of electricity consumption profiles in enterprises with the profile of power demand in the National Power System, only the cases of C2 café and H1 hotel showed a value above 0.4 (moderate dependence). It is worth noting, however, that at the same time the Spearman's rho-statistic showed the existence of a much stronger non-linear relationship in the case of the C2 cafe with the Spearman correlation coefficient at the level of rho = 0.70.

With regard to the insolation conditions, that is, the productivity of a potential PV installation, a decrease in the correlation power was noted, and the highest non-linear correlation value at the level of 0.5 was achieved by the C3 café. The R5 hotel reported a slightly worse result (0.43).

However, in the case of the analysis of the correlation with the demand profile in the transmission network, the existence of an average to strong correlation occurring between approx. 70% of the analyzed cases (values of Pearson's and Spearman's coefficients ranging from 0.7 to 0.82 in the period before and during the COVID-19 pandemic) entitles one to attempt to draw conclusions about the restaurant industry on a national scale. Similarly, there is a moderate Pearson and Spearman correlation with coefficient values of 0.6–0.7 for 75% of the analyzed hotels and 0.5–0.6 for 66% of the analyzed cafes.

A high positive correlation of the energy consumption profile in relation to the profile of power demand in the pandemic period was observed in cafe C2, although its volume of energy consumed is several times lower than that of other representatives of the sector. Thus, the significance of inference based on its example in the context of the impact on the stability of the power grid may be flawed.

The strength of this dependence in the pandemic period, and thus the destabilizing effect on the distribution network, was increased by the H1 hotel and the R6 restaurant, which are in an intermediate position among the analyzed cases in terms of the amount of energy demand. The case of the R6 restaurant shows that it is a facility that has successfully recovered from the unprecedented COVID-19 situation. The average consumption during the pandemic decreased in the case of the R6 restaurant by less than 9% compared to the same period 2 years earlier. This may indicate a strong market position and an established brand that previously successfully offered a kitchen for delivery, which thus constituted a market advantage in the new reality.

On the other hand, a decrease in the value of correlation coefficients of 25–50% was recorded by: café C3, hotel H4 or restaurant R5. Other enterprises noticed multiple decreases in the value of the correlation power to the demand profile in the energy system, at the same time showing the average value of energy consumption two or even three times lower than in the corresponding period in previous years. This proves the problems of those entities that encountered difficulties in functioning in the new reality. The gap between restaurants with lower energy consumption and those with a stronger market position is particularly visible. The same applies to cafes. The four analyzed hotel cases recorded a decrease in the volume of electricity consumption of approx 100%.

In the context of the change in the correlation of the electricity demand profiles in the analyzed enterprises in relation to the insolation conditions, it is worth noting that the average value of correlation coefficients during the pandemic decreased compared to the comparative period by 19% in the case of cafes—64% in the case of hotels and 18% in the case of restaurants.

Only in two cases, that is, the R1 and R5 restaurants, an increase in the value of correlation coefficients was recorded in the pandemic period. On the other extreme, however, there is the case of the R6 restaurant whose demand profile is characterized by a peak coinciding with the evening peak of demand in the distribution network and in the hours of the highest availability of solar radiation, the level of electricity consumption is relatively low. The highest, an almost six-fold decrease in value, was recorded in the case of the H1 hotel, the energy demand profile of which results directly from the nature of the accommodation facility—daily peaks occur before checking out and at dinner time.

To sum up, it should be stated that among the analyzed enterprises, the greatest potential for using photovoltaics for the purposes of self-consumption of electricity was retained by entities from the catering industry.

4.5. Analysis of Self-Consumption Levels of Electricity Generated in Potential PV Installations

The study of the potential degree of self-consumption of electricity from own photovoltaic installation confirms the above observations. Apart from the H1 and C1 cases, in the pandemic period, there is a higher value of the degree of electric energy self-consumption compared to the comparative period. The course of the variability of the coefficient is shown in Figures 17–19.

The highest value of the self-consumption coefficient, at the level of 52%, is for the C1 cafe and the R5 restaurant. The next ones are the cases of C3 (50%), R1 and R4 (49%), R3 and C2 (47%) and R2 and H2 (45%).

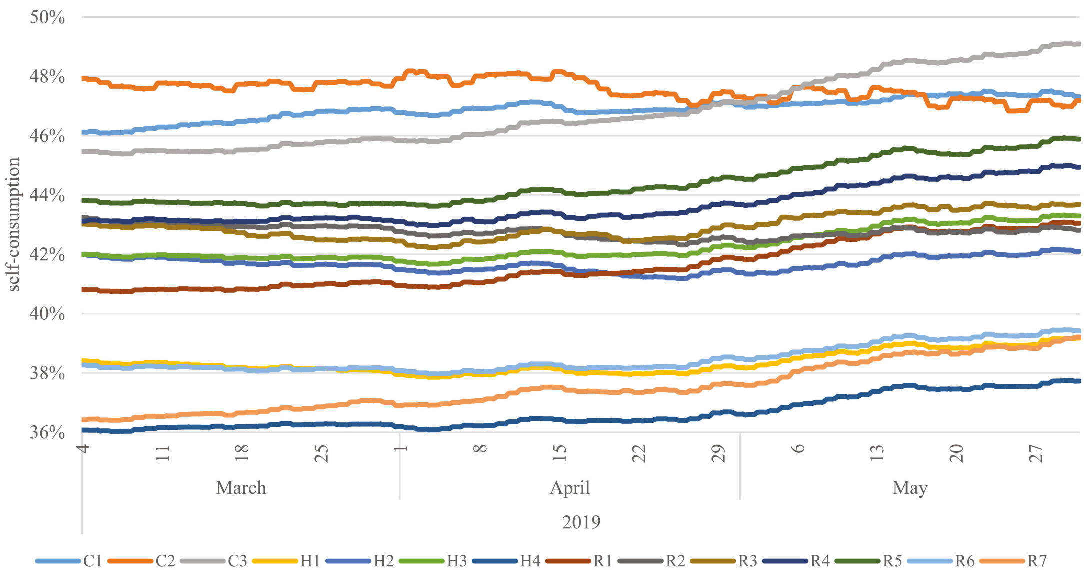


Figure 17. Variability of the percentage of self-consumption of electricity produced in the potential photovoltaic installation for the previous 8.760 h in the pre-pandemic period. Source: own study.

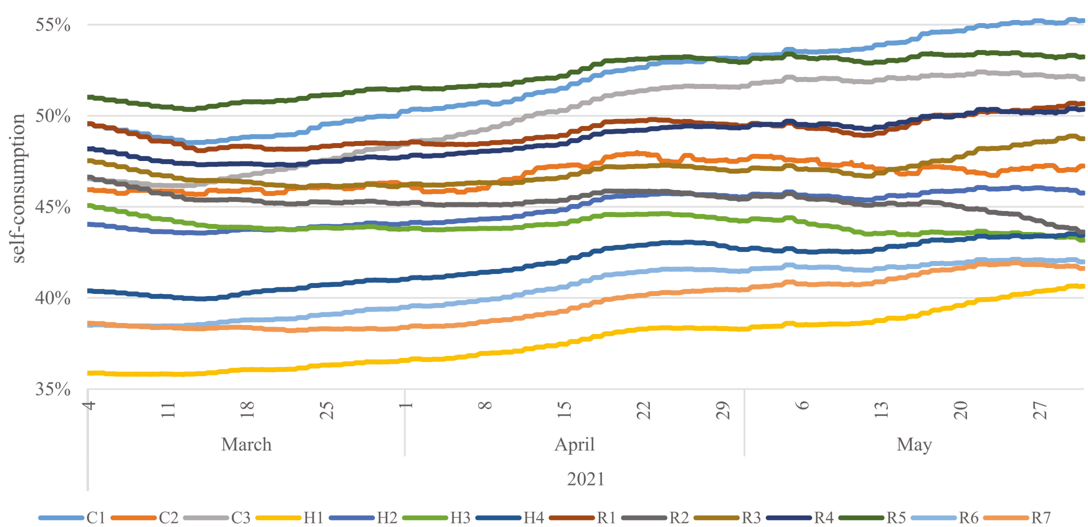


Figure 18. Variability of the percentage of self-consumption of electricity produced in the potential photovoltaic installation for the previous 8.760 h during the pandemic period. Source: own study.

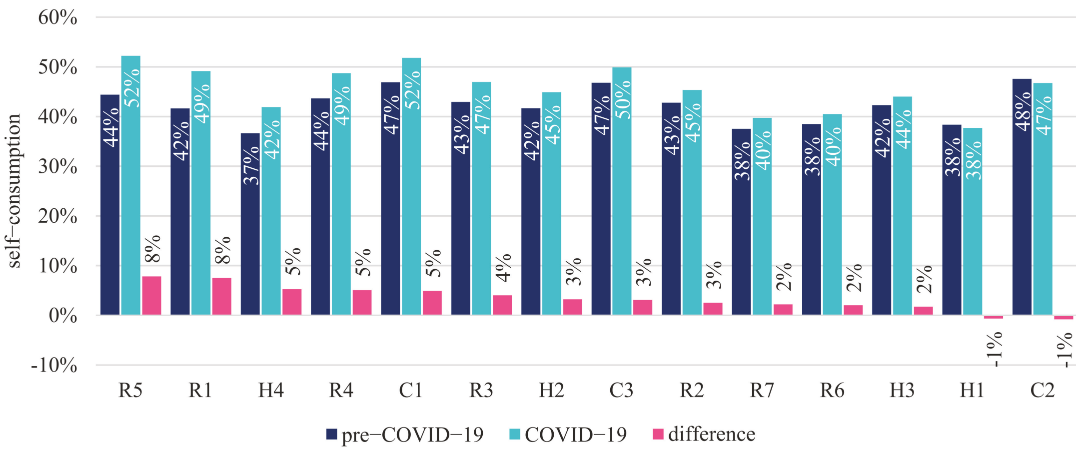


Figure 19. Average indicator of self-consumption of energy from PV and its difference in the pre-COVID-19 and COVID-19 periods in the analyzed case studies. Source: own study.

5. Conclusions

The occurrence of the black swan in December 2019, which is undoubtedly the emergence of the SARS-CoV-2 coronavirus epidemic in the Chinese province of Hubei and its spread throughout the world by the end of the first quarter of 2020, triggered a series of events that changed the face of the known so far in the world. Some of the industries most affected by the scale of unprecedented restrictions in individual waves of the pandemic consist of those areas of activity where people-to-people contact is on the agenda so far, such as the catering and hotel industries.

The picture of the world affected by the pandemic in the context of the energy demand of these sectors is quite different from its previously known form. The high correlations between the profiles of electricity demand in restaurants, cafes and hotels and the profile of power demand in the national power grid or production profiles of photovoltaic sources reaching the Pearson or Spearman correlation coefficients of 0.6–0.7 for the pre-pandemic period a significant change. Especially in the case of the hotel industry, there is a noticeable decrease in the volumes of electricity demand as well as their daily variability that is different from the demand profile in the network.

In the case of restaurants and cafes, these dependencies still remain at a moderate level. which is tantamount to a destabilizing impact on the parameters of the distribution network. At the same time, these industries appear to be potentially effective entities to install photovoltaics for the self-consumption of more expensive electricity. This is confirmed by the relatively high determined index of the hypothetical self-consumption of energy from own PV sources in the analyzed enterprises.

A positive correlation with a moderate value of the coefficient of the order of 0.5 means that these enterprises currently consume relatively expensive energy which in the context of the introduction of dynamic tariffs in 2027 justifies the interest in investing in their own PV source. Proper selection and flattening of the resultant profile of energy demand from the grid may also reduce costs and create preferential conditions for DSOs.

It is worth noting that the self-consumption coefficient, unlike the industries initially associated with the energy transformation, in the case of broadly understood services. has a justified potential to increase due to the increase in EV popularization. Especially in the case of restaurants located on busy thoroughfares car chargers could be an interesting supplement to the PV installation subject to preferential conditions. Such a service would be an additional incentive to stop at this specific place, which would translate into an increase in the competitiveness of the company's offer. The economic efficiency of such a solution seems to be a natural development step for the research presented in this article.

In the case of hotels, with the indicated values of correlation, the justification for such solutions could be found by entities focused on business customers and conferences. Intelligent energy management system could be integrated into the Vehicle-2-Grid and/or Grid-2-Vehicle model. In this way, the hotel could obtain preferential conditions and/or create an additional level of relationship with the customer by offering him a financial advantage in return for providing a vehicle for the V2G/G2V model.

The directions of the further development of research problem presented in this article may be:

1. Taking into account the application of concentrated (CPV) or bi-facial PV panels,
2. Taking into account the change of the prosumer support model to the net metering model,
3. Actions that can be taken to increase the matching of the consumption and generation profile of PV electricity due to the reorganization of key processes such as water heating in hotels at noon,
4. Transferring the research process to other, potentially sensitive to pandemic restrictions, economic sectors,
5. Correlation of the level and profile of energy demand with data on business bankruptcy statistics and the assumption of new ones reported by the Central Statistical Office.

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Abbreviations

EV	Electric Vehicle
HI	Horizontal Insolation, kWh/m^2/year
LPS	Load of Powers System, GW
PV	Photovoltaics
V2G	Vehicle-2-Grid
G2V	Grid-2-Vehicle

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Article

Sustainable Value Chain of Industrial Biocomposite Consumption: Influence of COVID-19 and Consumer Behavior

Didzis Rutitis [1,2,*], Anete Smoca [3], Inga Uvarova [2,4], Janis Brizga [1,5], Dzintra Atstaja [2,6,*] and Inese Mavlutova [7,*]

1 Circular Economy Center, Liepaja University, Lielā st. 14, LV-3401 Liepaja, Latvia; janis@zalabriviba.lv
2 Management Department, BA School of Business and Finance, K.Valdemara st. 161, LV-1013 Riga, Latvia; inga.uvarova@gmail.com
3 Institute of Design Technologies, Faculty of Materials Science and Applied Chemistry, Riga Technical University, Kipsalas st. 6, LV-1048 Riga, Latvia; anete.smoca@rtu.lv
4 ArtSmart, Vidrižu st. 1c-29, LV-1006 Riga, Latvia
5 Department of Geography and Earth Sciences, University of Latvia, Jelgavas st. 1, LV-1004 Riga, Latvia
6 Legal Department, Faculty of Law, Riga Stradins University, Dzirciema st. 16, LV-1007 Riga, Latvia
7 Department of Economics and Finance, BA School of Business and Finance, K.Valdemara st. 161, LV-1013 Riga, Latvia
* Correspondence: didzis.rutitis@ba.lv (D.R.); dzintra.atstaja@ba.lv (D.A.); inese.mavlutova@ba.lv (I.M.)

Abstract: The COVID-19 pandemic has been one of the most unprecedented crises of recent decades with a global effect on society and the economy. It has triggered changes in the behavior and consumption patterns of both final consumer and industrial consumers. The consumption patterns of industrial consumers are also influenced by changes in consumer values, environmental regulations, and technological developments. One of the technological highlights of the last decade is biocomposite materials being increasingly used by the packaging industry. The pandemic has highlighted the problems and challenges of the development of biocomposites to adapt to new market conditions. This study aims to investigate the industrial consumption of biocomposite materials and the influence of the COVID-19 pandemic on the main stages of the value chain of sustainable industrial consumption of biocomposites. The research results reveal there is a growing interest in the use of biocomposites. Suppliers and processors of raw materials are being encouraged to optimize and adapt cleaner production processes in the sustainable transition pathway. The study highlights the positive impact of COVID-19 on the feedstock production, raw material processing, and packaging manufacturing stages of the value chain as well as the neutral impact on the product manufacturing stage and negative impact on the retail stage. The companies willing to move toward the sustainable industrial chain have to incorporate economic, environmental, social, stakeholder, volunteer, resilience, and long-term directions within their strategies.

Keywords: sustainable industrial consumption; sustainable value chain; biocomposite; sustainable packaging; COVID-19 pandemic influence; consumer behavior

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1. Introduction

The Sustainable Development Goals (SDG) of the United Nations (UN) provides a global road map of seventeen objectives promising access to sustainable development, and SDG12 in particular is devoted to the promotion of sustainable consumption and production [1]. According to the UN (2021), the material footprint has significantly increased (by 70%) since the year 2000, highlighting threats of a sharp increase in the use of plastic bags and bottles and a comparatively small amount of plastic and electronic waste recycled. The scientific community confirms the importance of SDGs in addressing economic, social, and environmental issues that plague the world and promotes the concept of sustainability [2]. However, the implementation framework of SDGs is criticized by researchers and practitioners due to the lack of clear and sound practical tools for the sustainable transition and change toward sustainable consumption [3].

The circular economy advocates sustainable development, promoting the necessity to strike a balance between environmental and economic values. In turn, this leads to the need for solutions that help businesses ensure both a positive impact on the environment and insufficient financial returns on profit and investments [4,5].

While climate change remains one of the biggest global challenges, the current COVID-19 pandemic also highlights environmental and climate challenges. Achieving zero greenhouse gas emissions requires economic and social change. The packaging industry as one of the biggest contributors to the greenhouse effects is one of the first to be forced to respond to the goals of the European green transition, which envisages the implementation of an industrial policy for the circular economy [6], and the UN Sustainable Development Goals [1]. Several of the European Union leading retailers are committed to a full transition toward circular economy business models, including the use of 100% recycled or other sustainably sourced materials by 2030 [7].

The growing variety of environmental restrictions and requirements of policymakers is a catalyst for an increase in the demand for renewable and biodegradable composite materials. Recent advances in the availability of biodegradable polymers and the focus on the use of natural fibers have offered opportunities to produce highly durable biodegradable polymer composite systems [8]. During the COVID-19 crisis, consumers have also taken the lead in forcing industries to change and invest in innovations that facilitate the reduction of the environmental footprint [9].

With the overall increase in consumption stimulated with more sophisticated applications and products introduced within the market, the market for bioplastics is continuously growing and diversifying. The global production capacity of bioplastics is set to increase from around 2.11 million tons in 2020 to approximately 2.87 million tons in 2025. The production capacity of biodegradable plastics is increasing due to the availability of new types of raw materials [10].

There are several important arguments for the manufacturers encouraging improvements, which already have been substantiated in previous studies:

- Public and customer requirements [11] for sustainable and especially environmentally friendly solutions derived by regulations and quality management standards [12].
- Opportunity to stand out in the industry with innovations triggered by the adoption of environmental requirements asserted by the Porter hypothesis [13,14].
- Strategic goals and the motivation of companies to increase competitiveness and value by ensuring environmentally responsible and sustainable performance [15–17].
- Opportunities for the development of new sustainable business models and creation of revenue streams [18]
- Corporate social responsibility (CSR) program and the sustainability performance [19,20].
- Sustainable positioning of the company [20,21] and the green branding [22,23] as unique sales offers in the industry based on the product declaration or the Life Cycle Analysis (LCA) to avoid the "greenwashing" practice [24–27].

Unless the introduction of sustainable packaging has been shown to drive sales or reduce costs, companies, despite promoting their sustainability intentions, lack the business opportunity to pursue more sustainable packaging.

The circular economy emphasizes the importance of reuse and recycle principles rather than extracting natural resources. This means that previously used materials should be recovered and reused in different ways, thereby securing natural resources from overexploitation [28]. In turn, this requires the development of innovative technologies that allow the recovery of valuable materials [29].

At present, much more than before, the new sustainability transition has escalated the necessity of companies and their supply chains to reconsider the contribution to three important values—environmental, social, and economic: the so-called triple bottom line [30].

In the context of sustainable development, there is great potential for the cultivation and processing of durable natural fibers into new products. The demand for such products is increasing due to the growth of the level of education and well-being in developed countries [31].

Packaging has a major influence on sustainable consumption. The packaging value chain covers various industries and different actors in each stage of the value chain [32] (see Figure 1). The sustainable consumption value chain in this conceptual model consists of five main stages. The first stage in the value chain is Feedstock production & pre-treatment, which is represented by the source of the raw material: the farmer who is the supplier and processor of the raw material. This is followed by the Raw material processing and refining phase, which is represented by downstream processors of the raw material, who offer their processed products in several sectors. Packaging manufacturing is the stage where, using various technologies, the shape of the packaging is obtained and its characteristics are defined for further use. The product manufacturer uses this packaging to package its products as set out in its sustainable packaging strategy. The Retailer stage is represented by leading retailers of food, cosmetics, clothing, accessories, and other consumable products.

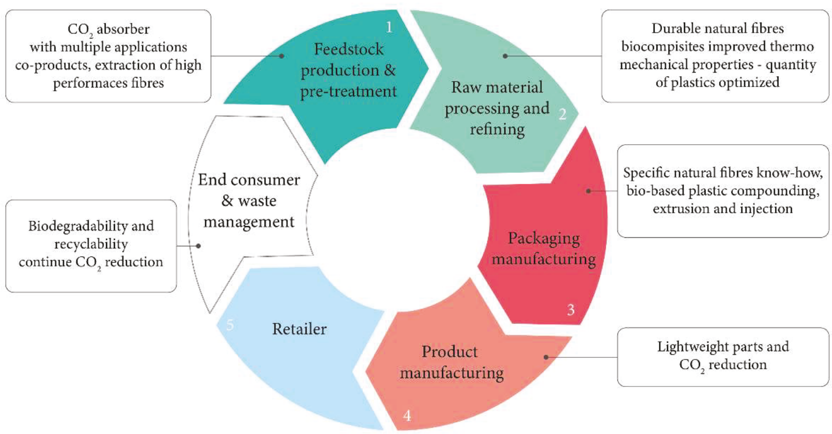

Figure 1. The conceptual model of the value chain of sustainable industrial consumption and related benefits from biocomposites (source: the authors).

This study has a particular focus on the investigation of sustainable preferences, consumption patterns, and derived challenges within the business-to-business (B2B) segment, namely, the industrial customers. Yet, the academic community has paid more attention to the sustainable consumption practices in the business-to-customer (B2C) segment expanding the scientific discourse on the consumption of individuals, their motivation factors to make pro-environmental and sustainable purchase decisions, while the sustainable industrial consumption is less studied [33]. This is strongly influenced by beliefs and the pro-environmental mindset of managers and owners of companies and their industrial partners [34].

This study aims to investigate the industrial consumption of biocomposite materials and the influence of the COVID-19 pandemic on the main stages of the value chain of sustainable industrial consumption of biocomposites. This research has a particular focus on the industrial stakeholders in the value chain until packaging reaches the end consumer. Thus, the end consumers and the waste management aspects have not been covered by this research, forming limitations and an avenue for future research.

This research contributes to the theory and practice regarding the enablers and challenges for the use of biocomposites in the further transformation toward more sustainable consumption. This study highlights the research gaps that still need to be investigated regarding the impact of COVID-19 on the sustainable consumption of end consumers and their changing behaviors that confront the traditional less sustainable practices of industrial consumers.

The paper is organized in the following sections: the second section provides an analysis of the literature. The third section explains the methodological approach and research methods applied within this study. The fourth section reveals the results of the exploratory research. The fifth section represents the interpretations of the main issues discussed and summarizes the implications stated. In addition, the conclusions, limitations, and the future research agenda are summarized in the last section of this article.

2. Literature Review

First, a comprehensive and non-systematic literature search was performed with Google Scholar to identify the most appropriate keywords and phrases in order to select the most appropriate literature and conduct a more accurate literature review. Based on the initial literature search and key concepts identified, we selected peer-reviewed articles from the SCOPUS database in order to conduct an in-depth literature review. In order to widen views and deepen the theoretical analyses, we purposefully added additional scientific articles (e.g., from Ebsco, Emerald databases, and other sources referenced by other researchers) [35–37].

Based on an in-depth literature review, this paper explores the related concepts of sustainable industrial consumption and the role of biocomposites within this area. The literature analysis provided an investigation of the overall insight and deeper artifacts from the academic debates into the relevant topics under investigation [38,39].

2.1. Sustainable Industrial Consumption

Within the literature review, publications were selected from the SCOPUS database using the keywords "sustainable consumption", with a particular focus on the business to business (B2B) or the industrial relationship. In total, 1238 publications were selected from the SCOPUS database using the following keywords: TITLE-ABS-KEY ("sustainable consumption") AND ("B2B" OR "Industrial"). A chronological analysis of the most common words was performed using VOSviewer grouping these keywords within clusters of interrelated keywords (Figure 2). At the beginning of the last decade, the research paid more attention to ensuring environmentally-friendly manufacturing [12,40–42], material flow [43–45], and resource efficiency [46–48] with its impact on the environment and climate change. The energy and natural resources were of particular interest [47,48]. The most common empirical research methods applied by the academic community are the input–output analysis [49], life cycle analysis [50], and statistical modeling of scenarios related to the footprint [51,52].

While in the previous decade, there was a significant interest in this field among environmental and engineering researchers, the scientific debate within the social sciences has been intensifying in the last 5 years in such disciplines as entrepreneurship, innovation, management, and marketing [53–55]. The academic community has widened investigation subjects to the adoption of practical tools and methods encouraging sustainable industrial consumption within organizations [56–58]. More importantly than before, researchers explore waste management from the perspectives of its recycling or use as a valuable resource for creating new products and the added value for the customer, shareholders of ventures, other stakeholders, and wider society [59–61]. Recently introduced research topics cover the sustainable value chain, new sustainable business models, the creation and delivery of sustainable value, and changes in the consumption patterns to more sustainable consumer behavior [54,62–64].

The most important trends within the scientific literature show that the term "sustainable consumption" appeared at the end of the last century, and its popularity has grown moderately over time. The dynamics can be linked to different political and historical events. In a broader sense, researchers link sustainable consumption with more specific patterns and habits for purchasing and consuming goods [65,66] or an introduction of the product service systems [67] or the sharing [68,69]. Armstrong [70] exploits the term "mindful consumption" where mindfulness strongly reflects the spiritual consciousness and higher moral values of consumers that lead to sustainable and pro-environmental purchase decisions.

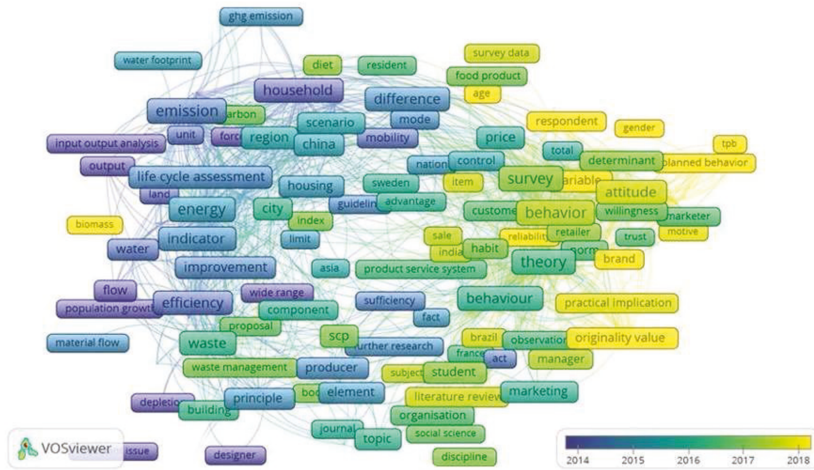

Figure 2. The overlay visualization of co-occurrence of keywords "sustainable consumption", "B2B", or "Industrial" based on the SCOPUS articles, which was created by the authors using VOSviewer (version 1.6.17).

Researchers consider that consumer behavior has a strong impact on the environment through consumer choices of products and services [71]. The scientific debate shows a consensus that sustainable consumption positively impacts the environment, reduces footprints, and contributes to the transition from a linear to a circular economy [72]. Researchers mostly analyze sustainable consumption within specific sectors or product groups, such as food, textiles, clothing, plastics, and energy [72–75].

Studies more often associate sustainable consumption with the consumption of individuals or households [65,66,76] but less with the industrial supplies into the business-to-business (B2B) segment, proving the existing gap within this scientific domain. The research on the consumption of industrial customers often leads to a discussion about the sustainable value chain or the sustainable supply chain. The term "value chain", which entered the colloquial language in the 1980s, experienced a surprisingly rapid rise in the mid-1990s and a real breakthrough at the turn of the century.

Scholars highlight the importance of industrial symbioses in the promotion of sustainable consumption to industrial customers [77]. Researchers are also seeking new business models and forms of collaboration that promote greener consumption, such as the sharing of resources or assets [78], product–service systems [67,79], online shopping, and digital services and platforms [80].

In total, 580 articles were selected within the SCOPUS database using keywords "sustainable supply chain" and "value chain" (TITLE-ABS-KEY ("sustainable supply chain") AND ("value chain")). The chronological frequency and interconnection of keywords were analyzed by VOSviewer, and the visualization of results highlights the main clusters of keywords (Figure 3). Porter [81] has laid an important foundation in the study of the value chain, explaining the stages of the value chain and their role in the development of the competitiveness and other economic factors of companies. While Porter describes the value chain within the firm or an industry level, Koval et al. [82] emphasize the economic relationships between the companies on the global scale of the value chain. The global and cross-sectoral economic relationships within the value chain are important factors in addressing the climate change and environmental threats [82]. The technological feasibility and economic interests of stakeholders are predominant factors to increase the value and achieve the competitive advantage. In a sustainable value chain, these factors must be balanced with environmental values. Accordingly, these factors often prevail as constraints for companies to develop a sustainable value chain, but they should be major within the sustainability policies [83].

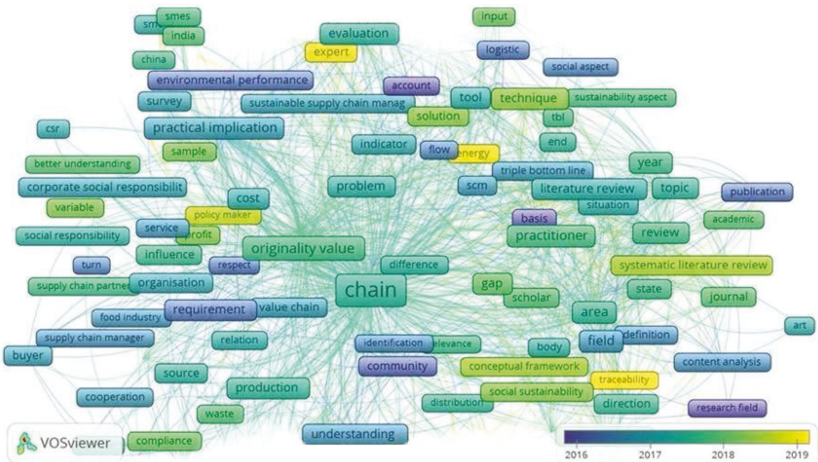

Figure 3. The overlay visualization of co-occurrence of keywords "sustainable supply chain" and "value chain" based on the SCOPUS articles, which was created by the authors using VOSviewer (version 1.6.17).

The chronological application of keywords reveals that in the middle of the last decade on sustainability issues in the context of supply chains, academic discussions were focused on environmental requirements as well as the footprint and the environmental performance of the manufacturers [37,84–86]. The food industry has been of large interest to researchers [85,87]. Moreover, geographically, the issues of India and China are most often discussed and reflected in the research. In recent years, sustainability issues have become increasingly important and analyzed in a much broader context [85,88].

Seuring and Müller [37] emphasized that the sustainable value chain envisages the integration of environmental and social principles in addition to the economically rational purchase and supply decisions; although often, the motivation to integrate environmental and social principles is derived from specific standards (e.g., ISO, TEQM) or government regulations. These researchers proposed the necessity of more transparent collaboration between the sustainable supply chain actors, allowing for the possibility to track and evaluate the performance, risks, and the clean, green, and lean aspects of production of raw materials [37].

Researchers Ahi and Searcy [89] argue that the sustainable supply chain means having a greater focus and coordination over the materials or product flows, encountering the involved stakeholders in a closer relationship, as well as keeping a strong streamline on the value, efficiency, and performance. Thus, the sustainable supply chain requires the management of the flows of materials, resources, finances, and information, paying specific attention to engagement with collaborative networks as well as the economic value and also the creation of environment and social values, thus leading to more satisfied customers. Ahi and Searcy [89] highlight that the sustainable value chain incorporates the economic, environmental, social, stakeholder, volunteer, resilience, and long-term strategies or business directions. These are not just declarative statements but important issues that should be observed and adopted in any organization belonging to the sustainable supply chain [89].

2.2. The Sustainable Industrial Consumption of Biocomposite Materials

Ngram Viewer allows conducting the content analyses by tracing the frequency of the selected concepts and keywords (plastic waste, biocomposite, microplastic) during the specified time period (since the year 2000). Ngram Viewer digitalized how often these selected terms or concepts appear in digitalized texts of the literature accumulated within Google, in particular, Google Books [90].

Accordingly, the analytical information of Ngram Viewer demonstrates that the topicality of the term "biocomposite" has been dynamic since the late 1970s until the turn of the century, then showing a rapid increase, especially from 2013. For comparison, studies on "plastic waste" have been investigated since the middle of the last century. It should be highlighted that, simultaneously with the rapid rise of the use of the term "microplastic", the curve of "biocomposite" also increases in parallel.

The use of all three researched concepts has grown rapidly over the last ten years (see Figure 4). This justifies the wider applicability of these terms in the theoretical or scientific literature and other sources used by practitioners. In the figure, the horizontal axis indicates the specific time period, while the vertical axis shows the rate of the occurrence of that particular concept or keyword from all search strings (so called n-grams) in a particular year [90].

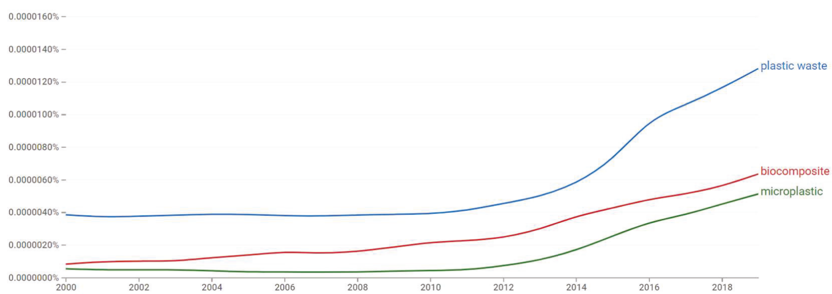

Figure 4. The frequency of using keywords "biocomposite", "plastic waste", and "microplastic", which was created by the authors with Ngram Viewer.

The analytical results of the Ngram Viewer screening verify and confirm the relevance and significance of selected concepts and keywords for the further in-depth literature review. Given that "what makes the Ngram Viewer a valuable research tool is not primarily its accuracy, but rather its potential for quick-and-dirty heuristic analysis" ([90], p. 9), this illustrates the dynamic changes and trends on the interest of particular terms, keywords, and concepts.

The creation of a model of sustainable industrial consumption that would help reduce the environmental problems associated with conventional plastics, including microplastic pollution in habitats, still seems a utopian idea in the near future, given that conventional plastics (polypropylene—PP, polyethylene terephthalate—PET, high-density polyethylene—HDPE, etc.) play a key role in the economy [91].

While the world is struggling with the recycling of conventional plastics, another way to respond to this problem would be to develop and use bio-based or biodegradable plastics as a sustainable alternative to petroleum-based plastics [92]. These materials mainly help to preserve fossil reserves by replacing fossil carbon. They also provide additional benefits: biocompatibility, biodegradation, and carbon dioxide (CO_2) sequestration, which are important for reducing global warming [93].

It is important to emphasize that the terms "bio-based plastic" and "biodegradable plastic", which are often used in the scientific literature, are fundamentally different. Biodegradable polymers are materials that are capable of degrading when subjected to aerobic, anaerobic, or microbial processes. Biodegradability can be defined as the ability of compounds to degrade completely under the influence of various factors, including the size, thickness, and composition of the material. However, it should be stressed that bio-based plastics are produced from renewable sources and can be either biodegradable (e.g., polymerized starch or polylactide) or non-biodegradable (e.g., bio-polyethylene), which is a significant part of the environmental impact assessment. It should also be mentioned that bio-polyethylene is only recyclable for a few cycles until it significantly loses its original properties [94,95].

Many initiatives have been introduced to promote the concept of sustainable packaging. The Sustainable Packaging Coalition (SPC) in 2011 formulated the industry-accepted definition of seven conditions specifying the following seven criteria for sustainable packaging [96]:

- Beneficial, safe, and healthy for all individuals and communities throughout their life cycle;
- Meets market criteria for performance and costs;
- Obtained, produced, transported, and processed using renewable energy;
- Produced using renewable or recycled raw materials and clean production technologies;
- Made of harmless materials in all possible end-of-life scenarios;
- Designed to optimize used materials and energy consumption;
- Recovered and utilized in industrial and/or biological cradle-to-cradle or closed-loop cycles.

The SPC definition is widely recognized and includes the functional, environmental, and technological dimensions of sustainable packaging. Therefore, sustainable packaging may protect the product and communicate its properties, including reusing materials and reducing waste throughout the packaging life cycle from production to consumption, as well as during the disposal and post-disposal phases [97,98].

Sustainable packaging has to be designed with innovative bio-based plastic packaging materials and meet the following parameters:

- The materials must be optimized to improve the shelf life of the product;
- The packaging should be intended for recycling;
- Bio-based materials should be efficiently produced from the second-generation feedstock.

Monoplastic materials are preferred because the recycling of such packaging material preserves functional properties and chemical safety. The sum of the climate and environmental impacts of packaging/food systems should be assessed throughout their life cycle and reduced to the chosen design [99,100].

Designing a more sustainable food packaging is a difficult task, as many different parameters need to be considered. Life Cycle Assessment (LCA) tools are available and should be used to quantify and compare the environmental impact of different types of packaging, considering the overall product framework. LCA should be able to make informed and holistic decisions about how to improve the sustainability of food packaging [50,100].

Some of the factors hindering the introduction of more sustainable packaging solutions on the market are consumer awareness of unknown technologies, costs, regulatory issues, and the belief that sustainable packaging fails to protect food (e.g., moisture barriers) [100].

With the introduction of the concept of sustainable development, there is also a rapidly growing interest in the use of biodegradable polymers in the production of new composite materials [101,102]. One of the fastest-growing industries is polylactic acid, which differs from the commonly available form of thermoplastic polymers. It is mainly derived from renewable resources such as maize starch or sugar cane [103].

Recently, during the COVID-19 pandemic, consumers showed an increased desire for their personal safety and health [104,105]. This affects the safety standards and requirements for packaging materials, and in addition to the flexibility or rigidity, the durability or physical integrity of materials; thus, there is a growing interest in the use of sustainable and natural materials [8,106,107]. It means that at the same time, while considering the possibilities to adopt sustainability characteristics, the packaging materials must provide adequate isolation properties against water vapor, gases, odors, and other protection against various external factors. Polylactic acid (PLA) is one of the most recognized biodegradable materials [108], which is not only used in the food industry but also in the biomedical and pharmaceutical industries [109,110]. As reported by Cohn et al. [111], PLA is recognized as safe for use in the food contact. Nevertheless, the final properties of PLAs may vary and depend on their chemical–physical, barrier, thermal, and mechanical properties. These properties can be adapted to the intended use by altering the structure of the PLA (amorphous and crystalline ratio, different meso-lactide ratio, and molecular weight) [108].

Previous research [8,107,108] proved that biodegradable polymers are promising and potentially in-demand materials not in the near future but already in the reality of today's packaging and delivery systems. However, there is still a scope to explore ways for improving the applicability of these materials, both in terms of their characteristics of the technical feasibility and in terms of their desirability and cost-effectiveness to use them by various industries. The main advantage of biocomposite materials is found not only in their natural origin but also in providing a closed circle "from nature to nature" as these materls decompose into the naturally occurring components.

2.3. Role of Biocomposites in Industrial Consumption

In order to conduct further in-depth literature analysis, in total, 1361 articles were selected within the SCOPUS database using keywords "biocomposite" and "biopolymers". The interconnection of keywords was analyzed by VOSviewer, and the visualization of results highlights the main clusters or concepts explored most often in the previous studies. The following picture demonstrates the chronological frequency and interlinkage of the keywords applied in the research (Figure 5).

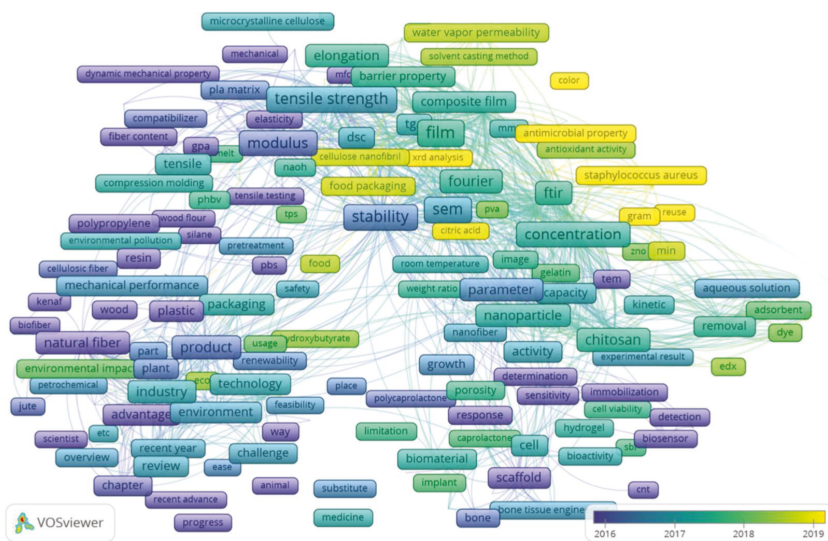

Figure 5. The overlay visualization of co-occurrence of keywords "biocomposite" and "biopolymer" based on the SCOPUS articles, which was created by the authors using VOSviewer (version 1.6.17).

Industrial production based on non-renewable resources, a growing demand for end products, a rapidly growing population, and density are all placing an increasing burden on the resources, and all types of pollution are proliferating at an alarming rate. Consequently, more and more attention is being paid to sustainable economic development by using new natural materials. High hopes are placed on the development of composites reinforced with natural fibers and the versatile use of materials based on non-renewable raw materials [102].

The non-degradable nature of conventional plastic waste in ecosystems has increased consumer interest and scientific research into more environmentally friendly bio-based plastic materials and biocomposites [111]. Due to the advantages of recyclability, lightness, and cost-effectiveness, biocomposites are of interest to researchers in the field [111–114]. Biocomposite constituents such as bio-based polymers and fillers are obtained from renewable natural sources and can serve as a possible replacement for oil-based non-renewable plastics [115]. Biocomposites are reasonably less likely to have an impact on the environment and therefore are considered safer for both human and other living habitats. In addition, most of them are recyclable and reusable. One of the most important benefits of biocomposites is that these materials have a manageable potential at the end of disposal [116]. Biocomposite raw materials are divided into two groups: the first group of raw materials is wood (their use in larger quantities can lead to deforestation and affect biodiversity), while the second group of raw materials is lignocellulosic waste or production by-products collected from food, forest, and agricultural residues. Until now, the second group of by-products has been used for the development of biocomposites, although their commercialization is still limited. Extensive research in the field of biocomposites has led to the development of various types of biocomposites [117].

The role of the reinforcement phase in biocomposite material is to increase the mechanical properties of the polymer matrix system, with different reinforcements having different properties, thus influencing the composite properties in different ways [118]. The need to improve and stimulate rural economies as well as reduce the world's dependency on petroleum-based materials has resulted in much interest and focus on the use of various varieties of natural fibers as reinforcing agents for composite materials [119]. The high strength, availability, low cost, sustainability, and eco-friendly characteristics of natural materials such as agricultural waste make them quite beneficial and efficient as reinforcement for composite materials [120]. Other advantages of natural fibers over synthetic fibers include their acceptable specific properties, ease of separation, and enhanced energy recovery. These advantages of natural fibers (flax, hemp, kenaf, henequen, banana, oil palm, and jute) over synthetic fibers have given lignocellulosic fiber substitutes huge potential for synthetic fibers. In contrast to synthetic fiber-based polymer composites, natural fiber-based composites can be disposed of easily or composted at the end-of-life stage without polluting the environment [121,122].

The commonly used natural feedstocks for biocomposites are flax, hemp, jute, and sisal (see Table 1). There is growing market interest in the use of hemp fiber for a variety of applications due to its quality, availability, and cost. Hemp is a sustainable multi-purpose crop, because it is possible to use all parts of the plant efficiently. Hemp-based materials are reusable, biodegradable, and/or compostable, which helps in achieving the goals of the EU Circular Economy Action Plan and initiatives to stimulate lead markets for climate-neutral and circular products in energy-intensive industrial sectors [10].

Hemp fibers are one of the most environmentally-friendly natural fibers with high tensile strength; they retain their strength in the wet state and other properties that make them suitable for a variety of industrial products. Therefore, hemp is one of the most promising sources of renewable resources to replace non-renewable components in a wide range of industrial products. From the point of view of the concept of sustainable development, the advantage of hemp fiber extraction is that it is possible to use all parts of the plant to produce different products at the same time—hemp seeds, their shells, hemp stalks, thus maximizing their added value. Combining natural fibers in the composite with a matrix derived from natural products succeeds in solving one of the most important problems of the century—preserving the viability of the environment [123].

The European Industrial Hemp Association [124] reported that hemp could allow us to capture and store significant amounts of CO_2. One tonne of harvested hemp stem corresponds to 1.6 tonnes of CO_2 absorption. Based on land use, using an average yield of 5.5 to 8 t/ha, this is 9 to 13 tonnes of CO_2 absorption per hectare harvested. Hemp cultivation requires little or no resources, and it has a positive impact on soil and biodiversity. As all parts of the plant can be used or further modified, its treatment does not generate waste. Beneficial effects can also be seen in future crops in this soil: studies have shown that wheat yields have increased by 10 to 20% since hemp cultivation [124].

Table 1. Property comparison of the commonly used fibers for biocomposites, created by authors based on [122].

Fiber Type	Flax	Hemp	Jute	Sisal
Density (g/cm^3)	1.4–1.5	1.4–1.5	1.3–1.5	1.3–1.5
Tensile Strength (Mpa)	343–2000	270–900	320–800	363–700
Tensile Modulus (Gpa)	27.6–103	23.5–90	8–78	9–38
Specific Modulus	45	40	30	17
Elongation to Break (%)	1.2–3.3	1–3.5	1–1.8	2–7
Cellulose (wt %)	62–72	68–74.4	59–71.5	60–78
Hemicellulose (wt %)	18.6–20.6	15–22.4	13.6–20.4	10–14.2
Lignin (wt %)	2.3	3.7–10	11.8–13	8–14
Moisture content (wt %)	8–12	6.2–12	12.5–13.7	10–22
Cost per weight (EUR/kg)	8.0	1.1	0.3	0.9

New composite materials are constantly being developed in the world, which envisages a wide range of applications. Biodegradable composite material from hemp fiber and polylactide or polymerized corn starch provides the necessary mechanical properties for a wide range of applications, and also the material development technology is suitable for products of various shapes and scales.

Biocomposites are innovative materials consisting of an environmentally friendly polymer matrix and reinforcing fibers and are currently an alternative to traditional composite materials. These materials have a wide range of applications. For biocomposites to be classified as biodegradable and green, they must comply with the principles of Green Chemistry, which is part of the concept of sustainability [125]. To integrate the SDG with biocomposites development and consider them sustainable materials, the acceptance of Green Chemistry principles plays a fundamental role [126,127]. Natural fiber-reinforced PLA biocomposites have potentially valuable properties such as their low density, low cost, and reduced solidity when compared with synthetic biocomposite products [108].

Biocomposites could be classified as bio-based only when both their constituents originate from natural resources. However, it is defined as a green material if the polymer matrix is derived from biomass or petroleum-based sources, and at the same time, the biocomposite is biodegradable [128]. Chemat et al. [128] reported that a relevant example of the petrochemically-derived green biocomposite is poly (ε-caprolactone) (PCL), which is sourced petrochemically, and yet, it is completely biodegradable by aerobic/anaerobic biological processes to carbon dioxide, water, methane, and biomass. It should be noted that the concepts of biological and green should not be confused with "sustainable" biocomposites, which take into account not only one or two aspects, but the whole life cycle of the composite, from cradle to grave [129].

The biocomposite development process could involve the use of biotechnological methods to replace the non-renewable resources, using low-impact manufacturing chemicals and methods, and utilizing waste and recycled content to contribute to circularity. According to this definition, a sustainable biocomposite could be one that contains at least one naturally derived ingredient, and the overall impact of the biocomposite throughout its journey from production to consumption is considered positive without interfering with the environment [129].

Sustainable industrial consumption has been at the core of the Sustainable Development Goals (SDGs). It clearly emphasizes resource efficiency, the minimization and potential use of waste, as well as the minimal use of hazardous substances, also the integration of environmental and social responsibility.

3. Materials and Methods

This section describes the methodological approach and research methods used within this study (see Figure 6). The main research tasks are as follows:

- T1: To develop the cognitive model of main stakeholders and processes of the value chain of the sustainable industrial consumption of biocomposite materials;
- T2: To investigate the influence of the COVID-19 pandemic on the sustainable industrial consumption of biocomposite materials;
- T3: To substantiate the research based on the integration of economic, business management, and natural-science perspectives and justify the interdisciplinary conceptual basis for further research.

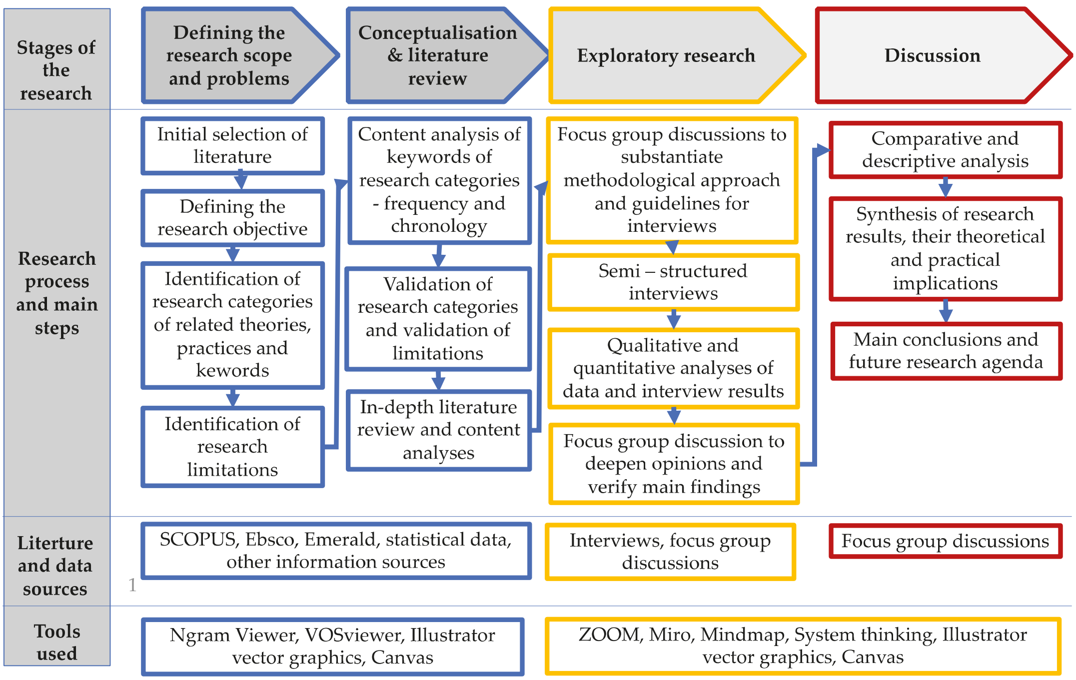

Figure 6. The methodological framework of this research (source: the authors).

The methodology of the research was based on the literature review, the content analysis of the literature, the focus group discussions, and expert semi-structured interviews. Using the descriptive analyses and the system thinking approach, the cognitive model of the process and main stakeholders of the sustainable consumption value chain has been visualized and described. The comparative analyses were applied to investigate empirical practices in the recent changes in the consumption patterns of industrial consumers.

To answer the research questions, the exploratory qualitative research was conducted, which helps to analyze the importance of biocomposite materials in sustainable industrial consumption and the impact of COVID-19.

The semi-structured interviews were conducted, transcribed, and classified. Semi-structured interviews are commonly applied in the studies related to the sustainability and the circular economy [30,130,131]. The purposive sampling method [132] was used in the selection of informants for the interviews. In the beginning, a sample of informants was created based on the following criteria: (1) deep knowledge and expertise, (2) the comparatively high degree of involvement or engagement in the value chain, and (3) the position and the role in the process of the sustainable production of the biodegradable composite.

In order to ensure reliability and competency in assessing and selecting potential informants, several focus group discussions were organized. Using the snowball sampling principles [133], during the interviews, informants were asked to suggest other important stakeholders or experts that should be included in the sample of interviews, thereby enriching the list of informants, based on the initial set of the criteria defined for the informants. In total, 10 interviews with an average duration of 60 to 120 min were conducted by phone or video calls (e.g., using zoom) were conducted (see Appendix A). All interviews were recorded for further data analyses and processing.

The selected sample of interviewees represented industrial actors related to the consumption of biodegradable composite materials. The interviewees were industry experts who had represented the industry on a long-term basis and could provide a comprehensive insight into it. These are both global and local companies representing the food, cosmetics, fashion, and furniture industries. All interviewees were related to the European market.

The structure of the questions of interviews is presented in Tables 2 and 3. The interview questions consisted of two parts: (A) and (B). While part (A) revealed the general profile of the interviewee, part (B) collected opinions; the main research questions included such topics as EU Green Deal guidelines for industry, how consumer behavior affects industrial consumption during COVID-19, insights into the use of biocomposite materials at each stage of the value chain, and possible impacts of the COVID-19 pandemic.

Table 2. The structure of the questions of interviews—Part: A—Interviewee Profile.

Label Codes	Questions	Types of Responses
A-IQ1	Represented sector/industry/field	Open
A-IQ2	Size of the company	Open: turnover in EUR
A-IQ3	Role in the sustainable production chain	Closed: #1 Feedstock production & pre-treatment; #2 Raw material processing and refining; #3 Packaging manufacturing, #4 Product manufacturing, #4 Retailer
A-IQ4	Field of expertise/position	Open

The interview questions were piloted with several researchers before being given to our sample. The analyses of the interviews were performed in two stages. First, to ensure the validity and quality of data processing, the interviews were coded after being recorded and transcribed. After the coding, we proceeded with the data analyses through the detailed analyses of all questions by each interviewee and comparing the opinions of informants in each question discussed during the interview. The main results and conclusions of the analyses were synthesized.

This research has a particular focus on the industrial consumers of the value chain, excluding end consumer and waste management stages, specifying the limitations of this paper. Accordingly, the chosen methodology was adapted to assume these limitations and keep the focus of the research aim following methodological approaches kept by previous studies [134–138]. The literature analyses provides deeper insight into the nature and characteristics of concepts investigated. The exploratory research with semi-structured interviews and focus group discussions investigated the practice of companies regarding the sustainable industrial consumption and established the relationship of the potential impact of the COVID-19 pandemics.

This study was performed applying the multi-disciplinary approach by composing the expertise of the business management, engineering and material sciences, as well as the earth and environmental sciences. The lack of such multi-disciplinarity has been identified by previous research [139,140], and this study addresses this research gap. This multi-disciplinary approach allowed the sustainable industrial consumption chain to be empirically analyzed in an in-depth and contextual way and to develop a conceptual model in order to reflect on the practices of the industrial sustainable consumption of biocomposite materials.

Table 3. The structure of the questions of interviews—Part: B—Main questions.

Label Codes	Questions	Types of Responses
B-IQ1	The general perception of the EU Green Deal Strategy and the sustainability goals within the industry	Open
B-IQ2	The general perception of the sustainability principles within the company of the interviewee and its value chain	Open
B-IQ3	The adoption/introduction of the sustainability principles into the practice of the company of the interviewee and its value chain	Open
B-IQ4	If and how consumer behavior affects industrial consumption during COVID-19	Open
B-IQ5	The general intention and the practice regarding the use of biocomposite materials	Open
B-IQ6	The opinion about the functionality, technological feasibility, environmental, and economic aspects of the sustainable packaging and, particularly, the use of biocomposite materials	Open
B-IQ7	Any changes observed within the use of biocomposite materials during COVID-19	Open
B-IQ8	Possible impact of COVID-19 on the use of biocomposite materials at each stage of the value chain (stages: #1 Feedstock production & pre-treatment; #2 Raw material processing and refining; #3 Packaging manufacturing; #4 Product manufacturing, #4 Retailer)	Closed: Positive, neutral, negative

4. Results

The interview results reveal that the impact of external forces such as a change of consumer values, pro-environmental regulations, technologies, and new risks would require industrial consumers and packaging manufacturers to focus more on the use of raw materials and biocomposites. Recently, the food, cosmetics, and clothing sectors have been facing increasing importance of the problem regarding packaging sustainability. This is causing a growing interest in the use of biocomposites. Suppliers and processors of raw materials are forced to review, optimize, and adapt production processes in the direction of sustainable transition. It is important for industrial consumers to be fully aware of, and for the manufacturers to be able to justify, the origin of the raw materials. Such an assumption is supported by plans to introduce a declaration of origin (DoO) for products in the coming years. The participating stakeholders in a supply chain will be held responsible for arranging the respective flow of information, ensuring that every raw material is substantiated by a DoO. This will be facilitated by implementing strict requirements and regulations by the governing organizations.

The insights gathered from expert interviews have been used to develop the conceptual model for estimating the influence of COVID-19 on each stage of the value chain of sustainable industrial consumption of biocomposites (see Figure 7). The results show positive impact (green arrows in Figure 7) for the first three stages of the value chain, neutral impact for the Product manufacturing stage, and negative impact for the Retail stage. More details on these impacts are described in the following paragraphs.

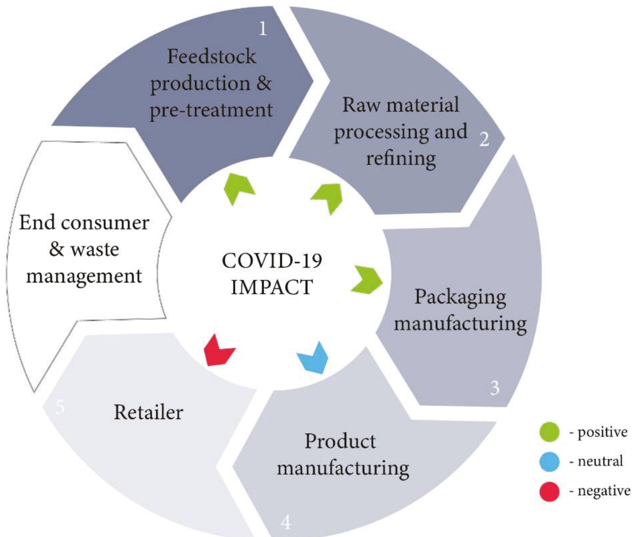

Figure 7. Conceptual model estimating the impact of the COVID-19 pandemic on the use of biocomposite materials within each stage of the value chain (source: the authors).

4.1. Feedstock Production and Pre-Treatment

Conclusions from the interviews reveal that the impact of COVID-19 on this stage of the value chain is generally positive. There is a growing interest in high-quality natural fiber raw materials and the use of hemp by-products. Experts have confirmed that hemp-based packaging has potential since no major material producer has introduced hemp-based packaging so far. Hemp producers would support the provision of hemp as a feedstock to be utilized for hemp packaging production purposes.

Feedstock production industry representatives reflect that the capacity to grow hemp in the Baltic states would be sufficient given that the relevant price is paid by the manufacturers or raw material buyers. In addition, it would be more advantageous, and the final fiber price would be better if both fiber and spools were sold.

An automotive industry expert indicated that there are already several car manufacturers, such as Tesla, who are developing saloon interior components that are made of composite materials, which include hemp. New solutions for integrating biocomposite materials into automotive engineering are also being developed; however, they are likely to be available on the market in several years.

4.2. Raw Material Processing and Refining

Overall, the impact of COVID-19 has not been negative due to increased demand for consumer products, while the introduction of new component product lines has been delayed.

Due to the continuity of production processes during COVID-19, the employees of the conversion and formulation units (manufacturing and technical staff) have been working as usual, while the employees of the R&D department worked remotely. Therefore, the development and introduction of new products to the market was delayed and took longer than previously.

The consumption of organic and plant products has grown very rapidly over the past year; for example, the German market has grown by about 20% (it was 6–8% in previous years), and the Scandinavian market has grown by 30–40%. It has been pointed out that this is a huge challenge for supply chains and a risk for suppliers of organic raw materials, as there are companies that are starting to replace growing demand with imported organic raw materials. However, it is becoming increasingly important for the consumers that the product is locally sourced and otherwise organic rather than using organic imports.

> *"Maybe in some extent, we are much prepared for pandemic time and new customer trends—healthy, natural, and with traceable or local materials than other entrepreneurs that are currently dependent on limited supplies of specific materials"*
>
> (an interviewee—I8)

4.3. Packaging Manufacturers

The responses reveal that the impact of COVID-19 at this stage of the value chain is generally positive and the interest in packaging made from biocomposites is growing.

Representatives of the food packaging industry pointed out that in the context of climate change, the public increasingly wants to see manufacturing companies doing business in a sustainable way that does not harm the environment. When it comes to health, safety, and the environment, food packaging manufacturers, along with end consumers, are keen to take control if chemical companies really practice what they preach and correspondingly can attest to the credibility of their communications.

Cosmetics packaging manufacturers indicated that brands selling natural cosmetics also prefer environmentally friendly packaging. On the other hand, the cosmetics (end product) manufacturing trends are currently focused on simplicity—fewer ingredients, concentrated composition, addressing a specific problem.

The cosmetics packaging manufacturing industry is also considered to be less sensitive to the price of packaging. Packaging manufacturers understand that it is important to offer a quality product and also relevant packaging that delivers on what has been promised to the end customer. At the same time, the cosmetics packaging industry is very complex—as technical and complex as food packaging manufacturing.

The demand for biodegradable packaging in the cosmetics industry is huge. Currently, all cosmetics manufacturers are looking for packaging solutions that are recyclable or alternative materials that do not contain microplastics. If the packaging is biodegradable, impermeable, and does not contain microplastics, there will be huge market demand for such packaging.

Conventional flexible plastic packaging is a rapidly growing segment, yet historically, less than 4% of flexible packaging is recycled. Flexible plastics are the leading polluting source to the oceans, with a minimum of 5 M tons (of 11 M) being disposed of each year into the sea.

The overall results of the interviews show that there is rapidly growing interest from product manufacturers toward biodegradable packaging, especially over the recent years.

4.4. Product Manufacturers

The impact of COVID-19 has been evaluated as neutral by product manufacturers. Informants of the interviews confirm that entrepreneurs following the sustainability shift continue this development direction also during COVID-19.

> *"We continue to work with eco and sustainability issues as we did it before. It may take 3 or 4 years from the idea of the new product to the production and sales requiring more time than prior to COVID-19"*
>
> (an interviewee—I5)

Packaging is considered to be an important sales tool by product manufacturers and the first opportunity to educate the consumer. For instance, the type of packaging for eco products is being selected by cosmetics manufacturers based on brand values and the requirements of the ECOCERT standards for eco-cosmetics.

This implies that only recyclable plastics or materials that decompose relatively quickly may be used. Cosmetics manufacturers choose the packaging according to the design and feeling that occurs when using the product packaging. The packaging must be convenient and easy to use. For instance, it is important that customers hear a nice click when the button is pushed and that the lipstick cases have a magnet. Product manufacturers confirm that the price of packaging is not the most important aspect. Instead, the composition of the packaging and its compatibility with the product is first assessed. At least several samples are tested before the right product packaging is selected, as one needs to make sure that the packaging meets all the manufacturing and end-user requirements. Manufacturers also evaluate the life cycle of the packaging including the process of obtaining raw materials and select the material that is the most environmentally friendly.

4.5. Retailers

The impact of COVID-19 has been evaluated as negative by retailers. Remote work and lockdowns in various countries have caused considerably bigger demand for e-commerce and online shopping, which in turn has caused higher demand for additional packaging that is required for shipping purposes to secure products from damage in transit. Thus, the negative impact is due to the increasing costs that retailers are required to cover for extra materials on packaging in comparison to the traditional in-store shopping requiring less packaging.

Since supply chains in the coming years will have the task of arranging the flow of information to substantiate the use of any raw material by a declaration, it is likely that it will be increasingly important for the retailers to justify the origin of the packaging materials, as this will be determined by strict regulations in the future.

Circular economy strategies are advancing faster than ever before because it is likely to become mandatory for retailers and other value chain members in the upcoming 10 years. For instance, for the furniture retail sector, the sustainability elements and requirements to be met are already included in part of the product profiles. In addition to the introduction of sustainability aspects in furniture production, companies are already actively abandoning disposable plastics for retail space, and only recyclable plastics are available in stores.

5. Discussion and Conclusions

The study found that the pandemic has left a positive impact on feed-stock producers, raw material producers, and packaging manufacturers due to an increase in online shopping that requires additional packaging, while product manufacturers felt no major impact. However, a negative impact has been left on retailers that experience increasing sales over online sales channels that correlate with a shipment of goods with courier delivery requiring additional packaging in comparison to the traditional in-store consumption.

Those companies that had previously taken the approach of the gradual transition toward the sustainability principles and the use of biodegradable materials are now continuing this process at an even faster pace and are generally a step further. That means that other value chain members will have to adjust respective internal processes and change, as this will be determined by the requirements of international regulations. For companies that have already started this sustainability shift and developed a sustainable strategy for the company several years ahead, the transition will be easier.

The use of the biocomposite materials within the sustainable value chain has mostly been related to the choices to adapt and introduce sustainable packaging. Based on previous efforts of researchers [98,100] and professional organizations in defining the criteria of the sustainable packaging, the following matrix (see Table 4) has been proposed by this study, which integrates the functional, technologically feasible, environmental, and economic dimensions with the criteria of the sustainable packaging [97] and the sustainable supply chain [33]. For the successful promotion of the sustainable value chain and thus, in general, cleaner production, it is important to balance all four dimensions [141].

The analyses (Table 4) show which of the four dimensions are more explicitly influenced by each of the sustainable consumption criteria, thus indicating the dominant areas for managerial decisions to evaluate packaging options and opportunities for more sustainable supply chains. These dimensions highlight four directions of the implications and contributions to be addressed to managers and owners of businesses, practitioners or experts, policymakers, and other stakeholders. The environmental dimension is explicitly dominant and is strongly followed by the economic dimension. Pournader with co-authors [33] argue that the economic issues are the major drivers impacting managerial decisions, but environmental and sustainability issues are becoming important and bringing larger opportunities within the sustainable supply chain. Meanwhile, the functionality and technological feasibility plays a lesser role in the industrial consumption within the supply chain. The current technological advancement allows to reduce the importance of these issues in the strategic decision-making of managers, but these issues still are relevant for individual consumers and product end-users in the B2C consumption.

Table 4. Matrix of criteria and dimensions of the sustainable packaging.

Criteria for Sustainable Packaging	Dimensions of Sustainable Packaging			
	Functional	Technologically Feasible	Environmental	Economic
1. Safe and healthy for all individuals throughout their life cycle	X		X	X
2. Meets market criteria in terms of its performance and costs				X
3. Obtained, produced, transported, and processed using renewable energy		X	X	X
4. Produced using renewable or recycled raw materials and clean production technologies		X	X	X
5. Made of harmless materials in all possible end-of-life scenarios	X		X	
6. Physically designed and validated to optimize used materials and energy consumption		X	X	X
7. Fully recovered and utilized in industrial and/or biological cradle-to-cradle cycles	X		X	

It is essential for the development of a sustainable value chain to identify and map various stakeholders to acknowledge those who can positively contribute to the development of sustainability principles within the industrial consumption as well as identify those stakeholders who will be positively or negatively affected [83]. This will allow for a more comprehensive planning and design of sustainable business activities to meet the interests and needs of various stakeholders and the involvement of the most engaged stakeholders within balancing economic and environmental values, and developing the sustainable value chain.

Dangelico et al. [142] believe that with the growing number of green products in the market or green branding strategies, companies far more than ever before should acknowledge the concept of sustainable industrial consumption, sustainable packaging and, in general, the green behavior of consumers.

The Europe Commission released key data on the behavior of consumers in 2020. Some of the main findings were that 56% of consumers said environmental concerns influenced their purchasing decisions and 67% said that they bought products that were better for the environment, even if such products were more expensive. From this, we can conclude that these could be one of the main signals influencing industrial consumption trends [10].

The growing demand for the use of natural resources in the manufacture of biocomposites reflects the need for the circular economy for biocomposites while allowing them to be recycled and reused. It is noted that the development of biocomposite materials must be integrated into a circular economy model to ensure environmentally friendly and sustainable production. Such a conclusion supports the findings of the current research and the value chain member aims to achieve sustainable manufacturing processes [114].

The interest of industries in using biopolymers is also fueled by the sharp rise in the price of fossil-based raw materials (PP, HDPE, etc.) in recent months, as shown in Figure 8.

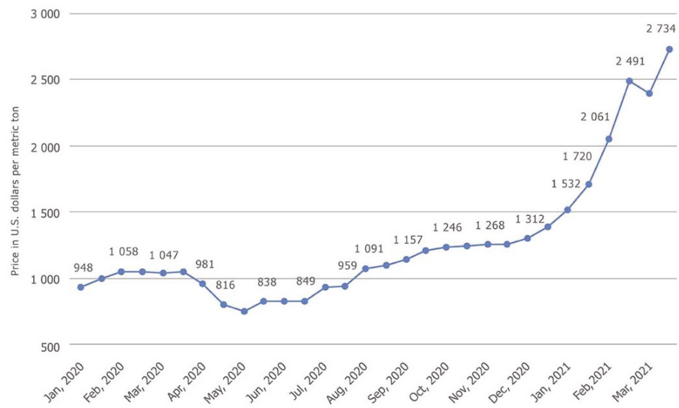

Figure 8. Global price increase in polypropylene (PP) from January 2020 to March 2021 (source: the authors based on [143]).

During the pathway toward sustainable materials use within industrial consumption, it is essential to recognize and address existing barriers and challenges. Researchers [144,145] have identified the main groups of barriers that currently hinder the development of sustainable value chains: among them, the insufficient critical mass of the production of sustainable plastics, relatively low demand for sustainable materials, lack of the economic justification and the technological feasibility for the development of recycling in this area, the comparatively high production costs, as well as a lack of proper technical and functional features, such as thermal instability as well as high oxygen and water vapor permeability. These are further issues relevant for both the academic society in planning future research directions with, for instance, the action research and experimentation methods aiming at the demonstration of practices and proving the feasibility and viability of the use of biocomposite materials. In addition, the desirability of industries to adopt new practices in using the biocomposite materials is essential and needs to be promoted, which is highly dependent on the technological possibilities and the economic interests of stakeholders. Researchers [144] have proposed various solutions that should help in this transition, including the following: (1) changing the general business mindset from the "firm-centric" or solo-preneurship practice to collaboration; (2) competing not with the price of products but the value proposition of the sustainability benefits and the general green nature of products; (3) reorganizing material flows and smart material solutions; and (4) companies sharing assets and developing common infrastructure instead of solely developing their own technologies.

The conceptual model developed above will require cross-functional coordination and collaboration. The COVID-19 pandemic has significantly strengthened the digital capacity of different sectors [146]. These lessons learned and newly obtained digital capacities should be used for the adoption of digital technologies throughout the value chain encouraging innovations as well as more efficient and smart use of materials.

The COVID-19 pandemic has reduced various business activities and general consumption, leading to decrease in emissions; however, this progress is more due to the slowdown in economic growth [147]. The COVID-19 pandemic has created or exacerbated a number of consumption trends that business representatives should acknowledge and escalate in the future, including health, sustainability, the circular economy [145]. The adoption of these trends are outstanding issue within the packaging and in the supply chain as a whole.

Climate-neutral packaging and the product as a whole are expected to receive increasing attention in the near future not only for marketing purposes but also to improve their competitiveness and reduce the cost of the natural resource tax. It is important to pay attention to the promotion of innovative industrial processes and the development of new technologies as soon as possible in order to stimulate the wider adoption and use of biocomposite materials [148].

The likely implications on business and policy and consumer trends are related to the need for the higher transparency and traceability of each process including the value chain of the sustainable consumption of renewable and biodegradable composite materials. For example, this could manifest as growing expectations between B2B suppliers and customers for the traceability of the material and product origin, increasing the public discussion of end customers in social networks and online media by retail customers regarding the use of specific materials and their origin. This is also likely to be the subject of research in the near future. In this context, the discussion on different aspects related to greenwashing should take place more often.

It is important for both smaller and larger companies now to think a step forward, implement a sustainability strategy, plan LCA in the development of new products, and thereby improve their competitiveness in the future.

The companies willing to move toward the sustainable industrial chain will have to incorporate economic, environmental, social, stakeholder, volunteer, resilience, and long-term directions within their strategies. The importance of all these issues and the necessity to adopt them is crucial in any organization belonging to the sustainable value chain [83,89].

Within such grand challenges as the COVID-19 pandemic, social issues related to general resilience first become crucial, which affects also industrial consumption. Yet, this study and the interviews of experts confirm the need to pay more attention to environmental issues in order to ensure the well-being of the earth and natural capital. Otherwise, the progress achieved within sustainable development will regress backwards with negative effects. Positively, those actors acknowledging the sustainable values and implementing the sustainability principles into their logistics, purchases, supplies, and other processes need to continue and even reinforce this path during such grand challenges as the COVID-19 pandemic. In turn, this is a signal to policymakers to strengthen the financial and non-financial support for the identification and implementation of sustainability principles in the supply chain of industrial customers and the total value chain of the B2B segment.

This research contributes to the theory and practice regarding the enablers and challenges for the use of biocomposites in the further transformation toward more sustainable consumption. This study highlights the research gaps that still need to be investigated regarding the impact of COVID-19 on the sustainable consumption of end consumers and their changing behaviors that confront the traditional less sustainable practices of industrial consumers.

In the coming years, the topic will not only be about how to rebuild the economy after the impact of COVID-19 but also how to make it more sustainable. At present, cross-sectoral cooperation and a willingness to help industrial companies understand environmental, social responsibility, and governance standards are particularly important.

The development of the sustainable value chain is largely linked to investments in eco-innovations and the environmentally friendly technologies that are especially important in industrial regions neglecting sustainability challenges [149]. In this regard, government support at national, regional, and local levels is essential to strengthen the values of sustainable consumption and environmentally friendly production by creating a greater critical mass of the sustainable value chains within the industrial consumption and economic relationships.

Possible future research directions and current gaps identified after implementation of the research include but are not limited to the following:

- The role of waste recycling policy in facilitating sustainable industrial consumption.
- More detailed investigations of hindering factors of the introduction of biocomposites and recycling, in particular, related to the economic interests of stakeholders and technological factors.

- Promoting the competitiveness of sustainable industrial consumption partners by eliminating greenwashing.
- Difficulties in the introduction of biocomposites in the industry and overcoming them.
- The impact of the actualization of microplastic pollution problems on the production of non-degradable bioplastics.
- The end of the life cycle of conventional plastics after recycling, when they have lost their properties for further use.
- Industrial consumer difficulties within the EU green transition.

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Appendix A

Table A1. Characteristics of the Interviewees.

No	Field of Expertise of Interviewee	Role in the Sustainable Production Chain	Industry or Field of the Operation of the Organization Represented (Part of the Value Chain)	Size of the Company (Turnover EUR in 2020)	Duration of Interview	The Time Period of the Interview
I1	Corporate Social Responsibility, Sustainability	Retailer (BE)	FMCG Retail	36 bn	1 h	2nd quarter of 2021
I2	Country Manager	Retailer (LV, LT)	Furniture Manufacturing and Retail	39 bn	60 min	3rd quarter of 2020
I3	Head of Store Development Department	Retailer (IT)	Clothing Retail	17 bn	90 min	3rd quarter of 2020
I4	Manufacturing, Lead of R&D	Product manufacturer (LV)	Cosmetics	16 M	60 min	3rd quarter of 2020
I5	General Manager	Product manufacturer (LV)	Food	1 M	60 min	2nd quarter of 2021
I6	Regional Head of R&D	Packaging manufacturer (DE)	Cosmetics, Consumer Goods	102 M	120 min	3rd quarter of 2020
I7	Head of R&D	Packaging manufacturer (IL)	Food		60 min	2nd quarter of 2021
I8	CEO	Raw material (SE)	Starch Producer	1 M	60 min	2nd quarter of 2021
I9	CEO	Raw material (DE)	Fiber Producer	1 M	60 min	2nd quarter of 2021
I10	Board Member	Feedstock (LV)	Hemp Raw Materials		60 min	2nd quarter of 2021

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Article

Measuring Green Marketing: Scale Development and Validation

Neringa Vilkaite-Vaitone [1,*], Ilona Skackauskiene [1] and Gonzalo Díaz-Meneses [2]

1 Department of Management, Faculty of Business Management, Vilnius Gediminas Technical University (VILNIUSTECH), 10223 Vilnius, Lithuania; ilona.skackauskiene@vilniustech.lt
2 Department of Economics and Business, University of Las Palmas de Gran Canaria, 35017 Las Palmas, Spain; gonzalo.diazmeneses@ulpgc.es
* Correspondence: neringa.vilkaite-vaitone@vilniustech.lt

Abstract: Academics and practitioners are paying increasing attention to green marketing as lesser damage to the environment and future generations become a priority in a current complex business environment. Despite the expanding studies in this field, there is still a lack of psychometrically sound scales to measure green marketing practices. To fill this gap, the research aimed to develop and evaluate a multifaceted green marketing scale. First, we draw on theoretical evidence to define and conceptualize the construct of green marketing. Then, we use a multistudy scale development process to create and validate the Green Marketing Scale (GMaS). Two groups of participants were used for the validation of the scale. Study 1 (n = 102), with the help of exploratory factor analysis (EFA), refined and reduced the items, proposed the factor structure. Study 2 (n = 155) established the validity of the construct and the reliability of the scale. The authors have tested the six-factor model against the four-factor models using confirmatory factor analysis (CFA) with a sample of marketing managers. The results of the CFA have indicated that the revised version of the four-factor model appears to be the most tenable solution, as it shows the best fit for the data. The resulting 14-item GMaS captures a variety of green marketing manifestations across organizational settings and involves the dimensions of Strategy, Internal Marketing, Product, and Marketing Communication. In general, the research confirms the validity and reliability of the GMaS scale and can be used to measure green marketing in organizational settings in the energy industry.

Keywords: green marketing scale; scale development; scale validation; internal marketing; external marketing; strategy; tactics; operations; clean technology

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1. Introduction

Under current complex business conditions, the traditional attitude towards marketing practices becomes insufficient to face serious competition, rising concerns of customers, stakeholder requirements, rapid technologic development, public regulation, and strict environmental policies [1–4]. The intense evolution of global markets raises a demand to involve the pillars of sustainability (environment, society, and economy) in marketing decisions when aiming to satisfy the needs of the digitally empowered customer [2,4,5]. Fluctuation of marketing towards the pillars of sustainability has given rise to efforts to meet customer needs with lesser damage to the environment and future generations [1,2,6]. Thus, marketers are induced to use limited resources efficiently in accordance with individual and organizational aspirations by embracing green marketing solutions. These solutions in current circumstances become imperative for organizations rather than a matter of choice in order to combat sustainable development problems.

During the past decade, green marketing has attracted extensive attention among marketing scholars and practitioners. The increasing number of academic publications on the topic is evident [1–6]. However, the measurement of green marketing is not yet well-established. Researchers have measured the performance of green marketing and its components using various methods. In numerous studies, interviews with experts [7] or managers [8–11] were conducted. Researchers have also used direct observations of business environments [12,13], case studies of progressive companies [14,15], and customer surveys [1,2,4,6,16–19]. Although the value of these techniques comes from insights into the context of green marketing, scholars [20–25] have argued that perceptions of marketing managers offer exhaustive information about business experience. Marketers' perceptions of green marketing performance are based on their professional and experiential knowledge. There are several measures of green marketing practices in organizational settings based on marketers' perceptions. However, in most cases, measures of green marketing have not undergone essential procedures of scale development and validation (e.g., [7,20,26]). Consequently, there exists a gap of certainty related to the accuracy of the measurement, as the scales lack either construct or/and content, discriminant validity. The lack of a specific measurement scale for green marketing indicates a vital knowledge gap. It suggests the most appropriate investigation to assess the concept of green marketing in organizational settings applicable in the energy industry.

Given the absence of a valid scale to measure it, the theoretical and empirical development of green marketing could be stunted. Marketing discipline cannot advance scholarship on green marketing without solid conceptualization and well-founded measures. A valid instrument for evaluating green marketing is expected to allow scholars and practitioners to conduct a more direct and systematic examination. Hopefully, it will assess the current level of green marketing and determine the issues and risks that prevent a progressive practice in the field. Therefore, a primary goal of the present research is to develop a measure of green marketing that could be easily applied in organizational settings.

To this end, the paper is divided into several classic sections. First, we reviewed the literature on green marketing scales. Second, we explained the methodology and described the surveys that were carried out. Third, we analyzed the results intending to come up with a new validated green marketing scale. Finally, we acknowledged limitations and put forward new lines of research.

2. Literature Review

The intense interest in the problems of green marketing with a focus on clean technology and environmental problems started in the late 1980s and early 1990s [6]. At that time, green marketing was conceptualized as a combination of organizational activities to promote causes of environmental issues and suggest solutions to their counteraction, prevention, and elimination [27]. Although these ideas remain integral to the current conceptualization of green marketing, the concept has become considerably crystallized and enriched over time. Based on previous research [28], we characterize green marketing as the organization's participation in strategic, tactical, and operational marketing activities and processes that have a holistic objective of creating, communicating, and delivering products with minimal environmental impact. Therefore, we center our scale development on this definition.

The literature review on green marketing reveals some instruments developed to measure marketers' perceptions of green marketing initiatives (Table 1). Among these measures are the green marketing audit [7], the green marketing strategy scale [29], etc. Green marketing audit [7] involves the evaluation of mission/goals, global green competence, stakeholders' requirements and green marketing activities. The green marketing strategy scale [29] measures two types of green marketing: process-oriented and market-oriented. Although the scales proposed in the literature present a significant theoretical contribution, some have drawbacks that could become an obstacle to an accurate assessment of green marketing.

Table 1. Description of instruments for the measurement of green marketing.

Source	Number of Items	Dimensions	Procedures for Scale Development and Validation
Chan [20]	30	1. Green products and services 2. Green distribution 3. Green pricing 4. Green promotion	None
Chen and Yang [7]	16	1. Mission/goals 2. Global green competence 3. Stakeholders' requirements 4. Green marketing activities	None
D'Souza et al. [30]	28	1. Green environmental processes 2. Green supplier selection 3. Green research and development 4. Green resources 5. Green marketing strategy	Face validation of the scale (interviews with managers), pre-test, consultation with academics, pilot study, exploratory factor analysis, Cronbach alpha
Dzulkarnain et al. [26]	20	1. Green product 2. Green place 3. Green price 4. Green promotion 5. Green people 6. Green physical evidence 7. Green process	None
Fraj et al. [29]	14	1. Process-oriented green marketing 2. Market-oriented green marketing	EFA, Cronbach alpha
Papadas et al. [21]	21	1. Strategic green marketing 2. Tactical green marketing 3. Internal green marketing	EFA, CFA, Cronbach alpha, convergent validity, discriminant validity, nomological validity
Yadav et al. [31]	13	1. Green/eco-friendly activities 2. Corporate communication 3. Green image	EFA, Cronbach alpha, Average variance extracted (AVE)
Richey et al. [22]	21	1. Program timing 2. Resource commitment 3. Environmental strategic focus	CFA

We point out that some scales measuring green marketing were not proven to be valid measures as scholars failed to evaluate their construct, content and discriminant validity [7,20,26]. Some of them were content validated, but construct validation was missing [29,32]. Therefore, it is not clear whether the scales measure green marketing as they are supposed to. To the best of our knowledge, only one green marketing orientation measure developed by Papadas et al. [21] has undergone the diligent scale development process through 4 studies. Currently, the scale is one of the most comprehensive measures of green marketing. It is a 21-item questionnaire that comprises three subscales: strategic green marketing, tactical green marketing, and internal green marketing. Although this scale was shown to be a valid and reliable measure of green marketing orientation, the conceptualization chosen that involves a mix of three unequal components raises some issues. Strategic and tactical activities may contribute to external and internal marketing, while both external and internal marketing may feature strategic and tactical activities and operational activities. Regarding the limitations mentioned above, developing a comprehensive scale for assessing green marketing is warranted. This scale would benefit as an effective tool for assessing dominant strengths and weaknesses in organizational settings.

Although the presented instruments for evaluating green marketing (Table 1) are based on different theoretical models, they have several similar constructs. A construct common to several measures is strategic green marketing [21,22,25,26,33,34]. Strategic green marketing has been investigated using different labels such as enviropreneurial marketing [21], strategic environmental focus [22]. In one study, Mukonza and Swarts [33] found that green marketing at the strategic level positively affects the corporate image and business performance. D'Souza et al. [30] suggest that green marketing initiatives at the strategic level positively influence the greening of organizations' products, processes, and overall behavior. These initiatives cover green environmental processes, green supplier selection, green research and development, and green resources. According Fraj et al. [29], strategic green marketing refers to transformations of products and processes that aim to improve environmental performance. Such transformations require considerable investments and support from other members of the supply chain. In addition to strategic green marketing measures, green marketing assesses tactical issues [21,29]. Several lines of research on tactical green marketing have shown that it is focused on short-term decisions related to product design, pricing, communications, etc. [2,21,29]. According to Amoako et al. [2], such decisions should clearly emphasize the ideas of sustainable development. Along with the effects of strategic and tactical green marketing, the perception of marketing activities at the operational level is also important [29].

Usually, green marketing studies concentrate on the external dimension of green marketing [6,20,22,26,32], i.e., external green marketing at the strategic, tactical or operational level that aims to reach customers, government institutions, competitors, etc. However, green marketing as a construct consists of multiple activities and should also be geared towards internal audiences [4,7,21,30]. Internal green marketing involves promoting environmental awareness within the organizational setting, employee training, and environmental leadership [21].

The identified structure of green marketing guided our efforts to develop a measurement scale. We elected to include six dimensions of green marketing orientation: (1) external green marketing at a strategic level, (2) external green marketing at a tactical level, (3) external green marketing at an operational level, (4) internal green marketing at a strategic level, (5) internal green marketing at a tactical level, (6) internal green marketing at an operational level. Although these dimensions are common in the literature on marketing [21,22,25,26,29,33,34], their combination into a single measure of green marketing orientation is unique, comprehensive and omnibus. Therefore, the coherence of six dimensions can be utilized as a yardstick for evaluating green marketing. Simultaneous evaluation of external and internal green marketing facets is essential for the complete description of the situation and increased accuracy of the evaluation leading to superior marketing decisions.

3. Materials and Methods

The purpose of the research was to develop and evaluate a multifaceted GMaS. In our research, we used a multistep process to create GMaS that was realized through two separate studies. Study 1 aimed to establish the validity of the content by testing the scale's dimensionality and further reducing the pool of items. Study 2 was designed to assess the validity of the construct, and discriminant validity. Data for both studies were collected in Lithuania in September and October 2021.

3.1. Sample

The research was directed at marketing managers of Lithuanian business entities operating in various industrial sectors. Marketing managers were chosen as the target population as these are the people who are expected to be highly involved in green marketing planning and implementation. The participant inclusion criteria for both studies were: responsibility for marketing activities in an organizational setting (1), willingness, and ability to complete the survey in Lithuanian (2).

One hundred forty-seven marketing managers filled questionnaires using SurveyMonkey in Study 1. A total of 45 participants did not complete the survey. This reduced the final sample size to 102. The literature ranges in recommendations for the minimum sample size for a reliable EFA. Although 50 is considered an absolute minimum, larger samples over 100 are preferred to obtain factor solutions [35]. The sampling procedure was non-probabilistic and, to be more specific, it followed a judgmental criterion by selecting the managers. Accordingly, we confirm that the collected sample is satisfactory for EFA technique to yield good quality results.

In terms of demographic characteristics, 54% were women in Study 1 (Table 2). The average age of the respondents was 45 years, and the average tenure in marketing was ten years. The majority of the research participants (58%) had a master's degree. The participants all worked in various industries, including wholesale and retail, construction, education, transport, etc. A total of 155 marketing managers completed the survey for Study 2. Their demographic profile was similar. A total of 59% of the marketing managers who participated in Study 2 were women. The average age was 47 years. The average tenure in marketing was almost ten years. A total of 52% of the respondents confirmed that they had completed master's studies.

Table 2. Sample characteristics.

Characteristics		Study 1 (N = 102)		Study 2 (N = 155)	
		N	Percentage	N	Percentage
Sex	Male	46	45.1	63	40.6
	Female	55	53.9	92	59.4
	Other	1	1.0	0	0.0
Age	21–30 years	5	4.9	17	11.0
	31–40 years	34	33.3	31	20.0
	41–50 years	30	29.4	45	29.0
	51–60 years	24	23.5	37	23.9
	61 years or older	9	8.8	25	16.1
Education	High school	2	2.0	3	1.9
	Vocational Education	4	3.9	5	3.2
	Bachelor's Degree	31	30.4	57	36.8
	Master's Degree	60	58.8	80	51.6
	Ph.D. Degree	5	4.9	10	6.5
Professional experience	Up to 5 years	34	33.3	80	51.6
	6–10 years	20	19.6	18	11.6
	11–15 years	22	21.6	15	9.7
	16–20 years	15	14.7	17	11.0
	21–25 years	3	2.9	10	6.5
	26 years or more	8	7.8	15	9.7

3.2. Development of the Preliminary Version of the Instrument

We suggest that the final scale of green marketing would contain both external and internal aspects of green marketing. Specifically, we propose that the final scale would consist of three levels of green marketing that have been previously confirmed [21,22,25,26,29,33,34]. The results of the literature review allowed us to come to the list of the following dimensions: external marketing at the strategic level (1), external marketing at the tactical level (2), external marketing and operational level (3), internal marketing at the strategic level (4), internal marketing at the tactical level (5), internal marketing at the operational level (6). In order to generate an initial pool of items, we used a deductive approach. The literature review resulted in 61 initial items in a consistent order according to the presumed research constructs. The authors collectively examined the face validity of the items, improved the clarity of the items, and eliminated redundancies. Items with the best face validity and clearest formulations were chosen in case of redundant items. This process resulted in 58 items. Five experts in marketing reviewed the list of 58 items and reduced it to 55 items as the best constructed (Appendix A).

We used a 55-item self-report instrument to measure external and internal green marketing at three theoretically derived levels (strategic, tactical, and operational). To measure strategic green marketing oriented toward external audiences, we employed ten statements proposed by Chan [20], Chen and Yang [7], Fraj et al. [29], Papadas et al. [21]. These five-point Likert scales collected propositions in which marketing managers had to indicate their degree of agreement. The scale of tactical green marketing oriented towards external audiences included 29 items that involved aspects related to 4P (product, price, place and promotion). The items were adapted from Chan [20], Chen and Yang [7], D'Souza et al. [30], Fraj et al. [29], Papadas et al. [21], Yadav et al. [32], Dzulkarnain et al. [26]. Appropriate changes were made to the statements to fit precisely the chosen constructs and the aim of the investigation. The scale of operational green marketing oriented toward external audiences refers to the degree of integration of green aspects into the operational level of green marketing. It consisted of 3 items that addressed facets relating to urging environmental awareness in operations. The items were adapted from Chen and Yang [7], Papadas et al. [21]. Strategic green marketing oriented towards internal audiences refers to the degree of internal green marketing implementation at the strategic level. The scale consisted of 7 items proposed by Chen and Yang [7], Fraj et al. [29], Papadas et al. [21], Richey et al. [22]. Tactical green marketing oriented towards internal audiences was defined within three items. They were adapted from Papadas et al. [21]. Operational green marketing oriented toward internal audiences was measured using the statements proposed by Papadas et al. [21]. This scale consisted of 3 items. The research participants were asked to respond to the items on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). Reversed scoring was used for two items (I30 and I31). Averages were calculated for every subscale, with a higher score indicating a higher green marketing orientation.

3.3. Data Collection and Analysis Procedure

The survey questionnaires in SurveyMonkey (Momentive Inc., San Mateo, CA, USA) ran in September and October 2021. The data was inserted into a data matrix in SPSS 23.0 (https://www.ibm.com/support/pages/downloading-ibm-spss-statistics-23, accessed on 1 November 2021) software for further analysis. Initially, the data were screened for normality. Then an EFA was carried out to identify the number of factors that explain green marketing, as this technique helps to understand and clarify new scales [36]. EFA aims to reduce the scale dimensionality, pin down the subjacent dimensions, and guide the subsequent CFA. It is a transformative statistical tool to find out the underlying dimensions and convert them into new variables to use. As in performing it, some scale's variables are deleted. Therefore, it is a valuable tool to enhance the reliability of the final obtained scale [37].

The CFA using Amos 23.0 (https://www.ibm.com/support/pages/downloading-ibm-spss-amos-23, accessed on 5 November 2021) was then performed to validate the scales empirically. CFA is used to uphold a theory and is loosely based on the EFA since it starts with testing the obtained experimental dimensions structure [38]. For this reason, it goes beyond refining and validating the original scale [39] because it attempts to test the underlying dimensions derived from both the EFA and the supporting theories. Consequently, CFA aims to test the convergent validity of the scale inasmuch as it demonstrates that several items are rooted in the same factor. Similarly, it can indicate the discriminant validity if some things do not belong to the same element [37]. A CFA aimed at assessing construct validity, i.e., discriminant validity and convergent validity. The goodness of fit between the factor models was measured as discriminant validity. Convergent validity was tested using standardized factor loadings that indicated how acceptably latent variables explained each observed variable. The chosen combination of EFA and CFA was in agreement with Otaye-Ebede [40], who confirmed that EFA and CFA together may ensure higher accuracy and provide more robust evidence for a more valid instrument.

4. Results

4.1. Results of Study 1

First, we used a data set collected from 102 marketing managers (Study 1). The endorsement rates and variance were checked for each item. According to the scaling metric, the ideal values for the means are between two and four, while for standard deviation (SD), it is ≥ 0.80 [41]. Needless to say, while means describe the concentration of responses, standard deviation shows how dispersed they are. Each item fits into the suggested intervals, thus assuring an appropriate distribution. The normality check resulted in an absolute value of univariate skewness between −0.895 and 0.672, which fits the standards for absolute skewness below two [42]. Univariate kurtosis was between −0.990 and 2.099. It means that no item exhibited a severe deviation from a normal distribution. Therefore, no items were removed after this initial check. The Kaiser–Meyer–Olkin measure of sampling adequacy (0.872) greater than 0.6 and the Bartlett test of sphericity (5112.456 [df = 1326], $p < 0.001$) that was less than 0.05 [43] indicated that the application of factor analysis was appropriate.

We have examined the data matrix for underlying factors applying EFA with principal axis factoring and Promax rotation. The first EFA analysis resulted in a 12-factor solution that explained 78.03% of the variance. Aiming for a more meaningful solution, we have deleted the items if the load was equally heavy on more than one factor. Considering the relatively small sample size, the loadings smaller than 0.55 were deleted [44]. After every removal of items, we have rerun factor analysis and reestimated coefficients until we have received a satisfactory result. Revisions continued until every item remained factor loaded onto one factor with a loading value greater than 0.55. After deletions, the number of items was reduced to 29 (Table 3).

Table 3. Results of the exploratory factor analysis (EFA) for the retained Green Marketing Scale (GMaS) items (Study 1).

Item	**Strategy**	**Internal marketing**	**Product**	**Marketing Communication**	**Digitalization**	**Price**	**Resources**
I46—We try to promote environmental preservation as a major goal across all departments	**0.950**	−0.087	−0.068	0.009	0.049	0.102	0.029
I48—Our employees believe in the environmental values of our organization	**0.910**	0.029	−0.073	0.118	−0.220	0.129	0.013
I47—At our company, we make a concerted effort to make every employee understand the importance of environmental preservation	**0.873**	0.099	−0.123	0.116	−0.071	0.071	−0.016
I45—Our company culture makes green marketing easier for us	**0.811**	0.027	0.079	0.004	−0.082	0.005	0.131
I40—We have a clear statement urging environmental awareness in all areas of operations	**0.799**	0.014	−0.165	0.237	0.067	0.022	−0.015
I43—Environmental issues are very relevant to the major functioning of the company	**0.732**	−0.048	−0.079	−0.213	0.108	0.191	0.180
I3—We form collaboration agreements with government agencies	**0.700**	−0.051	0.344	−0.242	0.054	−0.233	−0.201
I44—Our company has a clear policy statement that calls for environmental awareness in all areas of operations	**0.621**	0.053	0.134	0.076	0.035	−0.079	0.182
I2—We engage in dialogue with our stakeholders about environmental aspects of our organization	**0.613**	0.072	0.335	−0.174	0.048	−0.150	−0.050
I28—We promote green environmental components of the product	**0.593**	−0.055	0.092	0.324	0.042	0.085	−0.062
I52—We have created internal environmental prize competitions that promote eco-friendly behavior	−0.152	**1.065**	0.027	−0.014	−0.010	0.027	−0.034

Table 3. *Cont.*

Item	Strategy	Internal marketing	Product	Marketing Communication	Digitalization	Price	Resources
I54—We form environmental committees for implementing internal audits of environmental performance	0.132	**0.876**	−0.144	0.023	−0.013	0.065	−0.197
I51—Exemplary environmental behavior is acknowledged and rewarded	−0.056	**0.864**	0.107	0.021	−0.085	−0.027	0.179
I53—We organize presentations for our employees to inform them about the green marketing strategy	0.128	**0.796**	−0.075	0.055	−0.012	0.052	0.038
I50—Environmental activities by candidates are a bonus in our recruitment process	0.268	**0.504**	0.029	−0.092	0.062	0.112	0.177
I15—Raw materials are safe for the environment and health	0.104	0.056	**0.912**	−0.039	−0.240	−0.040	0.048
I16—Organization provides environmentally friendly products	−0.157	−0.062	**0.847**	0.051	−0.091	0.200	0.140
I17—We use ecological and clean materials for packaging	−0.255	0.027	**0.747**	0.202	0.119	0.234	0.037
I14—We use recycled or reusable materials in our products	0.110	−0.020	**0.730**	−0.013	0.147	−0.033	−0.114
I13—The company seeks to bring innovative green products and services to the market	0.300	−0.112	**0.569**	0.145	−0.057	0.077	−0.027
I36—The company uses eco-labels on packaging	0.096	−0.038	0.082	**0.910**	0.005	−0.081	0.017
I37—The company shows eco-labels on the corporate website	0.016	0.105	0.065	**0.874**	0.082	−0.182	−0.060
I33—We prefer digital communication methods for promoting our products because it is more eco-friendly	0.018	−0.086	−0.181	−0.019	**0.895**	0.068	0.117
I25—We encourage the use of e-commerce because it is more eco-friendly	−0.138	−0.053	0.049	0.129	**0.709**	0.231	0.031
I5—We implement market research to detect green needs in the marketplace	0.139	0.266	0.083	0.049	**0.563**	−0.219	−0.089
I21—Customers agree to pay higher green prices when part of the amount is donated to green activities	0.120	0.144	0.066	−0.099	0.029	**0.836**	−0.139
I20—Customers who are more receptive to environmental goods and services are willing to pay more for environmentally friendly products	0.121	−0.026	0.180	−0.166	0.131	**0.830**	−0.104
I42—We apply a paperless policy in our procurement where possible	0.072	0.033	0.053	−0.092	0.162	−0.103	**0.837**
I55—We apply a paperless policy in our personnel management where possible	0.115	−0.041	0.014	0.038	−0.013	−0.154	**0.831**
Variance explained (total = 75.834)	0.950	−0.087	−0.068	0.009	0.049	0.102	0.029

A clear seven-factor structure with an eigenvalue of more than one has been supported. Every item clearly loaded onto one factor. We have examined all factors to find interpretations of their conceptual meanings. The factors were labeled as follows: Strategy, Internal Marketing, Product, Marketing Communication, Digitalization, Price, and Resources (Table 3). After the eliminations and modifications of items, a 29-item pool was used in the following study. After the exploratory analysis, we proceeded to run a confirmatory factorial analysis to check the scale's convergent validity.

4.2. Results of Study 2

Another dataset (n = 155) was used to confirm the dimensionality of the GMaS. The CFA was conducted with AMOS 23 software. We ran CFA for four models (Figures 1–4). Model 1 consisted of the initial pool of items structured into six factors based on the level and dimension of green marketing (Figure 1). Even though such a structure does not match the results of the EFA, the authors decided to check the model just for the sake of the interest of its goodness of fit. Table 4 shows that the CFA result indicated that Model 1 fits poorly with the collected data.

The theoretical model with six latent factors did not show an acceptable fit to the data. The measurement model did not fit satisfactorily with TLI = 0.673 and CFI = 0.688). The RMSEA value determined by Model 1 was not considered acceptable, as it did not range between 0.05 and 0.08 as recommended in the literature [45].

Table 4. Fit indices for the models.

Fit Indices	Obtained Values				Norms [1]
	Model 1	Model 2	Model 3	Model 4	
χ^2	3625.33	571.073	309.4	116.006	N/A
df	1416	224	163	83	N/A
$\Delta\chi^2$	–	−3054.257	−261.673	−193.394	N/A
Δdf	–	−1192	−61	−80	N/A
Scaled χ^2/df	2.560	2.549	1.898	1.398	1–3
Tucker−Lewis index (TLI)	0.673	0.844	0.917	0.958	>0.90
Comparative fit index (CFI)	0.688	0.862	0.928	0.967	>0.90
Root Mean Square Approximation Method (RMSEA)	0.101	0.100	0.076	0.064	0.05–0.08

[1] Sources for norms: [45,46].

Then we ran Model 2 (Figure 2) that consisted of the four factors determined by the EFA. SPSS AMOS requires a factor to have at least three items. Therefore, the factors of marketing communication, price, and resources were eliminated from the dataset. The goodness of fit of Model 2 appeared to be insufficient (TLI = 0.844, CFI = 0.862, RMSEA = 0.100). Therefore, we aimed at ensuring the appropriateness of Model 2 by inspecting factor loadings, modification indices, and cross-loadings. We achieved a better fit by removing three items (Figure 3). We tested this four-factor model (Model 3), which returned a much better data fit (TLI = 0.917, CFI = 0.928, RMSEA = 0.076).

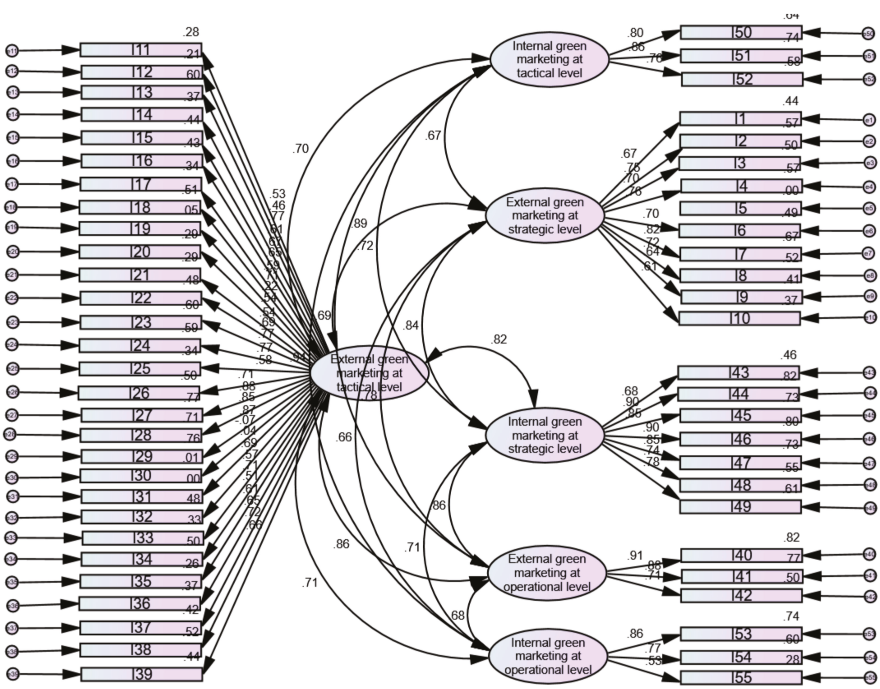

Figure 1. Model 1. The initial confirmatory factor analysis (CFA) model of the Green Marketing Scale (GMaS).

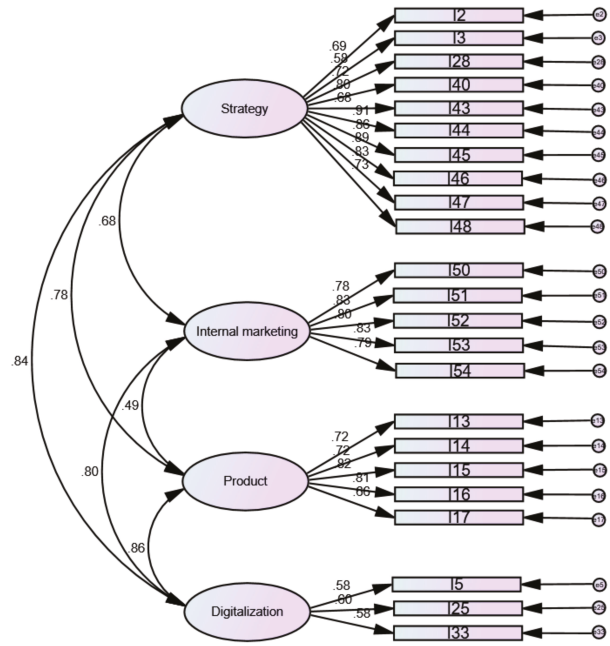

Figure 2. Model 2. The four-factor, 23 item confirmatory factor analysis (CFA) model of the Green Marketing Scale (GMaS).

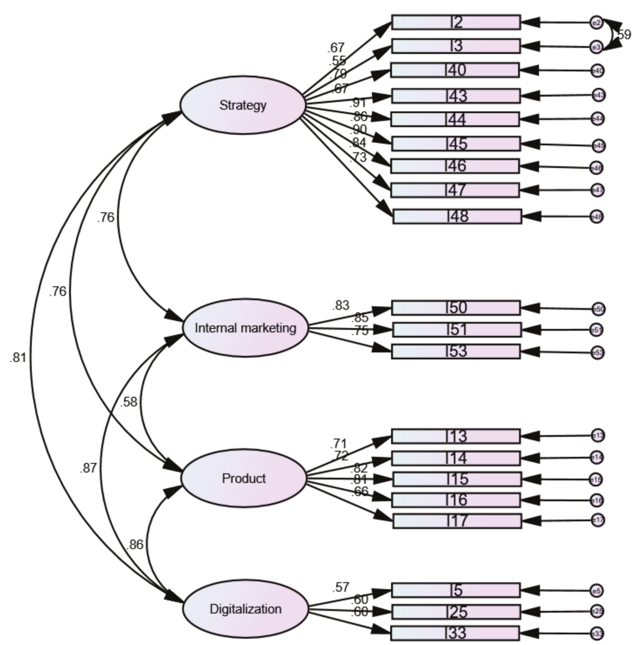

Figure 3. Model 3. The four-factor, 20 item confirmatory factor analysis (CFA) model of the Green Marketing Scale (GMaS).

Despite a good fit of Model 3, one of the scales (namely, digitalization) demonstrated insufficient internal consistency (α = 0.666). This deficiency of the model led us to slight modifications of the factor structure. Digitalization factor items were infused into marketing communication. Thus, items belonging to the factor of marketing communication were restored and merged with items of the digitalization factor (Model 4). After inspecting factor loadings and cross-loadings, fit statistics were not adequate. However, the configurations of some items improved the model fit (Figure 4).

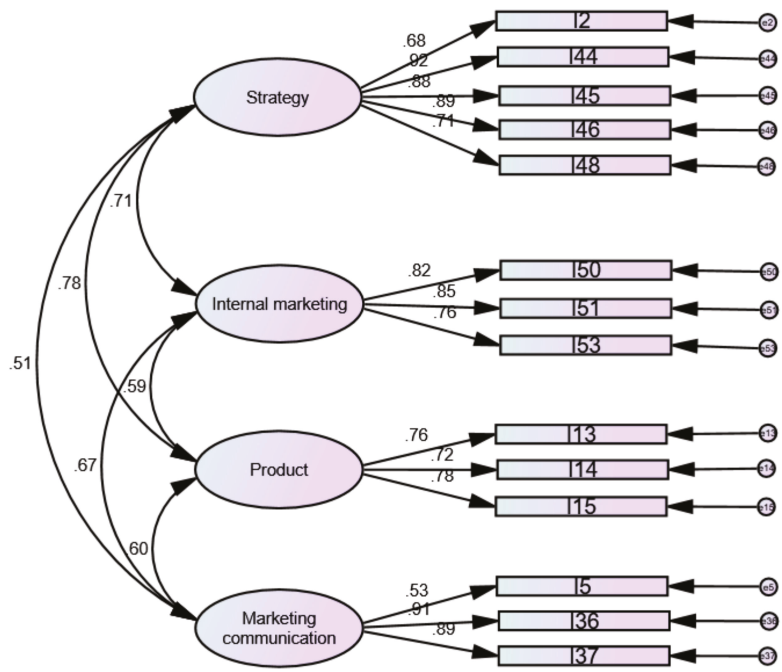

Figure 4. The final four-factor, 14 item confirmatory factor analysis (CFA) model of the Green Marketing Scale (GMaS).

Model 4 showed the best fit (TLI = 0.958, CFI = 0.967, RMSEA = 0.0.064). The *p* is greater than 0.05. Therefore, we conclude that the fit of the model is close. We finally conclude that Model 4 reasonably fits the data. In the final validated 14 GMaS, the Strategy subscale consists of five items (Table 5). The Strategy involves items related to dialogue with stakeholders, policy statements, culture, major goals, and beliefs. The Internal Marketing subscale consists of items about environmental activities of potential employees, rewards for environmental behavior of employees, and employee informing about green marketing. The Product factor reveals the innovation of the product, recyclability, reusability, and safety of the materials. Finally, Marketing Communication covers marketing research as a precondition for efficient communication and eco-labeling. The Cronbach alphas of the four subscales (0.908, 0.843, 0.794, and 0.801, respectively) indicated sufficient internal consistency between the items of every scale.

Table 5. The items in the Green Marketing Scale (GMaS).

Measures	Items
Strategy (5 items)	I2—We engage in dialogue with our stakeholders about environmental aspects of our organization I44—Our company has a clear policy statement that calls for environmental awareness in all areas of operations I45—Our company culture makes green marketing easier for us I46—We try to promote environmental preservation as a major goal across all departments I48—Our employees believe in the environmental values of our organization
Internal Marketing (3 items)	I50—Environmental activities by candidates are a bonus in our recruitment process I51—Exemplary environmental behavior is acknowledged and rewarded I53—We organize presentations for our employees to inform them about the green marketing strategy
Product (3 items)	I13—The company seeks to bring innovative green products and services to the market I14—We use recycled or reusable materials in our products I15—Raw materials are safe for the environment and health
Marketing Communication (3 items)	I5—We implement market research to detect green needs in the marketplace I36—The company uses eco-labels on packaging I37—The company shows eco-labels on the corporate website

To study the reliability, we run an analysis of compound reliability (CR) and AVE that can be seen in Table 6. In the light of the results obtained, as all the indicators are above the recommended threshold, that is, above 0.7 for CR and 0.5 for the AVE, we can confirm the reliability of the scale.

Table 6. Compound reliability (CR) and average variance extracted (AVE) of the measures.

Measures	CR	AVE
Strategy	0.909	0.669
Internal Marketing	0.831	0.621
Product	0.785	0.550
Marketing Communication	0.773	0.543

Lastly, to check the measuring instrument's discriminatory validity, we made a correlation analysis whose Pearson's Coefficient (r) is far below one (Table 7). Similarly, we checked that the square values of the extracted variance are greater (Strategy: 0.82; Internal Marketing: 0.79; Product: 0.74; Marketing communication: 0.74) than the correlation values and, hence, the discriminant validity is approved [47]. Therefore, we assert that the GMaS measures different dimensions such as Strategy, Internal Marketing, Product, and Marketing Communication.

Table 7. Correlation matrix.

Measures		Strategy	Internal Marketing	Product	Marketing Communication
Strategy	Pearson Correlation	1	0.631 **	0.669 **	0.517 **
	Sig. (2-tailed)		0.000	0.000	0.000
	N	155	155	155	155
Internal Marketing	Pearson Correlation	0.631 **	1	0.478 **	0.618 **
	Sig. (2-tailed)	0.000		0.000	0.000
	N	155	155	155	155
Product	Pearson Correlation	0.669 **	0.478 **	1	0.547 **
	Sig. (2-tailed)	0.000	0.000		0.000
	N	155	155	155	155
Marketing Communication	Pearson Correlation	0.517 **	0.618 **	0.547 **	1
	Sig. (2-tailed)	0.000	0.000	0.000	
	N	155	155	155	155

** Correlation is significant at the 0.01 level (2-tailed).

5. Discussion

Green marketing is a key factor for the successful operation of businesses. It relates not only to commercial benefits (such as stronger relationships with customers, increased profit, competitive advantage, etc.) but also to environmental and social benefits due to cleaner production, increased flexibility to choose green energy. This benefit leads to improvement of the natural ecosystem and increased quality of life [2,4,23,33,48–50]. Therefore, academicians and practitioners have an increasing interest in this construct and its measurement.

The literature review has shown that former green marketing scales had a limited scope and potential to evaluate green marketing in its entirety. Specifically, previous scales focused too heavily on the tactical components of green marketing [51], sometimes on strategic components [33,34], passing over operational components of the construct. It is an issue that prevents the clarification of processes of green marketing not only at the external dimension but also at the internal dimension. Therefore, the current study attempted to develop a scale that evaluated external and internal dimensions of green marketing at strategic, tactical, and operational levels. To do this, we completed a literature review to develop an initial item pool containing recycled items from previous scales. The authors created additional items to evaluate both the external and internal facets of the green marketing construct.

In two studies, we developed the GMaS. The subscales of the final GMaS were not consistent with the suggested domains. Rather than supporting six latent variables, EFA (Study 1) discovered seven interpretable factors that were reduced to four after CFA. Some factors are consistent with the literature [20,21,26,30,48,51].

The newly developed GMaS provides a measure of an important variable in a sustainable era. GMaS is a 14-item measure of four distinct components (Strategy, Internal Marketing, Product, Marketing Communication) that demonstrated adequate factorial validity and reliability. The scale consists of Strategy, which describes values, culture, policies as the basement of green marketing, Internal Marketing that involves green marketing arousal from the side of employees, Product that involves safety, recyclability, reusability, innovativeness of green products, and Marketing Communication, which terms communication based on eco-labeling and market researches. By developing a concise scale to measure green marketing in organizational settings, we hope to advance relevant theory and research on green marketing, its contents, and consequences.

5.1. Future Research

The most significant contribution of this study is the solid measure developed for the evaluation of green marketing. Although there have been previous attempts to measure green marketing through various combinations of variables, GMaS now presents a much-needed instrument for the direct measurement of green marketing. Researchers and practitioners will be able to apply it and expand the empirical knowledge of green marketing. Using GMaS, future research can better elucidate various aspects of green marketing necessary for the successful management of sustainability issues in organizational settings and strengthen organizational manifestations of green marketing that are environmentally and morally acceptable. In addition, researchers may use GMaS to find the impact of green marketing on business performance indicators. GMaS can also be applied to research to see the effect of the professional characteristics of marketers on green marketing in organizational settings. Toward this end, we expect that the upcoming research employing GMaS will contribute in meaningful ways to pursuing green marketing as a new normal for businesses and avoiding greenwashing in attracting more green-conscious customers.

5.2. Limitations

The results of this research should be considered in light of limitations. First of all, the data was collected using convenience samples. As a result, a certain level of caution may be required in generalizing the study results to a larger-scale population. Future studies may adopt a more systematic sampling approach in order to increase the validity of the scale. Second, this research includes marketing professionals working only in Lithuanian organizations. Future research may valuably validate the instrument among marketers working in other countries. Irrespective of the limitations mentioned above, we suppose that the GMaS is a valuable instrument that might be of good use to green marketing. This field demonstrates growing importance in the energy industry.

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Appendix A

Table A1. The initial version of the Green Marketing Scale.

	Level	Element	Item	Source
External green marketing	Strategic level	–	I1—Green is a central corporate value in our company I2—We engage in dialogue with our stakeholders about environmental aspects of our organization I3—We form collaboration agreements with government agencies I4—We cooperate with environmentally friendly partners I5—We implement market research to detect green needs in the marketplace I6—Amongst other target markets, we also target to environmentally−conscious customers I7—We make efforts to use renewable energy sources for our products I8—We invest in low−carbon technologies for our production processes I9—We invest in R&D programs to create environmentally friendly products I10—We have created a separate department/unit specializing in environmental issues for our organization	[7,20,21,29]
	Tactical level	Product	I11—Green marketing in the organization should begin with green product design I12—Green products may provide an opportunity for differentiation I13—The company seeks to bring innovative green products and services to the market I14—We use recycled or reusable materials in our products I15—Raw materials are safe for the environment and health I16—Organization provides environmentally friendly products I17—We use ecological and clean materials for packaging I18—The company's green products are desired by the customers	[20,21,26,29,32]
		Price	I19—Green products and services are almost always priced at a premium over conventional offerings I20—Customers who are more receptive to environmental products are willing to pay more for environmentally friendly products I21—Customers agree to pay higher green prices when part of the amount is donated to green activities I22—We consider environmental aspects within the price policy	[20,29]
		Place	I23—We consider environmental issues in the distribution I24—The organization tries to convince customers to be environmentally friendly during direct sales I25—We encourage the use of e-commerce because it is more eco-friendly I26—We select cleaner transportation systems	[21,29]

Table A1. *Cont.*

	Level	Element	Item	Source
		Promotion	I27—Our marketing communication aims to reflect the company's commitment to the environment I28—We promote green environmental components of the product I29—We employ green arguments in marketing communication I30—Company's customers are suspicious of environmental advertising and claims (reversed) I31—Environmental claims in advertisements are often met with criticism from competitors, consumer organizations, etc. (reversed) I32—The company uses promotional media that is environmentally friendly I33—We prefer digital communication methods for promoting our products because it is more eco-friendly I34—The company collaborates with environmental groups to promote the "green image" effectively I35—Environmental labeling is an effective promotional tool for our company I36—The company uses eco-labels on packaging I37—The company shows eco-labels on the corporate website I38—We inform consumers about environmental management in the company I39—We provide sponsorship or patronage for environmental groups or events	[20,21,26,29,30]
	Operational level	–	I40—We have a clear statement urging environmental awareness in all areas of operations I41—Daily marketing operations purposefully lead to the green image I42—We apply a paperless policy in our procurement where possible	[7,21]
Internal green marketing	Strategic level	–	I43—Environmental issues are very relevant to the major functioning of the company I44—Our company has a clear policy statement that calls for environmental awareness in all areas of operations I45—Our company culture makes green marketing easier for us I46—We try to promote environmental preservation as a major goal across all departments I47—At our company, we make a concerted effort to make every employee understand the importance of environmental preservation I48—Our employees believe in the environmental values of our organization I49—We encourage our employees to use eco-friendly products and services	[7,21,22,29]
	Tactical level	–	I50—Environmental activities by candidates are a bonus in our recruitment process I51—Exemplary environmental behavior is acknowledged and rewarded I52—We have created internal environmental prize competitions that promote eco-friendly behavior	[21]
	Operational level	–	I53—We organize presentations for our employees to inform them about the green marketing strategy I54—We form environmental committees for implementing internal audits of environmental performance I55—We apply a paperless policy in our personnel management where possible	[21]

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Sharing Model in Circular Economy towards Rational Use in Sustainable Production

Dzintra Atstaja [1,2], Viktor Koval [3,*], Janis Grasis [1], Iryna Kalina [4], Halyna Kryshtal [4] and Inesa Mikhno [5]

1 Legal Department, Faculty of Law, Rīga Stradiņš University, 16 Dzirciema Street, LV-1007 Riga, Latvia; dzintra.atstaja@ba.lv (D.A.); janis.grasis@rsu.lv (J.G.)
2 Department of Management, BA School of Business and Finance, 161 K. Valdemara Street, LV-1013 Riga, Latvia
3 Institute of Market and Economic-Ecological Researches, National Academy of Sciences of Ukraine, 54 Volodymyrska Street, 01030 Kyiv, Ukraine
4 Interregional Academy of Personnel Management, 2 Frometivska Street, 03039 Kyiv, Ukraine; kalinargz@gmail.com (I.K.); gkryshtal@ukr.net (H.K.)
5 Department of Tourism and Educational Management, International European University, 42V, Akademika Hlushkova Ave., 03187 Kyiv, Ukraine; inessa.mihno@gmail.com
* Correspondence: victor-koval@ukr.net

Abstract: Changing business models is a topical issue in a pandemic. Recent research has shown that the search for environmentally friendly and sustainable solutions in various sectors has become relevant. The article aims to promote cooperation and adaptation of good practices between countries. Comparing the country's history and economic situation and economic development and traditions can be seen as a precondition for success. The article examines the introduction of sharing economy and the creation of environment-friendly trends establishing a circular economy by minimizing the population's expenses, online business growth, and accessibility of Internet technologies. The article explores the difference between the linear economic model and the circular model by adopting sharing and the efficient joint use of materials to enhance and assess sustainable development. Based on a combination of theoretical and practical research, the article explores the dynamic system and development model of sharing a circular economy. The new concept of circular economy does not promote the overproduction of new goods but the rational use of already produced ones, which significantly reduces the amount of waste generated at all stages of the product life cycle. Population groups by different income groups for sharing services are analysed. An analysis of the price characteristics of popular sharing products was used from data from Internet portals. One concludes that due to the increase in Internet users, especially mobile apps, and social networks, C2C sharing has become quite popular over the past years. Other areas also show positive development indicators but have less demand, affecting supply. Based on an in-depth study of the economic situation in Ukraine, the authors have critically chosen an industry to set as an example with the actual business situation. Therefore, three packages were created: pessimistic, standard and optimistic ones with different characteristics of implementing circular economic projects. The chosen method allows rational management decisions for attracting financing and sustainable solutions. The company's business scenarios analysed in the article will allow to choose a system based on circular economy principles successfully.

Keywords: experience circular economy; rational use; resource consumption; sharing model

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1. Introduction

In recent years, we can see digital transformation, increasing globalization processes, more accessible access to resources and services globally. Social changes caused by digitalization also transform the lifestyle of each individual, affect preferences, demand, supply on the goods and services market, enhance the rate of capital turnover and generally accelerate all flows. The increasing speed of life processes and better access to necessary goods on the Internet results in the growing share of rental services. Individuals prefer to use goods temporarily when needed rather than possess them. Besides a reduced price when buying goods, the lessee declines the responsibility for further exploitation, storage and consumer properties of the object for a specified fee.

Along with the process of digitalization and the expansion of borders in developed countries, the ideas of the green economy are becoming popular. The development of green technologies will contribute to introducing the concept of a circular economy, the main distinguishing feature of which is to increase the life of the product and minimize waste, reducing the negative environmental impact. Therefore, sharing, which increases the social usefulness of the product, will contribute to the introduction of a circular economy. In addition to the positive effects associated with an increase in the possibilities of secondary production or reuse of products because of the development of a circular economy, there is a rebound, which is associated with cheaper products and an increase in the efficiency of its production, which leads to an increase in the level of production and consumption [1]. In this regard, changes in the consumer behaviour of users of the collaborative platform cause a circular economy to rebound that considers the environmental impact of product substitution and demand for recycled products. Using savings from co-sharing may increase personal income and lead to additional purchasing power. Still, the environmental benefits of the circular economy can be achieved if primary production is significantly reduced or more efficient [2].

Access to rental goods is accessible, efficient and affordable to most consumers, which has led to the emergence of the market of lease relations called 'sharing' and set a new trend in economic development in Ukraine and worldwide. Sharing allows inhabitants, businesses and public institutions to exchange services and goods, share consumer properties of goods, and efficiently use financial resources and time to achieve their goals. The most common sharing services include accommodation, car rental, taxi, equipment rental, hotel business, financial and credit transactions, etc. The establishment of the sharing economy is closely related to the development of Internet services and the ability to move freely over long distances.

The development of the sharing economy increases the responsibility of everyone towards society, reduces the environmental load and waste products, promotes inclusiveness and accessibility of goods [3]. The launch of online platforms, urbanization and increasing mobility of the younger generation have resulted in the everyday use of different means of transport. It is much more profitable than driving your car. Thus, online taxi, car-sharing and carpooling services are highly in-demand recently [4]. Sharing as a business has rapidly expanded by launching online platforms placing unspent assets and ensuring the quick connection between a customer and a seller.

The mechanism of providing sharing services is based on the lease of a particular product, the cost of which includes depreciation and additional funds that generate entrepreneur's profit in the long run, for a certain period with the obligatory return of goods to the owner and the further use of goods by other lessees. Lehto et al. [5] define the sharing economy as an innovative economic model based on the collective benefit of goods and services and considered financial interaction between economic agents (producers and consumers of services) without third parties.

As a new economic market, sharing has a number of problems and shortcomings that slow down the rapid adoption of technologies and methods of sharing goods, and contemporary insurance companies are not always an efficient mechanism for reducing business risks [6]. One of the promising areas of the sharing economy is HR management based on meeting manpower needs. Despite the manufacturing automation and inevitable mass dismissal of employees, the introduction of sharing services reveals a new problem: an acute shortage of highly skilled professionals with brand-new competencies [7]. Currently, the development of the sharing economy is unpredictable, but according to Eckhardt et al. [8] it is the impetus for new behavior patterns among both customers and third parties, which have five key characteristics: temporary access, transfer of economic value, mediation on the platform, the expanded role of the consumer and crowdsourcing supply.

Sharing as a resource-saving concept will encourage the adoption of the circular economy based on the repeated use of goods and the increase in their life span by repairing, maintaining and enhancing their usefulness [9]. The maximum use of goods increases the degree of meeting user needs, reduces the negative ecological impact by decreasing the volume of commodity production [10], creates resource-saving conditions. In contrast, shared goods are always circulated, which illustrates the introduction of principles of the circular economy [11].

The value of adopting sharing has long-term indicators where it is impossible to immediately assess the effect via the accumulative positive impact and the long payback period. Besides, sharing will allow decreasing the amount of waste, which is the framework for the circular economy and the prerogative of developing of the development of eco-friendly society based on ecological education, high moral and spiritual values that all governments of developed countries strive for. Sharing encourages the prevalence of long-term economic values over short-term economic advantages, encourages the decrease in waste flows and burial, as well as promotes resource-saving and the growth of macroeconomic indicators.

This paper aims to determine the attainability of the planned goals and to identify the factors that contribute to and hinder the development of sharing economy and creation of environment-friendly trends establishing a circular economy. The structure of the article includes an assessment of the economic situation of sharing in the former countries of the Soviet Union, which after its collapse are members of the European Union (Latvia) and an associate member (Ukraine), especially in its electric power industry associated with sharing, including electric vehicles. Different parts of the article are a statistical analysis that allows you to determine the directions for implementing the sharing economy and the circular economy, considering the application of European experience. In the final part of the article, conclusions and recommendations are presented to accelerate the implementation of the circular economy in terms of its efficiency increase through information technology and common use, which will significantly increase the usefulness of the product and extend its service life.

2. Methodology

The article analyses the main forms of human interaction using Internet technologies, creating a separate economic development area. One has used open data on the Web and conducted a public survey on specific selection criteria. Sharing is a new, dynamic and ambiguous concept that makes research more thorough and broader. Sharing implies the joint use of goods and rent and the increase in the life expectancy of goods by their upgrading and reusing. The article uses methods of abstraction, generalization, deduction and induction, methods of situational analysis, modelling and forecasting. The results are assessed according to the quality of strategy development and analysis with further implementation. One defines and presents graphically the research findings dedicated to the positive effects of resource sharing and preservation. The offered research methods allow using the obtained data for further experiments and other scientific areas. The investigation covers Ukraine and Latvia and reflects the local population's preferences and existing trends. The survey was conducted voluntarily.

Based on the theoretical analysis of the article, to construct a system of indicators for the development of a collaborative economy, the article uses data from Latvia and Ukraine for the annual time series for 2015 to 2020. The availability of sharing speeds up the overall production rate, increases the range of goods, allows start-ups to set up their own business without considerable investment, and such platforms as Kickstarter [12] help start-ups to implement their ideas.

The absence of ownership makes entrepreneurs more mobile, positively affecting the range and quality of goods, increasing business efficiency. The main tendencies and trends in the field of rank are analysed, and it is found out that flexible business systems can adapt to the constant economic changes. However, during the COVID-19 pandemic, some areas of the sharing economy suffered significant losses (hotel, restaurant business, machinery and equipment rental) because of the declining consumer demand for goods being in use and able to become the object exposed to the virus. Meanwhile, online platforms and such goods as music and games became increasingly popular globally. Partner consumption worldwide is growing, accompanied by new business structures, huge investments, governmental support and increasing market share. However, it often contradicts global goals and should be regulated while the legal framework is still established, and the sharing economy is an area of high risk. According to the survey of 100 respondents via the Internet, the risk of providing shared services in Ukraine has decreased over the past ten years, but 27% of respondents mentioned the hostile experience of providing sharing services, resulting in the loss of financial resources. Respondents were selected from regular Internet users in three age groups: the first—14–25 years, the second—25–40 years and the third—40–60 years. The survey was conducted anonymously in Google Forms.

The article also uses simulation modelling methods to analyse the company's behaviour strategy and select the optimal next steps.

One of the fundamental methods of scientific knowledge is the analytical method of comparison, which allows identifying the leaders of sharing in the countries under analysis. Latvia is like Ukraine in terms of its historical heritage, which belonged to the Soviet Union in the twentieth century. It is economically identical to Ukraine in terms of economic and analytical indicators, and we are analysing the sharing in these countries. Research modelling methods should set an example for other entrepreneurs. However, despite the short-term results, the authors propose to focus on the long-term perspective and environmental and economic efficiency, which will be an effective indicator.

3. Results

The introduction of the quarantine caused by the COVID-19 pandemic resulted in the increasing amount of Internet users who spent more time on the Web, increasing the share of online businesses, increased the share of online demolition, as evidenced by analytical data on purchases and activity in social networks. At the same time, many sectors suffered losses, which affected the population's revenues and encouraged the development of lease relations in society. Due to everyone's desire to minimize expenses and contacts with other people because of COVID-19, the development of the sharing economy has become not just ecologically grounded but also economically viable in many countries, particularly in countries with a low income per capita.

One international sharing example is Uber, which has set the fare and service fee and is available in more than 70 countries. The company has launched its application and developed a rating system to protect users' data to avoid fraudulent schemes. Ioanna Constantinou and others investigated the largest sharing platforms (Airbnb, Uber, Handy, Couchsurfing, Lyft, TaskRabbit, etc.) and distinguished four main areas of sharing: Franchiser, Principal, Chaperone and Gardener, which have several competitive advantages over traditional businesses [13]. The development of own digital systems, apps and services based on the everyday use of goods and the enhancement of the user function has become the foundation for the establishment of the circular economy that applies resources being in turnover and creating their market and business models of social cohesion where the Internet is the core method of information exchange [14].

The sharing services market in Ukraine has started growing rapidly over the past ten years due to free access to the Internet not only on PCs but also on mobile gadgets. It gave the impetus to the rapid exchange and sharing of goods and services. (Figure 1).

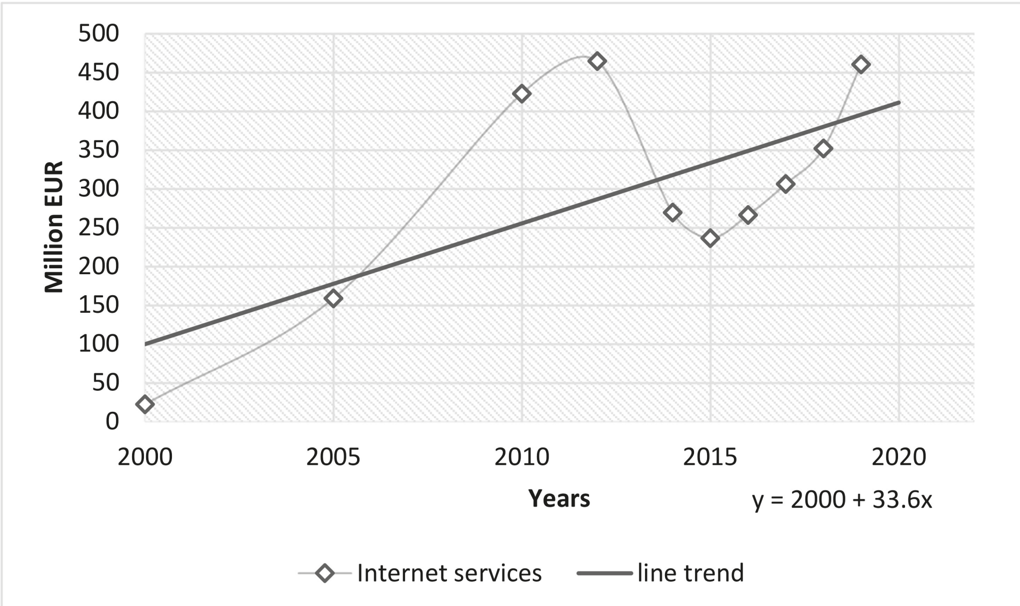

Figure 1. The volume of sold online services in Ukraine on a time interval, million EUR [15].

According to the State Statistics Service of Ukraine [15], mobile services (about 54%) and Internet services (17%) are leaders in terms of funds in the structure of telecommunications and postal services. The greatest amount of sold products in the communications sector due to regions can be seen in actual prices including VAT in Kyiv (898 million EUR), Donetsk (146 million EUR), Odesa (129 million EUR) and Kharkiv (1170 million EUR) regions, which are the most economically developed regions of Ukraine. These numbers are growing year-by-year (by 9% in 2018 compared to 2017), indicating an increase in the area of Internet coverage and increasing funding in this sector. It provides favorable conditions for the development of the sharing economy [13,14].

Data of the leader leading one shows an increase in the trend of sold services confirmed by data expressed in UAH, although we can see a decrease in sales (up to 257 million EUR) when calculated in EUR due to the exchange rate growth in 2014–2015 and its subsequent fluctuations. However, Internet users have been growing steadily since 2000, including during the pandemic. Car sharing, bicycle, scooter, household equipment and equipment rental were analysed. Over the past five years, we have seen an increasing number of mobile users and cash receipts in mobile services providing access to the Internet. The role of mobile gadgets plays a significant role in the lives of Ukrainians. This increases the number of online purchases and transactions, mostly in cities (76.3%–7.66 million households as of 2019, which is 10.5% more than in 2018) and settlements with more than 5000 inhabitants, which is explained by the predominance of the population under 50 in the age structure of the inhabitants who have modern mobile devices with free access to the Internet and can use online services. According to the State Statistics Committee of Ukraine, men aged 25–35 (22.4%) and women aged 18–24 (35%) accounted for the most significant percentage of the population buying or renting goods online in 2017. In 2019, men aged 25–35 accounted for 19.8%, increasing the age distribution of users, and women aged 25–35 (29%) became more active. This fact indicates an increase in the age interval between users in terms of both age reduction and raising [15]. Depending on the average equivalent monetary income of households per capita, one can conclude that more active users of sharing services are households with more than 4,800 UAH (148 EUR) in 2017 and families with an income of more than 12,000 UAH (372 EUR) in 2019. Sharing services are slowly developing in regions with the lowest number of Internet users at the regional level.

In 2017: Volyn, Zhytomyr, Odesa, Vinnytsia and Kherson regions. In 2019: Volyn, Ternopil, Khmelnytsk, Kirovohrad, Poltava and Kyiv regions.

Megalopolises and Kharkiv, Dnipropetrovsk, Zaporizhzhia, Mykolaiv, Zakarpattia, Ivano-Frankivsk Ternopil and Chernivtsi regions, were most active in 2017. In 2019, this list was supplemented with Donetsk, Lviv, Odesa and Sumy regions. The number of users increased by more than 10% of the total number of households. One of the leaders in providing sharing services is the Donetsk economic region (22.4% in 2019) characterised by the industrial economy, constant migration and increasing demand for temporary goods [15].

The share of the population aged 16–74 who have reportedly used the Internet over the past 12 months worldwide depends on the state's economic development, as shown in the tables [16,17]. Leaders in terms of access to Internet services in 2018 included Luxembourg (97.4%), Denmark (97.3%), Norway (96.4%), the United Kingdom (94.9%), the Netherlands (94.7%) [17]. The correlation coefficient between Internet users and gross domestic product per capita is 89%, indicating a direct close relationship.

According to the EVO group of companies, the total amount of physical goods and services purchased by Ukrainians on the Internet in 2020 reached 3.4 billion EUR [18], and the number of online payments increased by 50% compared to 2019. The pandemic has accelerated the development of e-commerce and increased confidence in the use of innovative services. The largest sharing services websites in Ukraine include Blablacar, Rozetka.com.ua, Olx.ua, Ria.com, Jarmarok.com.ua, Rentaua.com, Ogolosha.ua, Obyava.ua, Besplatka.ua, Prom.ua. They provide information about different types and categories of sharing goods and services based on the rating system of users, which warn lessees about potential fraud and poor work. Online crediting, one of the forms of sharing, is also growing rapidly in Ukraine. However, it is still considered as an unfavourable service because of high-interest rates and poor performance of financial institutions, the involvement of banned collection companies and the abuse of fines.

Due to the reduction of Ukraine's GDP in 2020 by 4%, amounting to 1 trillion 36 billion EUR and 3.25 thousand EUR per capita [15], one expects the increasing use of sharing services in order to reduce the cost of living of each individual and find the ways to increase business profits. The growing number of Internet users and the promotion of online purchases caused by the pandemic and the depreciation of contacts with people are also reasons for finding new options for obtaining necessary services, which will boost product sharing. One predicts the increase in sharing services among goods whose prime cost is more than 870 EUR by 30% in 2021 compared to 2020 and the increase in the number of users by 40% primarily in urban areas, while most rural residents with worse living standards will find sharing services non-demanded. According to search queries, Ukraine has about 29,200 companies providing sharing services, and their number will increase along with the number of sharing services provided to individuals without registration.

Price formation of sharing services depends partially on the cost of production of goods and mainly on depreciation expenses. There is a fundamental difference between lessors who consider sharing as a business and lessors who lease out goods that are not in use and have no consumer value for the owner at present. The supply of sharing services will be determined by lessors' interest to receive funds for the benefit of goods and not lose their ownership, caused by the need for additional financial income and the availability of free time to sell goods. Depending on the period of use, the residual value of the product decreases, determining the cost of its supply, analysing 100 products in five categories subject to selling and the loss of ownership and 100 products in similar categories leased out on the Olx.ua, the use-value of goods declines unevenly (Figure 2).

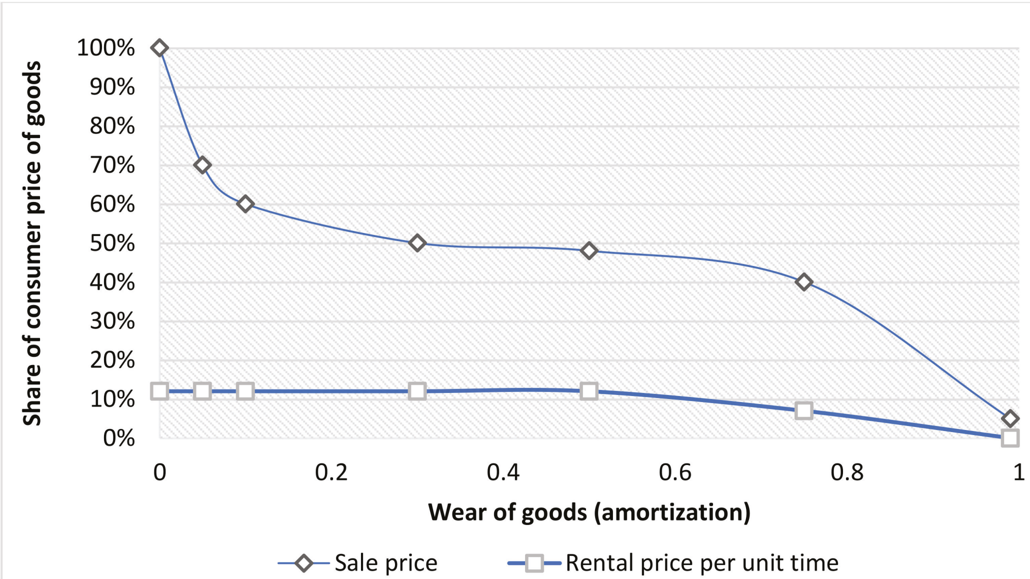

Figure 2. Changes in goods' sale (rental) price of goods depending on their physical wear in Ukraine, 2020 [19].

Figure 2 shows that in the case of the production of goods, their sale price is 100% and includes all the expenses for display and sale. In the case of zero use of the product, most sellers sell it at the total sale price on the market. In the case of leasing out the same effect, its rental price is on average 12% of the sale price and changes only when the product is worn by 80%. Unlike a rental yield, the sale price changes with the wear and tear of the product and even at maximum wear and mostly in invalid condition, it can be sold at a price of about 5% of the initial sale price in the absence of use. In contrast, the product losing consumer properties can no longer be leased out. It proves that the leased goods are stable in the rental price, which primarily includes depreciation expenses and the owner's profit and is less dependent on the product condition.

In contrast, the product's sale price is more flexible and depends on the product condition and external factors. The given conclusions can be used to predict the sale and rental price of the product, research its life cycle and analyse the market. Figure 2 shows that sharing goods and services is less flexible concerning goods sold on the market, equating them with essential commodities.

Prices for sharing goods determine their demand, which is reflected in the supply of goods. As 2020 and 2021 featured the increasing number of Internet users and declining incomes of most of the Ukrainian population, the demand for sharing services increased according to most online stores and customers leaving feedback about products on social networks. According to Olx.ua [19], the Rozetka online store and the survey of 50 respondents on social networks, one conducted a study on the demand for shared goods depending on the individual's income (Figure 3).

One has found out that the middle-income population is the most common user of shared services. In contrast, the people with insufficient budget (up to 172 EUR per month per person) (up to 10% of users) or with an income of more than 4312 EUR thousand per month (in Kyiv) uses shared services in small volumes, which can be the framework for the development of a strategy for promoting shared services and designing advertising campaigns [20].

Figure 3 shows that the share of the population using shared services increases with the growing income to 1300 EUR per month per person (about 60% of the demand) by some users. In contrast, the population with higher aggregate incomes tends to buy goods rather than share.

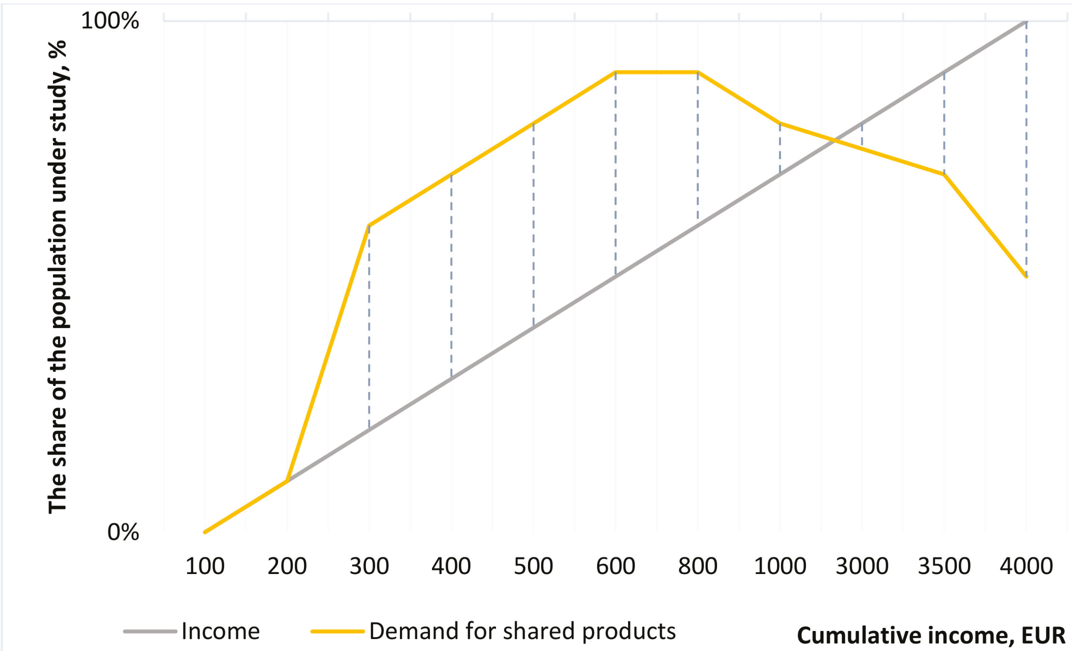

Figure 3. Diagram of population's differentiated income and the dependence of the demand for Scheme 2020.

The use of shared products can be considered a source of alternative income by reducing the price of using the product. In contrast, when buying the same product and meeting the exact needs, using the required resource decreases significantly (in the case of the constant total utility function, the price is lower).

The sharing of goods and services on the Internet (for example, websites sharing software, music, apps, games) has been growing recently. Most companies develop advertising strategies based on the snob effect (Veblen goods) due to their limited number and exclusivity, leading to non-market mechanisms and increased sharing [21].

Marketers widely use the promotion of Veblen goods because of the existence of many bloggers, celebrities who advertise the product on the Internet, increasing its importance and thus increasing the demand. The establishment of the individual's worldview as a potential customer increases the psychological dependence of people on the availability of a particular product that can shape its image and improve its status, which in turn also enhances the demand for sharing [22]. The increasing number of online transactions and the demand for remote goods create conditions for the emergence of the so-called digital market of goods and services, a part of which is sharing, allowing reducing costs and bearing no responsibility for storing goods, their proper condition and depreciation, as these obligations apply only to the owner of the goods, not the lessee.

As a country with poor environmental responsibility and education, Ukraine uses sharing to save costs and comfortably utilize goods without maintenance expenditures. At the same time, developed countries adopt the sharing economy from an eco-friendly perspective [23].

Considering sharing as a part of the concept of product rational use, we can see, at first glance, a significant increase in the life cycle of goods, which positively affects the global environment by reducing the production of goods and anthropogenic burden. The shared use of goods encourages the overproduction of goods and resource-saving and creates a more complimentary and more accessible system of user relationships. A striking example is the transport system based on sharing (public transport) and the recreational sector (resorts, hotels, entertainment, leisure areas, etc.) [24,25]. C2C is the critical trend in 2020–2021 characterised by the transfer of goods for public use from consumers to consumers using online services and social networks. People can spend the saved time on product maintenance to sort out garbage, which requires on average 15 min daily [26], equivalent to 0.34 EUR for Ukraine given the minimum wage as of 2021 [27]. Sharing helps reduce waste, improve the region's ecological state, and establish a circular economy that creates new mechanisms of economic activity in symbiosis with sharing.

When calculating the negative impact on the ecosystem in mechanical engineering, we can see the change in all ecosystem elements around the production plant (points of influence). Atmospheric emissions during the manufacturing of vehicles are dangerous because of the release of sulphur dioxide, carbon monoxide, hexavalent chromium and other heavy metals. Operations also produce waste that gets into the water, making it poisonous and unfit for drinking and dangerous to human health and life. Soils are polluted and natural landscapes and ecosystems are changing. The industry is characterised by significant waste generated, most of which is not reused. In addition to emissions during car operation, a modern car consumes about 50 kg of oxygen per hour.

The cost of car recycling as of 2020 is 260 EUR for passenger cars belonging to individuals; 1725 EUR for commercial vehicles, which is high enough for Ukraine and this leads to illegal disposal of vehicles that negatively affects the ecosystem.

The cost of changing the ecosystem in car manufacturing is about 2587 EUR (calculated based on the negative environmental impact that should be neutralised to bring the ecosystem to its original state at Skoda Auto). Speaking from the perspective of environmental conservation, the establishment of the sharing economy has a positive effect by meeting the public demand for goods and services via joint use without buying goods, which affects the production of goods, reducing the negative impact on the ecosystem. As to the transport sector, taxi services are the main lever for establishing the sharing economy.

The population of Kyiv as of 1 December 2020, was 2,963,199 people, i.e., seven taxi workers registered in taxi services per 1000 people, and the number of private cars per 1000 inhabitants of Kyiv is about 400 [15]. Thus, the reduction of the ecosystem burden due to sharing costs about 673 EUR per day in Ukraine, six thousand EUR (63 cars per 1000 people) in Moscow, and about 1121 EUR per day in Odesa [15].

The sharing economy is closely related to the circular economy based on the increase in the life expectancy of goods through its secondary use. With the introduction of the circular economy, companies plan their development differently, so it is reasonable to develop several scenarios for further activities.

The goal of the European Environment Agency is to reduce harmful emissions into the ecosystem by 2030 and implement decarbonization by 2050, which will also lead to the introduction of the sharing and circular economy [28].

Recently, car purchasing prevails over sharing in Ukraine and the EU countries, although later one will prefer car rental in order to reduce the negative environmental impact.

In the case of the linear economy (Figure 4), we can see a situation when resources are used to produce goods designed for one owner or user, which reduces the consumer properties of goods. The market and movements of financial resources around interests are limited, which is lesser than during sharing adoption. The resource–product–consumption–waste scheme has a negative ecological effect because of the increasing anthropogenic impact caused by a large amount of waste and production, resulting from the higher demand for new goods among consumers.

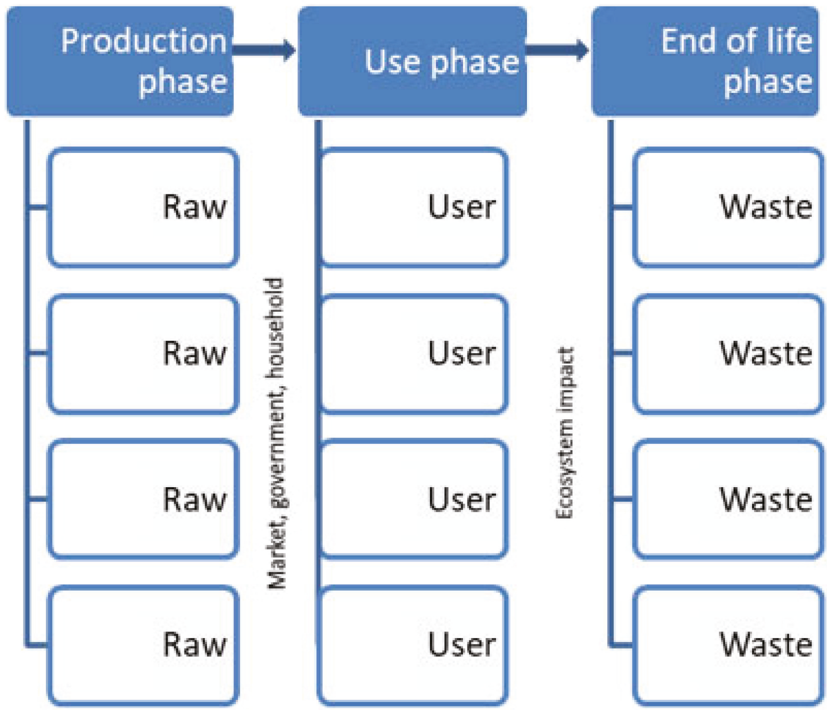

Figure 4. Linear economy model.

One should apply European experience to adopt the sharing and circular economy (Figure 5). Let us consider, for example, an enterprise adopting the sharing economy in Latvia as in a former-Soviet country that has developed according to European standards. However, it has a range of problems and similar situations occurring in the period of the breakup of the Soviet Union and Ukraine. Latvia features a symbiosis of critical principles and laws of Europe and particularities of numerous post-Soviet countries. Ukraine can use Latvia's positive experience in adopting European values, improving living standards and creating favourable conditions for business growth. Therefore, the research is focused on Ukraine and Latvia.

Based on the company's activities, the authors have created three packages: pessimistic, standard and optimistic ones with different characteristics (Table 1) of implementing circular economic projects based on the company's data as case study.

3.1. Pessimistic Package

This package assumes that the company does not change its current situation, namely does not introduce circular economy business models, does not participate in any programs to obtain a certificate ensuring and certifying eco-friendly farming of the company, does not move to other office spaces. The authors wanted to include the shift from three cars to one car and one electric vehicle in the pessimistic model. Project managers and designers mostly use the corporate vehicle. This model is intended to leave one car for other journeys, while the electric vehicle will move within the city [29].

The priority of this package is to reduce costs, and enterprises do not prioritize the integration of circular economy business models.

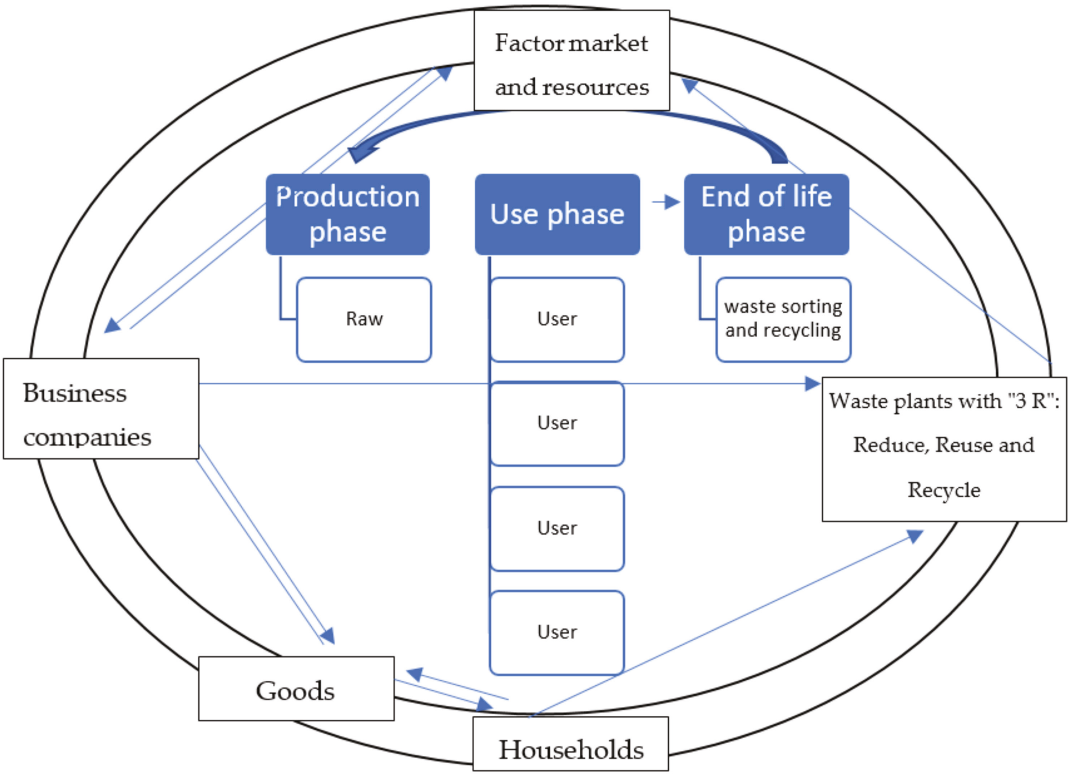

Figure 5. Circular economy model.

Table 1. Different characteristics of business model packages.

Pessimistic Package	Standard Package	Optimistic Package
The company remains in the existing building	Developing industrial symbiosis (sales of shavings)	The office building should be transferred to building A corresponding to the LEED certification
1 purchase of electric vehicles	The company remains in the existing building	Switch to a partial circular economic business model from product to service
1 purchase of a car	Marketing campaign	Obtaining the ISO 14001 certificate
-	1 purchase of electric vehicles	Developing industrial symbiosis
-	1 purchase of a car	Purchase of 2 electric vehicles

3.2. Standard Package

The standard package is based on introducing some circular economic projects, namely the company's more advanced industrial symbiosis. As mentioned above, the company should return by-products generated by the production process to local farmers. Still, the company is expected to accumulate more shavings and sell them to particle collectors to produce other goods. Implementing such a project requires additional expenses related to the accumulation of saws, but the proceeds from their sale are expected to cover the maintenance costs. The authors contacted several shavings purchasing companies such as

Reinpaul OU, Tikala ID, Ltd. Vegranti and Ltd. SK Green Energies. They concluded that the average purchase price of shavings is 6 EUR/m^3. The minimum number of shavings acquired by these companies is 500 m^3. Thus, the company will require additional premises for storing 100 m^2 of shavings (Formula (1)), given that the ceiling of the production building is 5 m [30].

$$S = \frac{V}{h} = \frac{500}{5} = 100\ m^2 \quad (1)$$

where: S—required area of the room (m^2); V—the volume of shavings/the volume of required storage premises (m^3); h—building ceiling height (m).

The company owns the production building. During the interview, the authors has found out that the company pays approximately 1.20 EUR/m^2 for heating the production building within the season (which does not include overhead expenses such as management, repair, etc.). Therefore, the cost of maintaining this building will be around 120 EUR per month. However, it should be noted that this building requires heating throughout the year in order to ensure the appropriate maintenance conditions (humidity, air temperature, etc.).

According to this package, the company is not expected to move to another building because it owns the current office building. As mentioned above, the company carried out marketing campaigns: Replace old things with new ones. However, this standard package provides that Furniture Factory customers return the worn-out chair to the company rather than throw it away. Like the suspicious package, the standard package implies that the company will shift from three cars to one car and one electric vehicle.

3.3. Optimistic Package

This package significantly differs from the above-mentioned packages. It is focused on the improvement of the environment. Therefore, unlike the previous two models, the initial expenses in this package will be higher and will be eventually paid off.

According to the optimistic package, the company adopts a partial circular economic business model, from a product to a service, as the full shift to this business model can face a number of risks [31]. In the optimistic package, the company is expected to lease out 200 office chairs for five years, amounting to 300,000 EUR, while the lease for five years will cost 183,153 EUR, assuming an investment return of 10% per year (Formula (2)) [32].

$$FVn = P_0 * (1 + i)\ n = 300{,}000 * (1 + 0.10) * 5 = 483{,}153\ EUR \quad (2)$$

where: n—period; i—interest rate; P_0—opening amount; FV—future value.

One can conclude that the enterprise will receive 36,630.60 EUR annually from the lessee or 3052.55 EUR per month for 200 leased chairs.

On the other hand, assuming that the company produces 200 office chairs for 300,000 EUR, we can conclude that the lessee will pay 15.26 EUR per month for 1 office chair. As part of the study, one calculates the introduction of the circular economic model provided the following:

- within the first 3 years, one produces 600 chairs and leases them out to three companies (A, B and C), 200 chairs to each one;
- the company produces 200 chairs for company A in 2019;
- chairs are leased out for 5 years and then returned to the company;
- the cost of producing 200 chairs is 300,000 EUR (information was defined during the interview);
- the returned chairs are renewed and become available for further leasing;
- along with chair leasing, the company also sells its products.

Based on these conditions, the authors summarizes revenues and losses from the enterprise's partial shift from manufacturing to providing services in Table 2.

Table 2. The financial result of Furniture Factory in the shift from products to services, 2019–2026, EUR [33].

Revenue, EUR	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**Total**
Company A Lease	0	36,631	36,631	36,631	36,631	36,631	0	0	183,153
Company B Lease	0	0	36,631	36,631	36,631	36,631	36,631	0	183,153
Company C Lease	0	0	0	36,631	36,631	36,631	36,631	36,631	183,153
200 chairs received back	0	0	0	0	0	300,000	300,000	300,000	900,000
Total revenue	0	36,631	73,261	109,892	109,892	409,892	373,261	336,631	1,449,459
Expenditure, EUR									
Production of 200 office chairs	300,000	300,000	300,000	0	0	0	0	0	900,000
Repair of returned chairs	0	0	0	0	0	50,000	55,000	45,000	150,000
Total expenditure	300,000	300,000	300,000	0	0	50,000	55,000	45,000	1,050,000
Benefits or losses from project implementation	−300,000	−263,369	−226,739	109,892	109,892	359,892	318,261	291,631	399,459

Following Table 2, one can conclude that the enterprise will earn 163,532 EUR within seven years in case of shifting from products to services. The overall benefit over the seven years will be 399,459 EUR. Still, the project will start paying off on the sixth year, i.e., from 2025, when the overall benefit of the project will be 107,828 EUR, while on the fifth year the project won't pay off with a total loss of 210,433 EUR (Figure 6) [33].

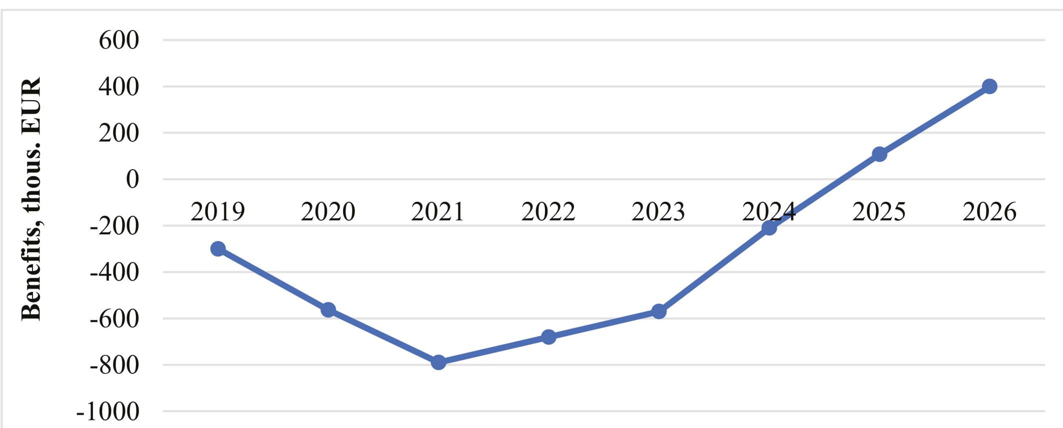

Figure 6. Total benefits from project implementation, thousand EUR [33].

The authors have calculated the overall benefits obtained if these chairs are renovated and leased to companies A, B and C, for the next five years. Given that these chairs are refurbished rather than re-made, the initial expenses are significantly reduced, resulting in the expected benefit of 287.75% higher compared to the first 5-year cycle of 1,548,918 EUR. Leasing out over 200 chairs to three companies for 10 years, NPV will be 940,315 EUR, so it means that the company is also worth leasing out along with product selling.

Besides the introduction of the circular economy business model 'from a product to a service, the company is expected to acquire the ISO 14001 certificate showing that the company cares about the environment and reduces the amount of waste generated by the production process through reuse, recycling, sharing and reducing the number of environmentally unsafe products through targeted research [34]. Similarly, the company moves to building A, corresponding to the LEED certification to reduce the consumption of resources.

Such a building is located near a centre of a North European capital city and surrounded by bank branches, cafes, shops and features easy and fast public transport. This building has 12 offices, and the authors believe that Furniture Factory should move to office 3A with an area of 415 m^2, which is 85 m^2 less than the current area. The rental fee for this office is 13 EUR/m^2, the service charge is 3.80 EUR/m^2, while the average water and energy consumption in this office ranges from 450 to 500 EUR, which is not included in the rental cost.

The total rental cost for the company will be 6972 EUR per month (Formula (3)) [35].

$$Cr = S * (R + SC), \tag{3}$$

where: Cr—Rental costs; R—Lease; SC—Service charge.

During the interview, the authors has found out that the company currently owns the 500 m^2 building while the cost of maintaining the office is 2 EUR/m^2. So, the company currently pays 1000 EUR per month for office maintenance on 177 Freedom Street.

As environmental improvement is a priority for the optimistic model, this package implies the purchase of two electric vehicles to be used by the project manager and designer.

The authors believe that the purchase of electric vehicles contributes to the future of the company as well as to the environmental friendliness. For example, Latvia has 72 charging stations, eight of which are located in Riga (CSDD, 2019). Electricity fees in Latvia also include the total number of electric cars. Total number of normal and fast public charging points in Latvia are shown in Figure 7.

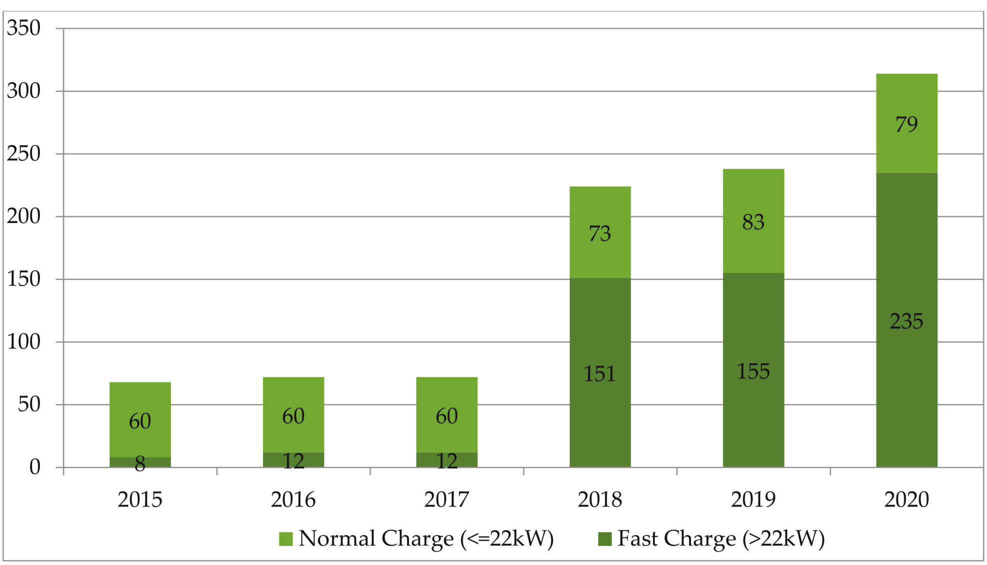

Figure 7. Total number of normal and fast public charging points in Latvia [20].

The purchase of electric vehicles in Latvia remains quite popular: in December 2018, the number of electric vehicles was the highest since July—2079; the amount of electricity transferred increased to 29,485 kWh while in February 2019, it decreased to 22,312 kWh, which was caused by the bad weather on roads.

Therefore, drivers prefer public vehicles. Besides, the electric car battery should always be fully charged in the winter. Otherwise, a half-empty battery freezes and cannot be used seamlessly after charging. In Table 3, the authors summarize the range of electric vehicles offered in Latvia in 2019 that could meet the needs of enterprises.

Table 3. Range of electric cars in Latvia in 2019 [36].

Brand	Model	Electricity Consumption, Wh/km	Distance to Be Travelled, km	Price, EUR
Nissan	e-NV200	259	200	36,252
	Leaf Acenta	206	270	35,900
Hyundai	Kona Electric	154	449	39,990
Volkswagen	E-golf PA	157	300	42,495
KIA	Soul EV	142	230	39,990

According to Table 3, it would be more profitable for Furniture Factory to acquire Hyundai Kona Electric because, first of all, the model of this brand offers a maximum distance of 449 km, so the company would be able to travel further outside the city and would not depend on charging stations.

Secondly, electricity consumption is 154 Wh/km, 12 Wh/km more than in KIA Soul EV. Still, we should note here the maximum distance to be travelled: Hyundai's length exceeds twice KIA's space. At the same time, both models have the same price: 39,990 EUR.

Thirdly, it is possible to change this model at home using the standard household outlet, but the full charge of the 64-kWh battery is considered to take 31 h. The battery can be charged quicker using a particular home charging station: in 9 h and 35 min.

Fourthly, this model has received the 2019′s Latvian car innovation prize and the 2019's Latvian eco-car, which shows its popularity and recognition on the Latvian market [36]. Assuming Furniture Factory buys two above-mentioned cars for 79,800 EUR.

Loading of electric vehicles would cost 73.92 EUR per month, taking into account 1200 km per month and 154 Wh km (Table 4); the loading charge would be 0.40 EUR/kWh [37]. On the other hand, car refunding would cost 100 EUR per month (see Annex 4). In order to ensure the comparable prime cost of electric cars and common cars, it is assumed that the two vehicles travel the same distance of 1200 km per month.

Note that the authors have made a number of additional assumptions during the study (for each package, see Table 4):

1. The discount rate is set at 4% based on Chapter 1.4 of the aggregated scientific literature and best practices in similar projects;
2. Prices rise due to the inflation rate of 2.5% in 2020;
3. The project would be implemented on 1 January 2020, and chairs produced in 2019 would used at a total amount of 300,000 EUR;
4. Annual sales of shavings: 1000 m^3 (information obtained in the interview)
5. As part of the study, the authors calculate the following:
6. The cost of Furniture Factory without the introduction and adoption of the circular economy for each package (pessimistic, standard and optimistic);
7. Total benefits or losses from the implementation of circular economic projects;
8. The net present value (NPV).

As shown in Table 4, the cost of the suspicious package amounts to 83,164 EUR. In comparison, the cost of implementing circular economic projects in the standard package amounts to 87,284 EUR, which is 4120 EUR, or 4.9%, more than in the suspicious package [38]. It is primarily related to the expenses for the company's marketing campaign.

In the optimistic model focused on sustainable environmental development rather than cost reduction, the expenses for implementing circular economic projects in the first year are 390,670 EUR, which is 303,386 EUR more than in the standard model. The increase in costs is related to the circular economy business model, from the product to the partial shift to services. As part of this project, the company will produce additional 200 chairs cost 300,000 EUR and move to the LEED certification building [33]. The suspicious package of enterprise financial results between 2020 and 2024 is presented in Table 5.

Table 4. Summary of the expenses for implementing circular economic projects according to a package type, in EUR [38].

Type of Expenses	Pessimistic Package	Standard Package	Optimistic Package
Rental fee of the office, per month	0	0	6972
Cost of office maintenance, per month	1000	1000	450
ISO 14001 certificate	0	0	3000
Cost of storing shavings in the production building, per month	0	120	120
Marketing campaign expenses	0	4000	0
Partial shift to the business model: from a product to a service	0	0	300,000
Purchase of electric vehicles	39,990	39,990	79,980
Electricity (electric vehicles), per month	74	74	148
Purchase of a car	42,000	42,000	0
Fuel, per month	100	100	0
Total expenses	83,164	87,284	390,670

Table 5. Financial results of Furniture Factory in implementing the suspicious package, 2020–2024, EUR [33].

Type of Expenses	2020	2021	2022	2023	2024	Total
Furniture Factory without circular economy						
Office cost	12,000	12,300	12,608	12,923	13,246	63,076
Cost of production building	90,000	92,250	94,556	96,920	99,343	473,070
Fuel, 3 cars	3600	3690	3782	3877	3974	18,923
Purchase of 3 cars	126,000	0	0	0	0	126,000
Total expenses	231,600	108,240	110,946	113,720	116,563	681,068
Furniture Factory with circular economy						
Office cost	12,000	12,300	12,608	12,923	13,246	63,076
Cost of production building	90,000	92,250	94,556	96,920	99,343	473,070
Fuel, 1 car	1200	1230	1261	1292	1325	6308
Purchase of 1 car	42,000	0	0	0	0	42,000
Purchase of 1 electric vehicle	39,990	0	0	0	0	39,990
Electric vehicles	887	887	887	887	887	4435
Total expenses	186,077	106,667	109,312	112,022	114,800	628,878
Benefits or losses from the introduction of the circular economy	45,523	1573	1635	1698	1762	52,190

Following Table 5, one can conclude that the circular economy projects mentioned in the pessimistic package should be implemented, as they provide the company with additional benefits: NPV over 5 years at a discount rate of 4% is 49,579 EUR, which is quite positive.

The standard package of enterprise financial results between 2020 and 2024 is presented in Table 6.

Table 6. Financial results of Furniture Factory in case of implementing the standard package, 2020–2024, EUR [33].

Type of Expenses	2020	2021	2022	2023	2024	Total
Without circular economy						
Office cost	12,000	12,300	12,608	12,923	13,246	63,076
Cost of production building	90,000	92,250	94,556	96,920	99,343	473,070
Fuel, 3 cars	3600	3690	3782	3877	3974	18,923
Purchase of 3 cars	126,000	0	0	0	0	126,000
Total expenses	231,600	108,240	110,946	113,720	116,563	681,068
Furniture Factory with circular economy						
Office cost	12,000	12,300	12,608	12,923	13,246	63,076
Cost of production building	90,000	92,250	94,556	96,920	99,343	473,070
Fuel, 1 car	1200	1230	1261	1292	1325	6308
Purchase of 1car	42,000	0	0	0	0	42,000
Electricity (1 electric vehicle)	887	887	887	887	887	4435
Purchase of 1 extra car	39,990	0	0	0	0	39,990
Marketing campaign	4000	0	0	0	0	4000
Cost of storing shavings in the production building	1440	1440	1440	1440	1440	7200
Total expenses	191,517	108,107	110,752	113,462	116,240	640,078
Revenue from the sale of shavings	6000	6000	6000	6000	6000	30,000
Benefits or losses from the circular economy	46,083	6133	6195	6258	6322	70,990

Following Table 6, one can conclude that the circular economy projects mentioned in the standard package should be implemented, as they provide the company with additional benefits: NPV over five years at a discount rate of 4% is 66,033 EUR, which is quite positive.

Comparing the standard model with the pessimistic one, we can see that NPV of the company in the standard model at a 4% discount rate over 5 years is 16,454 EUR, or 33.2%, higher than in the pessimistic model. This is mainly due to the circular economy industrial symbiosis model included in the standard model, namely the sale of by-products (particles).

One can conclude that when choosing between these two packages, the company should prefer a standard package because the overall benefits over 5 years are higher than in the pessimistic model.

The optimistic package of enterprise financial results between 2020 and 2024 is presented in Table 7.

Following Table 7, one can conclude that the implementation of the circular economy projects mentioned in the optimistic package causes losses to the company, as NPV over 5 years at a discount rate of 4% is 142,969 EUR, which is quite negative.

However, this is only if all projects mentioned in the optimistic package are implemented. If one adopts only the product-to-service business model, it brings overall benefits to the company (Table 2). Apart from losses to the company in the optimistic package, one assumes that the company moves to another building, resulting in additional expenses for the company compared to the current office costs. The overall benefits of the company's optimistic package are obtained if the company does not move to a new office building (Table 8). Following Table 8, we can see that without the company's moving to the building corresponding to the LEED certificate, the overall benefits of the 5-year optimistic package would be 259,026 EUR. On the other hand, NPV would be 191,773 EUR, which should be considered positively. This is mainly due to the company's partial shift to the product-to-service business model. However, this result is possible only if the company receives used chairs back in 2024 and does not immediately conduct their repair leading to increased expenses.

Table 7. Financial results of Furniture Factory in case of the implementation of the optimistic package, 2020–2024, EUR [33].

Type of Expenses	2020	2021	2022	2023	2024	Total
Without circular economy						
Office cost	12,000	12,300	12,608	12,923	13,246	63,076
Cost of production building	90,000	92,250	94,556	96,920	99,343	473,070
Fuel, 3 cars	3600	3690	3782	3877	3974	18,923
Purchase of 3 cars	126,000	0	0	0	0	126,000
Total expenses	231,600	108,240	110,946	113,720	116,563	681,068
Furniture Factory with circular economy						
Office cost	83,664	85,756	87,899	90,097	92,349	439,765
Cost of production building	90,000	92,250	94,556	96,920	99,343	473,070
Electricity (2 electric vehicles)	1774	1774	1774	1774	1774	8870
Purchase of 2 eco-vehicles	79,980	0	0	0	0	79,980
Partial shift to the business model: from a product to a service	300,000	0	0	0	0	300,000
ISO 14001 certificate	3000	0	0	0	0	3000
Cost of storing shavings in the production building	1440	1440	1440	1440	1440	7200
Total expenses	559,858	181,220	185,670	190,231	194,907	1,311,885
Revenue from partial shift to the business model: from a product to a service	36,631	36,631	36,631	36,631	336,631	483,153
Revenue from the sale of shavings	6000	6000	6000	6000	6000	30,000
Total benefits	42,631	42,631	42,631	42,631	342,631	513,153
Benefits or losses from the circular economy	−285,627	−30,349	−32,093	−33,881	264,287	−117,664

Following Figure 8, it is more beneficial for the enterprise to adopt the standard package between the standard and suspicious packages. The total benefits over five years are 18,800 EUR, or 36%, higher than in the suspicious package.

On the other hand, the authors point out that the optimistic package results in a total loss of 117,664 EUR over five years, as the number of projects is expected to be implemented in this package. The main reason for the losses is company's moving to the new office building. If the structure remains the same, the total benefits for the company would be 259,026 EUR.

The authors conclude that the company should implement projects in the optimistic package and stay in the existing office building. The critical circular economy project that the company should implement is the partial shift to the product-to-service business model, which creates additional benefits.

In Formulas (4)–(7), the authors compile and calculate the financial ratios of Furniture Factory for 2017 affected by the adoption of circular economy business models. They use the company's 2017 annual report for the calculation, as well as the company's 2016 and 2015 annual reports to compare the results obtained in previous years.

$$\text{ROE 2017} = \frac{267,366}{(504,700 + 237,333)/2} = 72.1\% \quad (4)$$

Table 8. Financial results of Furniture Factory in case of the implementation of the optimistic package without moving to a new office building, 2020–2024, EUR [33].

Type of Expenses	2020	2021	2022	2023	2024	Total
Without circular economy						
Office cost	12,000	12,300	12,608	12,923	13,246	63,076
Cost of production building	90,000	92,250	94,556	96,920	99,343	473,070
Fuel, 3 cars	3600	3690	3782	3877	3974	18,923
Purchase of 3 cars	126,000	0	0	0	0	126,000
Total expenses	231,600	108,240	110,946	113,720	116,563	681,068
FURNITURE FACTORY with circular economy						
Office cost	12,000	12,300	12,608	12,923	13,246	63,076
Cost of production building	90,000	92,250	94,556	96,920	99,343	473,070
Electricity (2 electric vehicles)	1774	1774	1774	1774	1774	8870
Purchase of 2 eco-vehicles	79,980	0	0	0	0	79,980
Partial shift to the business model: from a product to a service	300,000	0	0	0	0	300,000
ISO 14001 certificate	3000	0	0	0	0	3000
Cost of storing shavings in the production building	1440	1440	1440	1440	1440	7200
Total expenses	488,194	107,764	110,378	113,057	115,803	935,196
Revenue from partial shift to the business model: from a product to a service	36,631	36,631	36,631	36,631	336,631	483,153
Income from the sale of shavings	6000	6000	6000	6000	6000	30,000
Total benefits	42,631	42,631	42,631	42,631	342,631	513,153
Benefits or losses from the circular economy	−213,963	43,107	43,199	43,293	343,390	259,026

In Figure 8, the authors summarize the total benefits or losses over 5 years for each package.

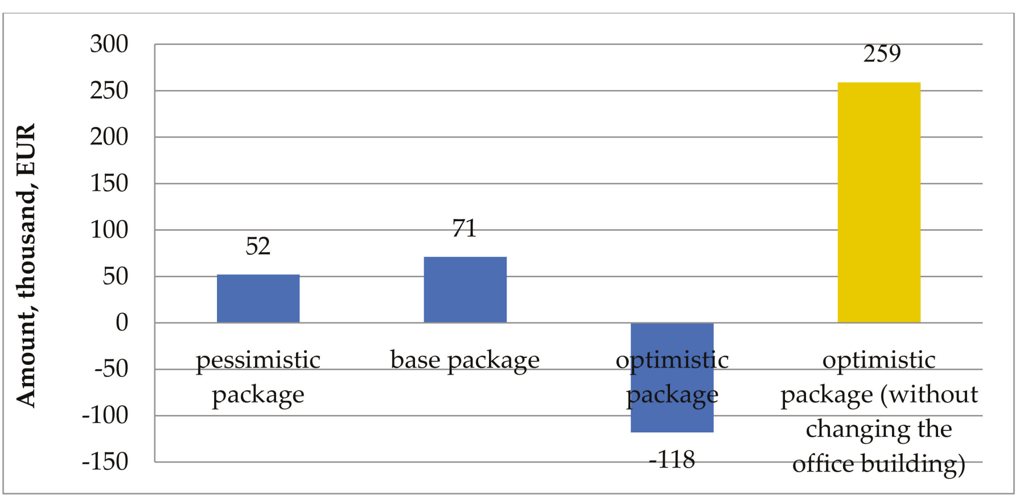

Figure 8. Benefits or losses from the introduction of a circular economy (thousand EUR).

One concluded that Furniture Factory had a high return on equity of 72.1% in 2017. The introduction of circular economy business models is expected to result in increasing revenues, so ROE will grow. However, if this does not happen, the company should find the cause.

The period of 2015–2017 is shown in Figure 9.

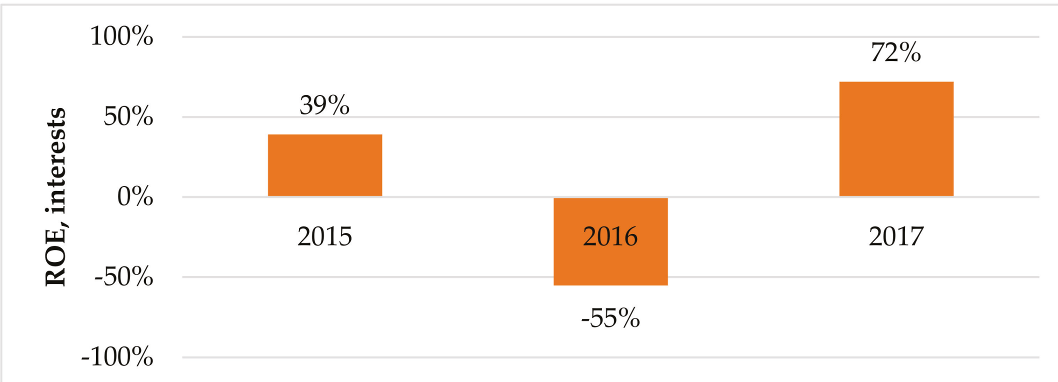

Figure 9. Return on equity, 2015–2017 (interests).

The ROE indicator is essential for owners as it shows the return on invested funds. According to Figure 9, the company's ROE is volatile: 35% in 2015, but 55% in 2016 because of the company's losses this year (211,370 EUR). However, in 2017, it increased to 72%, which should be considered positively, as it means returning of 0.72 cents from each EUR invested and receiving of 0.39 cents in 2015 from the owners of each 1 EUR invested, while in 2016, the owners did not obtain any profit on their investments, as the figure was negative.

At the return on assets of 35.2% (see Formula (5)), we can see that the company efficiently uses funds in its operations. The adoption of circular economy business models is expected to increase the company's revenues so that ROA will also increase in reducing expenses.

However, suppose ROA decreases after adopting the circular economy. In that case, one should conclude that the introduction of the circular economy does not benefit the company and that expenses are not reduced.

$$\text{ROA 2017} = \frac{267,366}{(956,056 + 574,382)/2} = 35.2\% \quad (5)$$

The period of 2015–2017 is shown in Figure 10.

ROA shows how efficiently the company uses funds in its operations. We can see that ROA shows a similar trend as ROE, which is harmful in 2016 because the company suffered losses. The return on assets in 2015 was 24%, while it increased to 35% in 2017, which should be considered positively.

The debt-to-equity ratio (D/E) of 87.4% (see Formula (6)) indicates that the company depends on borrowed capital. The company should closely monitor its share of liabilities. It could be difficult for a company to obtain a loan at that rate. However, note that it is 2017′s data. The situation could be better in 2018.

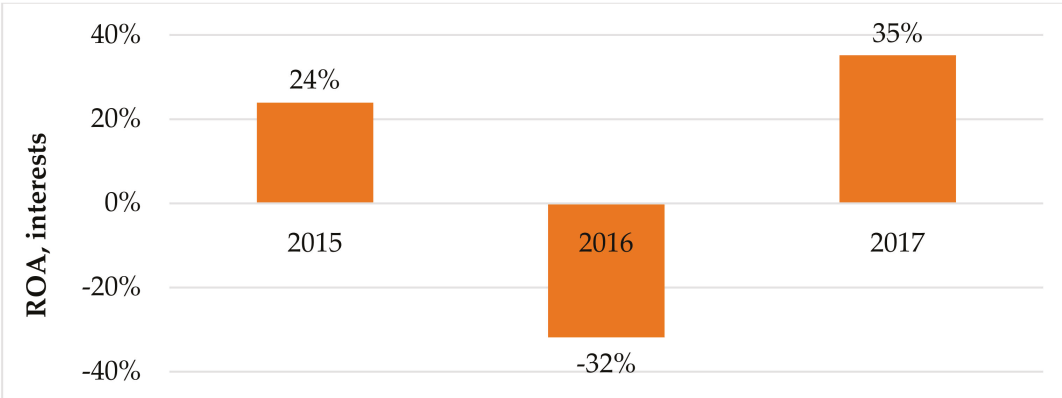

Figure 10. Return on equity in Furniture Factory, 2015-2017 (interests).

Analyzing the annual reports, the authors found that the most significant proportion of short-term liabilities accounts for other loans, primarily from Carpa Ltd. and financial leases. In our case study, the owner of Carpa Ltd. and Furniture Factory is the same person. In 2017, Furniture Factory received 90,000 EUR of interest-free loans from Carpa Ltd. for an indefinite period, amounting to 86.25% of the total amount of other loans, or 20.39% of the total amount of liabilities in 2017.

$$\text{D/E 2017} = \frac{441,356}{504,700} = 87.4\% \quad (6)$$

The debt-to-equity ratio in the examined years (2015–2017) was the highest in 2016: 136%. This is primarily caused by the company's losses this year (202,094 EUR), consequently reducing equity.

Besides, the debt-to-equity ratio grew in 2016: total liabilities raised by 49% in 2016 compared to 2015. The increase in liabilities was related to the rise in the other loans item, like 2017. The company received an interest-free loan of 90,000 EUR from Carpa Ltd., resulting in increasing liabilities.

On the other hand, in 2015, the debt-to-equity ratio was the lowest in the examined years, namely 43%, as the company did not receive any loans from related parties (like 2016 and 2017). Thus, the total liabilities were the lowest this year: 225,355 EUR.

The total liquidity shows whether a business entity has sufficient working capital to cover its short-term liabilities. The furniture Factory indicator is within typical limits in 2017 (Formula (7)).

Note that the calculation of the total liquidity considers short-term liabilities where the company's key share accounts for the other loans section, namely financial leasing and primary loans from related parties in the examined years from Carpa Ltd.

$$\text{Total liquidity 2017} = \frac{621,120}{424,662} = 1.5 \quad (7)$$

Following Formula (7), one can conclude that the company is a part of all examined years within the optimal limits of total liquidity (1–3). However, note that in 2016, the company's total liquidity was close to the lowest optimal threshold, i.e., 1.1, which cannot be assessed too positively, as when this figure falls below 1, the company could fail to settle short-term liabilities. In 2015, however, this indicator reached the optimal upper limit of 3, which cannot be judged too positively. If this indicator is above 3, it means the use of inefficient working means. On the other hand, in 2017, the company's total liquidity was

1.5, which should be assessed positively based on information from Lursoft (2019), and 0.70 on average in the sector in 2017 [33].

The authors believe that the calculated financial ratios and indicators contained therein provide valuable information to the company on adopting of circular economic business models.

The practical part of the study allows us to conclude that the company can successfully integrate circular economy business models in order to ensure positive NPV.

Considering environmental damages caused by the anthropogenic impact on the ecosystem, it is reasonable to adopt the principles of sharing economy at enterprises (Figure 11), which will positively affect company's economic performance in the long run [39].

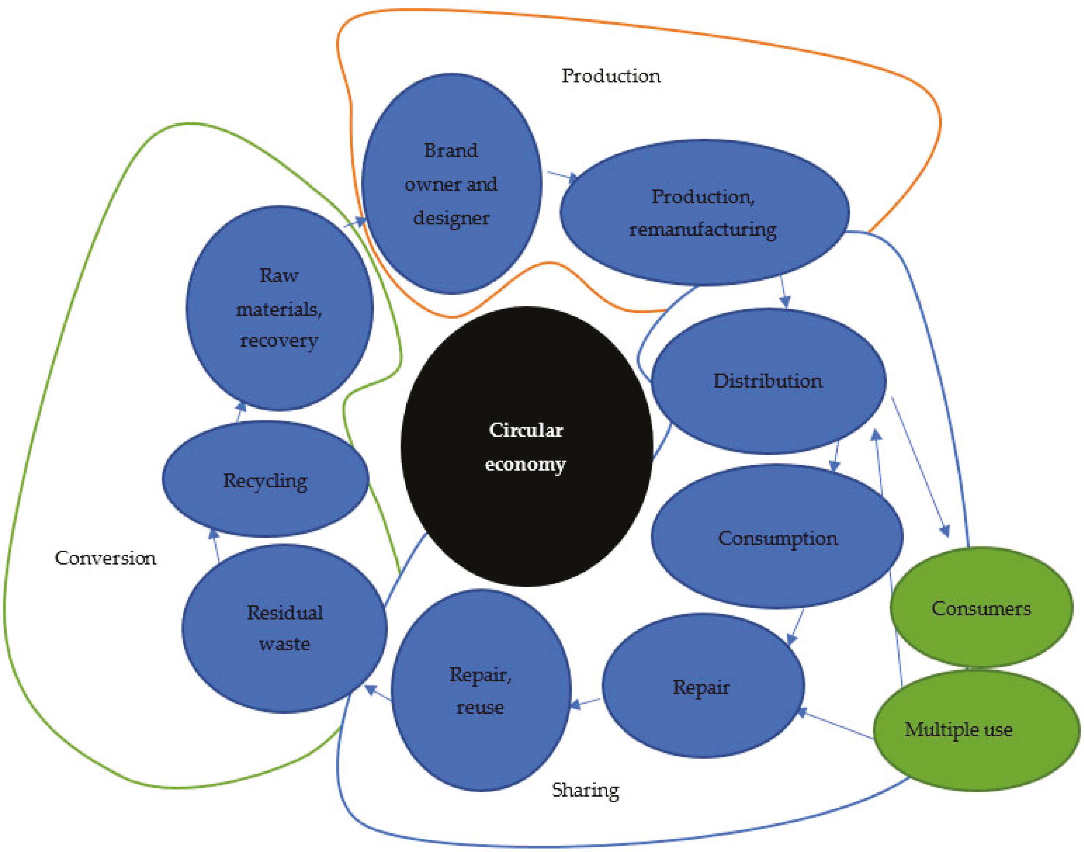

Figure 11. Relation between sharing and circular economy.

Considering the circular economy theory from the perspective of its increasing efficiency, it is reasonable to adopt sharing, as its part that functions at the stage of selling and using, which will substantially enhance product usefulness and prolong the life span of goods. The principles of sharing economy supplement the principles of circular economy, making it more flexible and comprehensive due to alternative options and information technologies [40]. Additional advertising of shared goods can boost sales of new similar products, increase the money turnover and the number of transactions, positively affecting macroeconomic indicators [41]. The functioning of the circular economy system will encourage resource-saving and energy-saving, manufacturing rationalization and reduction in negative remnants, which is a part of the zero-waste concept popular in numerous developed countries. The production stage also faces changes while adopting the circular economy, which have positive economic and ecological effects [42]. The introduction of the circular product movement system can also lead to changes in social life. We could see a sharp increase in employees in information, digital, innovative and services sectors. At the same time, one could reduce the share of inhabitants engaged in the manufacturing and extraction of primary resources. The foundation for the shift to the fully efficient circular economy is the recycling of goods and automation of manufacturing processes, giving an impetus for developing cutting-edge systems, software, innovative technologies, and their integration into life. Sharing is a model for establishing a robust system of small and medium businesses that are critical taxpayers in such developing countries as Ukraine and an efficient tool for improving the economic state. The authors can conclude that sharing is a part of the circular economy that should be implemented in society to achieve strategic national goals and improve the quality of social life and the ecosystem.

4. Discussion

Global experience has shown that companies in the sharing economy are achieving international success at an unprecedented rate. In developing countries, with the introduction of Internet technologies, the problem of limited resources and the production of substandard goods contribute to the introduction of sharing and the circular economy. However, the overproduction and insecurity of local producers pose a problem for entrepreneurs. The transformation of the economic system is slow in the post-Soviet countries, while Internet services are developing rapidly, but this is leading to Internet fraud and poor-quality services [43,44].

Urbanization processes also contribute to the development of sharing by reducing the distance and increasing access to rental goods, which should be studied in the time interval to analyze other trends.

The choice of a specific strategy for different activities primarily depends on the company's management and the government, although global trends have an increasing impact on the results. The rapid development of technology makes it necessary to evaluate the financial situation and choose the most convenient ways of developing the company. In this case, it is more convenient to adapt the experience of other companies and adapt to their interests. As sharing has a resource-saving effect, except the economic one, it should be adopted in all countries where it is possible to increase the product life span. In Ukraine, the widespread use of sharing can be prevented by insufficient financial resources of the population, the absence of the Internet and the out-of-date way of thinking among residents above 60 years of age. The concept of doing business in Ukraine and most post-Soviet countries is still based on maximizing profits in any way. At the same time, European trends focus on other areas, including the environment, used to improve the welfare of the population. All of this affects projects implemented in developing countries where short-term business models prevail and the anthropogenic impact increases, which will lead to the point of no return and the rapid shift to the sharing economy and reuse of goods and resources in the future [45].

As the problem of nature conservation and reduction of non-environmental production capacity with a simultaneous increase in products sold on the market is relevant and has a cumulative effect, this research has prospects for further improvement. The adoption of the sharing economy is dynamic due to the development of innovations that affect all processes of human life. The imbalance between human beings and the environment increases, and the risks grow. Therefore, the discussion of this topic is promising in further research.

5. Conclusions

Increased digitalization has led to increased provision of shared services, which is especially noticeable in developing countries due to the relatively low level of income and the tendency to save financial resources without additional expenses for their maintenance.

According to Ukrainian websites engaged in selling shared goods and services, the rental price of goods is less flexible than the sale price of similar interests on the market within the country. As a component of the circular economy, the sharing model promotes not the overproduction of new things but the rational use of those already produced, which can significantly reduce the amount of waste generated at all stages of the product's life cycle. Sharing is one of the factors in establishing a circular economy. The increase in the life span of goods and the enhancement of their social utility can positively affect economic indicators and ecological parameters. They can encourage resource-saving and adoption of the Zero waste concept.

Analysing the range of shared goods, we can see the greatest demand for goods and services with a purchase price of less than 1000 EUR for Ukraine, which indicates the unsatisfactory economic situation of citizens and the use of sharing primarily to save household finances while the environmental effect is not of high priority for the population of Ukraine. When developing scenarios for further development through the example of the furniture company, one has found out that the optimistic system based on the principles of the circular economy has a higher prime cost and a more extended payback period primarily because of marketing losses.

The calculations shown can help develop methodologies to help companies justify raising financial resources for circular economy measures.

The research reveals that the company's lease and subsequent repair and sale or restoration of sharing is more environmentally friendly. It is based on the circular economy principles, waste reduction, resource-saving for production and increase in product life. Due to the adoption of an optimistic model, which is preferred, more environmentally friendly and establishes the principle from simple production of goods to services for maintenance and repair of goods and their further operation, faces higher expenses. Still, it will be more profitable in the long run than in the standard and pessimistic scenarios by creating additional projects, saving resources and ensuring environmental friendliness, which will positively impact public health.

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Green Intellectual Capital as a Support for Corporate Environmental Development—Polish Company Experience

Edyta Bombiak

Faculty of Social Sciences, Siedlce University of Natural Sciences and Humanities, Konarskiego 2, 08-110 Siedlce, Poland; edyta.bombiak@uph.edu.pl

Abstract: Green intellectual capital (GIC) is a distinctive intangible asset that may assist organizations in pursuing sustainable development strategies. In Polish organizations, interest in this new concept is low. Analysis of the literature showed a lack of research regarding the implementation of GIC practices or their impacts on the sustainable development of organizations in Polish enterprises. In order to fill the detected research gap, the study covered 150 randomly selected Polish enterprises. The purpose of the research was to determine the impact of activities fostering GIC on the environmental development of companies in Poland and to identify major practices supporting GIC development. In addition, the author attempted to establish a correlation between the impact of individual practices oriented at GIC formation and their practical implementations in the analyzed enterprises. The first stage of the analysis focused on identification of activities leading to the accumulation of GIC implemented in Polish organizations. The second stage involved an assessment of the level of impact of actions contributing to GIC formation on the environmental development of the studied enterprises. During the third stage, the author investigated the relationship between the impact of individual practices oriented at GIC formation and their practical implementation in the analyzed organizations. The study demonstrated that actions supporting GIC formation have an uneven impact on corporate environmental development. Among the key factors identified by the author were environmental attitudes of employees in the working environment (such as paper and energy saving), environmental knowledge, and the implementation of innovative environmental projects. Furthermore, the author established a correlation between the impact assessments of activities leading to GIC accumulation and their practical implementations. The research demonstrated that activities assessed by respondents as more important are more often implemented in practice. The findings of the research may stimulate interest in GIC development and extend the scope of application of GIC-fostering practices over organizations operating in the energy sector.

Keywords: green intellectual capital; green human capital; green organizational capital; green relational capital; environmental development; sustainable development

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1. Introduction

Environmental management has recently become a major field of management [1]. In the contemporary business environment, sustainable companies succeed in the market, as they are able to secure resources and develop competencies to meet the challenges of environmental limitations [2]. Consequently, balance should be maintained amongeconomic, social, and environmental goals [3]. The motives behind the greening of economic activities are the growth in the awareness of and the responsibility for the conditions of the natural environment, the reinforcement of provisions on environmental protection, and the growing demand for ecological products [4].

Intellectual capital has recently come to the forefront as part of the search for methods thatimprovecorporate environmental effectiveness [5,6]. Intangible assets are commonly considered to be competitive advantages and as such may effectively stimulate achievement of sustainable corporate goals [7,8]. Despite diverse publications focusing on intellectual capital (IC), its full potential for building sustainable organizations has not yet been 'unlocked'. This is demonstrated by a small number of studies on green intellectual capital (GIC) [9–11]. The prime focus of research is on the impact of IC on corporate performance and competitiveness. However, the relationship between green intellectual capital and sustainable development is under-investigated [12]. The limited availability of publications addressing the issue of green intellectual capital leadsone to assume that the concept is unknown, given the Polish conditions. This fact inspired the author to research the implementation of practices supporting GIC accumulation in young Polish enterprises.

A review of the literature revealed a gap in the field of empirical research on the impact assessment of GIC on the environmental development of Polish enterprises. The author intended to bridge the gap, at least to some extent.

The objective of this research article was to assess the rate of use of practices oriented at GIC formation to support corporate environmental development and establish a relationship between the impact assessments of individual practices leading to GIC accumulation and their implementation in enterprises. The analysis includes an identification of practices oriented at GIC formation and prioritization according to the environmentaldevelopmentimpact of anorganization.

In the course of the analyses, the author addressed the following research questions:

- What activities leading to the accumulation of GIC do Polish enterprises implement?
- What is the impact of these activities on the environmental development of Polish organizations?
- What GIC-fostering practices are key to the environmental development of organizations in the Polish reality?
- Is there a relationship between the impacts of GIC-fostering practices and their implementation in the analyzed Polish enterprises?

This research article contributes to the source literature by diagnosing a gap associated with GIC use as a tool for building sustainable enterprises. The results of the research may motivate managers to take corrective actions in the management process. In the author's opinion, the findings of the research may stimulate interest in GIC development and extend the scope of application of GIC-fostering practices to organizations operating in the energy sector. The energy sector now faces enormous challenges presented by a growing energy demand. At the same time, the EU and other countries around the world are introducing new regulations to reduce climate change and secure energy supplies. This opens up an opportunity to create a novel sustainable energy sector for future generations. Effective management of green intellectual capital can contribute to the improvement of energy efficiency and support the development of renewable energy sources. The identification of a correlation between GIC and corporate environmental development increases the understanding of how companies can achieve sustainable results through strategic management of their green intellectual capital.

2. Literature Review

2.1. Sustainable Development and Its Objectives

Given the harsh international regulations concerning environmental protection and high green awareness of consumers, it is critical to adopt an innovative approach to contemporary organization management. This will pave the way towards new paradigms, which will show the route to follow in order to attain a lasting competitive edge. Sustainable development is based on the pursuit of best economic performances, while respecting the natural environment and social development [13]. According to the World Commission on Environment and Development, sustainable development is development that satisfies the needs of the present generation without preventingthe ability offuture generations to meet their own needs (World Commission on Environment) [14]. The concept draws upon/accomplishes goals inthree areas:

- Environmental—stopping environment degradation and eliminating environmental threats;

- Economic—capturing the use of technical and technological solutions in order to satisfy material needs that, at the same time, constitute minimum threats to the environment;
- Social—eradicating famine and poverty; focusing on health protection, safety, and education development [15].

As noted by Komiyama and Takeuchi, within the concept of sustainable development, there is considerable pressure on liquidating growth barriers, poverty, implementing innovative solutions, environmental protection, and resource restoration, which arecrucial, given the new global conditions [16]. Sustainability means finding a balance between the developmental needs of the organization and environmental protection [17]. The main vector of sustainable development is the “green economy” [18].

In 2015, in New York, 193 UN states unanimously adopted a new 2030 agenda, consisting of 17 sustainable development goals and 169 sustainable development tasks. The agenda started a new era of international-level cooperation, obliging all states to undertake a number of sustainable development-centered actions. Countries must seek ways to prevent poverty, increase welfare, and meet the health, education, and sporting needs of people, while protecting the environment [19].

Implementing sustainable development goals requires corporate sustainability in economic, environmental, and social areas. Economic sustainability involves increasingcorporateprofitability through efficientuse of resources, effective projects and undertakings, and good management practices. Ecological sustainability requires protecting the environment by sparing the use of natural resources [20] and promoting renewable resources. The core of social sustainability is to recognize and consider the needs of the local population [21]. Sustainable development is an unending process of change management because it requires permanent modifications of habits, values, awareness, and behaviors of employees, consumers, company owners, decision-makers, and managers. A shift in ecological awareness is particularly relevant [22].

The subject literature demonstrates an increasing popularity of the thesis—that the key elements of the modern sustainable management strategy are intangible assets, above all, green intellectual capital [12,23]. This is due to the fact that research studies corroborate the positive impact of GIC on corporate environmental performance [24].

2.2. Green Intellectual Capital and Its Components

Green intellectual capital (GIC) is defined as a “total of knowledge about the use of the process of environmental management in order to gain competitive advantage” [25]. This knowledge is demonstrated in various ways. It includes knowledge present in employees, databases, internal relations, external relations, processes, or systems. GIC comprises three components [7,26,27]:

- Green human capital (GHC);
- Green organizational capital (GOC);
- Green relational capital (GRC).

The three GIC components interrelate and interact with eachanother [28].

Green human capital (GHC) is made up of employees who demonstrate knowledge, qualifications, and experience in the field of environmental protection, and who present environmentally-friendly attitudes [7]. GHC is a green workforce that understands, appreciates, and undertakes green initiatives. It is the staff who aim to develop eco-friendly working environments and who arecommitted to ecological principles, not only at work but also in their private lives [29]. These individuals represent extensive involvement and pride in green initiatives. They form a distinct group known as “green-collar workers”, i.e., workers who are committed towardlimiting the negative natural environmental impacts of organizations [30,31]. These may be lower-, middle-, or higherlevelsof physical or intellectual employees. Green jobs include, among others, ecological auditors, ecological campaign management specialists, or energy efficiency advisors [32].

GHC are workers who [33]:

- Feel responsible for the condition of the natural environment;
- Use natural resources sparingly;
- Avoid activities leading to environment destruction;
- Engage in pro-ecological initiatives;
- Take care of green working conditions by limiting the amount of paper used in offices, use energy-saving equipment and renewable energy sources, and participate in recycling programs.

Green organizational capital (GOC), also known as structural capital, captures intangible and legal assets, databases, and invisible assets, such as green organizational culture, philosophy, systems of management of environmental knowledge, and processes, methods, and structures pertaining to environment protection and supporting green initiatives [7,8,24,34]. It provides the necessary support to GHC to achieve corporate environmental goals [9,35]. Unlike human capital, organizational capital is the property of the company and it may be traded, reproduced, or shared within the company [36].

Green organizational culture is a critical component of GIC. GOC is based on the regulations shaping the pro-ecological behaviors of employees [37]. Such culture fosters green practices among employees and that is why it plays a major role in the formation of sustainable companies [38,39]. As a result, green culture development is viewed as anunderlying condition for continuing the growth of the environmental effectiveness of an organization [40,41].

Another vital element of GOC isenvironmental management. It is oriented at product greening and implementing environmentally-friendly manufacturing processes. It is shaped by management boards and should encompass the following [42]:

- Priorities and objectives of environmental protection;
- Methods tomeet all legal requirements;
- Companyattitudes to environmental requirements concerning the recipients of goods and services;
- Direction of development of environmental requirements, with respect to the suppliers of raw materials and consumables;
- Rules toreduce the environmental burdens of companies and to produce goods;
- Methods to coordinate environmental policies with other company activities.

Pursuing any environment management strategy is associated with the need to conduct an environmental review, design action schemes, plan the execution of adopted tasks, and provide suitable staff.

The final component of GIC is green relational capital (GRC). GRC is defined as knowledge based on relationships with stakeholders. It is composed of relations with customers, suppliers, strategic partners, institutions, and other members of networks related to environment management and green innovations, which lead to sustainable operations [7,8,24]. These relationships are based on trust built up between partners through past interactions [43]. GRC is of major importance tothe formation of human and structural capital [44]. Both the organization and its stakeholders can benefit from relational capital development [45]. It enhances communication, augments willingness to cooperate, and spurs engagement in the joint creation of an added value [46–48]. According to Woo et al. [49], one effect of GRC is improved cooperation between the purchaser and the supplier in terms of environment protection. This is because GRC helps supply chain members share knowledge about ecological production. It facilitates cooperation in environmental protection, green innovation, and in developing business processes committed to reducing adverse environmental impacts [50,51].

One component of GRC is green reputation, also known as green corporate image or corporate environmental reputation [52,53]. Studies have demonstrated that green corporate image reinforces its industry position and simplifies competitive advantage development [54]. Other studies confirm the presence of positive correlations between corporate reputation and customer satisfaction and their loyalty [55]. Green reputation attracts customers who seek products that have positive impacts on the natural environment, strengthening customer relations. Moreover, it stimulates cooperation with stakeholders who feature environmentally-friendly attitudes. All of the above contributed to GRC improvement.

Another constituent of green image development is green reporting connected with green bookkeeping [56]. According to Dilling [57], environmental accounting proves the environmental and social responsibility of companies, whereas green reporting is an element of construing relations with the stakeholders [58]. The portrayal of how (and to what extent) a given company contributes to sustainable development [59] is the foundation of communicating an organization's green actions to its internal and external stakeholders [60]. It serves as evidence of a company's commitment to environmental issues, whichspurs green corporate image development [61].

Another crucial factor in GRC formation is green marketing, which is a type of social marketing. It ensures that the links in the production chain perform their tasks in socially and environmentally responsible manners [62]. Vilkaite-Vaitone et al. [63] defined green marketing as strategic, tactical, and operational marketing activities that support the creation and delivery of green products. It encompasses, among other things, the promotion of packaging, and products that are safe for the environment [64]. Green marketing not only favorsa green corporate image, it also plays a crucial role in increasing the environmental awareness of partners in a network of relations.

Overall, green intellectual capital comprises a series of intangible assets thataffect each other within an organization. It includes diverse types of knowledge about environment protection collected both in the heads of the staff and in databases, procedures, systems, and relationships with stakeholders. Given the complex structure of GIC, an important research issue is to identify the GIC components thatmay have the greatest impacts on the sustainable development of organizations.

2.3. The Impact of Green Intellectual Capital on Corporate Development

Various authors have analyzed the contributions of intangible resources to the development of corporate effectiveness, including environmental performance. Asiaei and Jusoh analyzed the contribution of intellectual capital toward improving company performance in Tehran. Their research results demonstrated that three of the capital forms, i.e., human, structural, and relational capital, occupied central roles in improving company performance [65].

Chen, in his research conducted on a group of enterprises located in Taiwan, showed that all three forms of GIC have powerful impacts on their competitiveness [7]. In turn, Yadiati et al. focused on investigating the contribution of GIC and company reputations to the development of corporate environmental performance. They determined that strengthening all three forms of GIC increased the environmental effectiveness of enterprises [4].

Moreover, Yusliza et al., in their research carried out in Malesia, demonstrated that green intellectual capital had a positive impact on both economic performance and environmental and social results [24]. Sidik et al. arrived at similar conclusions when studying manufacturing enterprises in Indonesia. Their research confirmed the positive and profound impacts of GIC on the improvements of both corporate environmental performance and competitive advantage [66].

On the other hand, Yong et al. drew attention to the value of environmental practical placement in the area of human resource management. The authors argued that said practices might help organizations adjust their business strategies to environmental requirements [8]. Malik et al. likewise emphasized that green human resources management and green intellectual capital are major elements of sustainable business development [27].

Chen and Chang conducted a study amongst Taiwanese manufacturing companies. Their study findings showed that environmental ethics had a positive impact on the development of green relations and green innovation capability. Moreover, it was established that green human capital is involved in the development of positive relations amongcorporate environmental ethics, green relations, and green innovation performance [1]. Whereas

Lin and Chen reported that green knowledge sharing and green service innovations were related to green competitive advantages [67].

The study of Greek companies conducted by Papadas et al. asserted the role of green marketing in the development of permanent competitive advantages [68]. Moreover, a study conducted in Indonesia, involvinga group of companies listed on a stock exchange, showed that even though GIC had a positive impact on financial performance, its effect was minor [69].

To confirm or deny the findings of the analysis of the source literature, the author undertook a research study onthe relationships betweenGIC and corporate environmental development, in attempt to assess the contributions of individual practices focused on creating green intellectual capital, from the point of view of the potential to develop sustainable organizations. The author of the study considers sustainable development an environmental achievement.

3. Materials and Methods

The subject matters of this research involved practices leading to GIC formation across Polish enterprises. The purposes of the research wereto:

- Determine the impacts of activities fostering GIC on the environmental development of companies in Poland and to identify the practices thatare key from that point of view;
- Establish a correlation between the impacts of individual practices oriented at GIC formation and their practical implementations in the analyzed enterprises.

The author addresses the following research questions:

- What activities leading to GIC accumulation are of utmost importance to achieve the environmental development goals in Polish conditions?
- Is there a relationship between assessing the impacts of practices leading to GIC accumulation and implementation in the analyzed Polish enterprises?

The literature review conductedby the study author, which presents the research findings of other authors, suggests that green intangible assets might be key to develop sustainable organizations [4,24,66] and to improve competitiveness [7,8,24,65–67]. In view of the above literature findings, the author puts forward the following hypotheses:

Hypothesis 1. *Actions leading to GIC accumulation have diversified impacts on the environmental development of anorganization, which enables identification of key practices*.

Hypothesis 2. *There is a correlation between the importance rate of individual practices contributing to GIC accumulation, from the point of view of corporate environmental development and implementation in the studied organizations*.

The first hypothesis is based on the Pareto principle. It assumes that 80% of achieved effects come from 20% of actions. The key is to find 20% of the most important actions thatdetermine the success. When applying the principle to the field of GIC management, the author assumed that it was possible to identify a group of actions promoting GIC accumulation, having major impacts on the development of sustainable organizations and actions of secondary importance.

The second hypothesis suggests that knowledge about GIC-fostering practices among the managing staff plays a vital role in the process of implementation. This is due to the fact that managers find it hard to successfully pursue activities thatare beyond their competencies. Hypothesis 2 is linked to Hypothesis 1. Hypothesis 2 assumes that if managers deem an action to be crucial, in terms of accomplishing the environmental objectives of an organization, they are more likely to implement it.

The analysis included a literature review, diagnostic surveys, and statistical analyses. In the process of verifying the hypotheses, the author applied average measures and Spearman's rank correlation coefficient. This allowed establishing the correlation between assessing the impacts of the practices in creating GIC (on the environmental development of enterprises) and their implementation. The correlation was presented using the linear regression model.

The diagnostic survey method allows one to learn a given social phenomenon, determine its range, scope, level, and intensity, and then allows one to rate it and design potential modifications. It is particularly helpful for examining opinions and attitudes of respondents. Acquiring information ona company's operations under intensive competition conditions is hampered by an organization's fear to lower itscompetitiveness. This is further applicable to information regarding intangible resources constituting a part of intellectual capital. Enterprises are under no obligation to publish the information in question in their annual reports. The use of the diagnostic survey method allowed the researcher to becomeacquainted with opinions of the studied managers concerning the range of implementation of GIC-fostering activities and their impact on the sustainable development of organizations on an anonymous basis. This information could not have been obtained otherwise. Ipso facto, the applied diagnostic survey method allowed accomplishing the adopted research objectives.

GIC is an elaborate category composed of intangible components thatare difficult to quantify. Due to the nonexistence of the financial methods of GIC estimation, the approach used in the course of the research was qualitative and based on a system of indices. The research model avails to follow the qualitative approach proposed by Edvinsson and Malone [70] and by Chen [7]. Eleven GHC indicators, twelve GOC indicators, and seven GRC indicators were applied in the analysis. A complete list of indicators is presented in Appendix A.

Reliability tests for the indicators applied in the diagnosis of the three GIC components—GHC, GOC, and GRC—were conducted with the use of the α Cronbach coefficient. The results are presented in Table 1. All constructs showed an $\alpha \geq 0.70$ reliability, which suggests high reliability and internal consistency of the applied measures [71,72].

Table 1. Results of Cronbach's Alpha.

GIC Components	Cronbach's Alpha
GHC	0.903
GOC	0.906
GRC	0.881

The survey was conducted in the year 2020 in 150 Polish enterprises. The method used in the study was CATI. In order to ensure the representativeness of the research, the author randomly selected twenty-five entities from each of the six regions of Poland. The respondents were managers employed in the surveyed companies. The characteristic features of the study population are shown in Table 2.

Table 2. Profiles of studied enterprises (N = 150).

Criterion	Number of Enterprises	Percentage
Employment number:		
50–249 employees	110	73.3
250–500 employees	37	24.7
Over 500 employees	3	2.0
Time on the market:		
up to 5 years	2	1.3
5–9 years	4	2.6
Over 9 years	144	96.0
Type of ownership:		
limited liability company	104	69.3
joint-stock company	30	20.0

Table 2. *Cont.*

Criterion	Number of Enterprises	Percentage
general partnership	10	6.7
limited partnership	3	2.0
private ownership	3	2.0
Scope of operations:		
international	86	57.3
European	32	21.3
national	26	17.3
regional	1	0.7
local	5	3.4
Capital structure		
Polish	111	74.0
foreign	23	15.3
mixed	16	60.7

Medium-sized enterprises with 50–249 employees constituted the largest percentage of the surveyed population. In principle, the companies were limited liability companies that conducting business activities on a global scale. Enterprises with domestic capital dominated in the capital structure.

The study covered production companies. The production sector is one of the main generators of sustainable development-related difficulties. Therefore, managers should view environmentalorientation and GIC reinforcement as both necessary and priorities.

4. Results

The impacts of the analyzed practices on the environmental development of the surveyed enterprises wereassessed using a five-point Likert scale. The results of the analysis are presented in Table 3.

Table 3. The impacts of activities fostering GIC on the environmental development of the studied companies.

Activity No.	Symbol of Activity	Aggregate Assessment of Impact (Points)	Mean Impact (Points)	Median	Modal Value	Standard Deviation	Asymmetry	Kurtosis
1	HC1	468	3.12	3.00	3	1.215	−0.392	−0.671
2	HC2	496	3.31	4.00	4	1.181	−0.593	−0.551
3	HC3	362	2.41	2.00	1	1.312	0.390	−1.096
4	HC4	315	2.10	2.00	1	1.230	0.706	−0.706
5	HC5	305	2.03	1.00	1	1.255	0.803	−0.737
6	HC6	350	2.33	2.00	1	1.324	0.384	−1.264
7	HC7	360	2.40	2.00	1	1.306	0.378	−1.127
8	HC9	284	1.89	1.00	1	1.165	1.010	−0.096
9	HC10	265	1.77	1.00	1	1.114	1.183	0.192
10	HC11	222	1.48	1.00	1	0.932	1.924	2.877
11	HC12	227	1.51	1.00	1	0.974	2.035	3,561
12	OC1	401	2.67	3.00	3	1.240	−0.019	−1.128
13	OC2	427	2.85	3.00	3	1.309	−0.148	−1.120
14	OC3	424	2.83	3.00	4	1.345	−0.148	−1.326
15	OC4	364	2.43	2.00	1	1.444	0.453	−1.250
16	OC5	388	2.59	3.00	1	1.362	0.138	−1.398
17	OC6	393	2.62	3.00	1	1.427	0.176	−1.374
18	OC7	300	2.00	1.00	1	1.237	0.819	−0.734
19	OC8	451	3.01	3.00	4	1.459	−0.222	−0.734
20	OC9	334	2.23	2.00	1	1.291	0.517	−1.382
21	OC10	351	2.34	2.00	1	1.340	0.441	−1.172

Table 3. *Cont.*

Activity No.	Symbol of Activity	Aggregate Assessment of Impact (Points)	Mean Impact (Points)	Median	Modal Value	Standard Deviation	Asymmetry	Kurtosis
22	OC11	341	2.27	2.00	1	1.326	0.500	−1.128
23	OC12	378	2.52	3.00	1	1.202	−0.012	−1.125
24	RC1	394	2.63	3.00	1	1.403	0.128	−1.415
25	RC2	307	2.05	1.00	1	1.318	0.877	−0.538
26	RC3	289	1.93	1.00	1	1.316	0.996	−0.575
27	RC4	305	2.03	1.00	1	1.271	0.771	−0.835
28	RC5	296	1.97	1.00	1	1.215	0.780	−0.825
29	RC5	364	2.43	2.00	1	1.377	0.319	−1.378
30	RC7	283	1.88	1.00	1	1.220	1.041	−0.331

Reviewing the analysis of the figures shown in Table 3, we can conclude that GIC-forming activities have an uneven impact on the environmental development of the studied organizations. The impact ratings of individual activities ranged from 1.48 to 3.31. The respondents considered activity no. 2, i.e., employees showing green behavior at work (e.g., paper and energy saving), to have the most impact on the environmental development of the studied enterprises (the average impact was 3.31). Other activities the respondents found essential for environmental organization development were:possessing environmental knowledge (the average impact of which was 3.12), implementing innovative environmentally-friendly projects (including technological solutions, the average impact of which was assessed at 3.01), including environmental goals in company strategies (with an impact average of 2.85), implementing environmental management (with an impact average of 2.83), updating employees on environmentally-friendly activities pursued by the organization (with an impact average of 2.67), complyingwith the principles of environmental protection in the product distribution process (the average impact of which was 2.63), environmental audits (the average impact of which was 2.62).

On the contrary, according to the respondents, the following actions had the least impacts on the environmental development of organizations (modal value 1): including environmental criteria in the process of employee recruitment (average impact 1.48), giving preference tocandidates with environmental competencies (average impact 1.51), informing employees about their environmental performances (average impact 1.77), supporting environmental initiatives (average impact 1.88), incentives to boost "green" competencies (average impact 1.89), the use of green marketing (average impact 1.93), providing reports about the environmental impacts to external stakeholders (average impact 1.97).

Against this background, implementing individual practices has become a crucial research issue. In the course of this research, the author attempted to examine the relationship between the impactratings of GIC-forming activities on the environmentaldevelopment of enterprises and their practical implementation. Table 4 demonstrates figures thatwere the bases for the calculations of the numbers of enterprises pursuing individual practices and the assessments of their impacts on environmentaldevelopment.

Table 4. The impact of activities fostering GIC on the environmental development of organizations and their implementation in Polish enterprises.

Activity No.	Aggregate Assessment of Activity Impact on the Environmental Development of Organization (Variable X)	Number of Enterprises Performing the Activity (Variable Y)	Rank X	Rank Y
1	468	122	2	2
2	496	137	1	1
3	362	77	13	12/13

Table 4. *Cont.*

Activity No.	Aggregate Assessment of Activity Impact on the Environmental Development of Organization (Variable X)	Number of Enterprises Performing the Activity (Variable Y)	Rank X	Rank Y
4	315	55	19	22
5	305	54	21	23
6	350	77	16	12/13
7	360	92	14	8/9
8	284	43	26	27
9	265	35	28	28
10	222	27	30	29
11	227	23	29	30
12	401	103	6	3
13	427	101	4	4/5/6
14	424	101	5	4/5/6
15	364	70	12	16
16	388	100	9	7
17	393	92	8	8/9
18	300	52	23	24/25
19	451	59	3	21
20	334	75	18	15
21	351	67	15	18
22	341	101	17	4/5/6
23	378	86	10	11
24	394	90	7	10
25	307	61	20	20
26	289	52	25	24/25
27	305	68	22	17
28	296	66	24	19
29	364	76	12	14
30	283	50	27	26

In order to establish the relationship between the impact assessments of practices on environmental development and their implementation, the author calculated Spearman's rank correlation coefficient (Table 4). The r = 0.878 rank correlation coefficient demonstrates a very strong relationship. This indicates that the pursued practices are those viewed as essential for the policy of sustainable development by the management, as expressed by the high rating of their impact.

Figure 1 represents a linear regression function. The analysis of regression was conducted with the application of the SPSS program based on data shown in Table 4. Variable X represents the managers' impactratings of actions leading to GIC accumulation on the environmental development of organizations. Variable Y stands for the number of enterprises pursuing the individual practices related to GIC development.

The linear regression model has the form of the equation:

$$Y = 0.354x - 49.66$$

The coefficient 0.354 indicates that, a 1-point impact growth in the impact of an activity on the environmental development of the organization results in an average increase of its realization by 0.354. The coefficient of determination $r^2 = 0.771$ means that, in 77.1%, the changeability of the number of enterprises pursuing GIC-fostering activities was explained by the estimated regression function. The coefficient of linear indetermination (1 − 0.771 = 0.229 = 22.9%) informs us that in the studied sample of organizations only 22.9% of changeability of the number of companies implementing GIC-fostering activities was not accounted for by the variability of the rating of their impact on the environmentaldevelopment of enterprises.

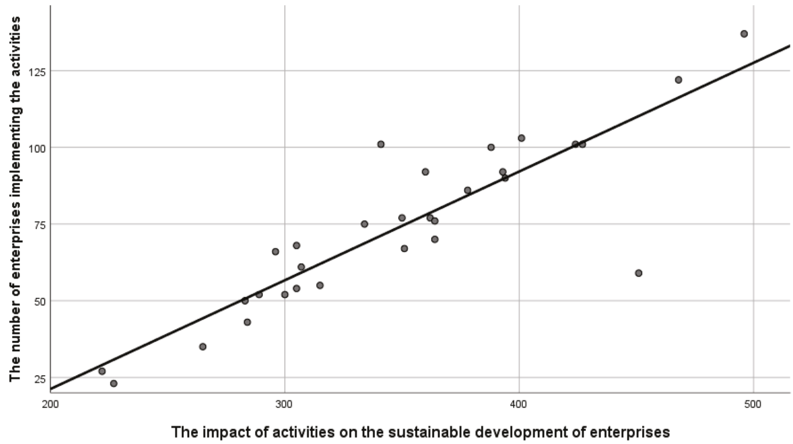

Figure 1. The correlation between the impacts of activities leading to the accumulation of GIC on the environmental development of the organization, and their implementations in the surveyed companies.

The regression function may be the foundation toforecast the implementation of GIC practices in the future. The established correlation allows the conclusion that an increase in the impactrating of GIC-forming activities may generate an increase in the level of their practical implementation. Therefore, popularization of knowledge about the GIC model among Polish managers can play a key role here.

5. Discussion

The effect of GIC on the environmentaldevelopment of organizations was confirmed by many authors. The studies by Yadiati et al., which covered Indonesian companies, demonstrated that green intellectual capital had a positive and essential impact on environmental performance. It was determined that a unit increase in green intellectual capital generated a 0.494 increase of environmental effectiveness inIndonesian-based international companies. Furthermore, corporate reputation, which is a key element of GRC, was recognized as another principal factor. It was found that a unit increase in organizational reputation also brought about a positive increase (by a 0.424 unit) in environmental performance in Indonesian multinational firms [4].

In addition, studies by Yusliza et al. conducted across 112 manufacturing companies in Malaysia showed that the role of green intellectual capital in sustainable performance was considerable [24]. It was determined that green intellectual capital had a positive impact on both economic performance and environmental and social results. Economic performance pertains to the reduction of the cost of purchased materials, energy consumption, waste processing, and penalties for pollution and emissions [73]. Social results correspond to the improvement of stakeholders' wellbeing, community health and safety, employee health and safety, and the mitigation of risks for society in general [74]. Environmental results are associated with the limitation of pollution and emissions, energy consumption, or hazardous material use [75].

Recent studies by Malik and et al. [27] also highlight the importance of GHC in the development of sustainable organizations. The research covered 510 small- and medium-sized enterprises employing between 10 and 250 employees in Pakistan. The studies proved that all GIC components, i.e., GHC, GOC, and GRC, had positive and considerable impacts on the sustainable performances of Pakistani companies. A more in-depth analysis was conducted with respect to the following elements of green practices of human capital management: green analysis and job description, green recruitment and selection, green training, green performance evaluation, and green rewards. The studies further demonstrated that green recruitment and selection, as well as green rewards, were most central to the formation of sustainable organizations [27].

The importance of green motivation was attested by the studies conducted by Forman and Joergensen.The authors proved that green motivation increased employee involvement in pro-environmental initiatives [76]. Moreover, studies carried out in 376 Pakistani companies demonstrated the importance of educational practices in achieving the goals of green management [77].

Dangelico [78], in turn, showed a key role of green management teams in the enhancement of company reputation and environmental effectiveness. Moreover, Gross-Gołacka et al., in a study involvinga group of 1041 small- and medium-sized enterprises in Poland, demonstrated that HC had the largest impact on sustainable business [79].

The studies carried out by Chen and Chang showed a direct link between sustainable development and green human capital [1]. Green staff members significantly contribute toward increasing the environmental effectiveness and sustainable development of organizations [80]. They initiate environmental innovation, which not only brings about novel products, technologies, and processes, but also increases natural resource use in the economy and softens any adverse environmental impacts. As a consequence, energy and material intensity of manufacturing processes start to reduce, soil, water, air, and noise pollution, resulting inless pollution or less hazardous materials, whereas waste, water, and substances are recovered or reused [81].

The special role of GHC in constructing sustainable organizations stems from the fact that "environmental knowledge and skills are the foundation of implementation of cleaner manufacturing strategies" [82]. Organizations benefit from the knowledge and skills of their employees in terms of stimulating development based on decreased energy consumption, less production waste, and reduced material waste.

However, not all findings related to the role of GHC in the development of sustainable organizations are unequivocal. Studies conducted among 168 small- and medium-sized manufacturing enterprises in Malaysia did not confirm the key role of HC in the formation of sustainable organizations. Nonetheless, it was determined that green structural capital, green relational capital, and sustainable businesses were positively correlated [83]. Researchers exploring this issue emphasized that human capital alone is not sufficient to achieve permanent and sustainable results. To do so, one needs to include both green structural and green relational capital. Intangible assets, such as green organizational culture, technologies, databases, trademarks, and copyrights, are vital to sustainable action. Other key actors in sustainable performance are relations with creditors, suppliers, customers, associations, and other stakeholders [24]. The low impact of green recruitment was also confirmed by studies conducted by Owino and Kwasira and Guerci et al. [84,85]. In view of the established discrepancies related to HC, further research on the role of GIC in the development of sustainable organizations, above all, with respect to the human component, is required.

6. Conclusions

Intellectual capital is one of the principal resources for the provision of the market value in aknowledge-based economy. A special type of IC is GIC, the formation of which requires an environmental approach to human, organizational, and relational resources. GIC may constitute the basis for the construction of environmentally-friendly organizations. This was endorsed in empirical studies.

This study validated the thesis that actions supporting GIC formation have an impact on the environmentaldevelopment of organizations, whereas thisimpact isuneven and depends on the types of practices. The studies conducted by the author demonstrate that Polish managers did not consider GIC impact as highly significant to achieve the environmental objectives for their organizations. Their rating was below average on a 5-point scale.

Given the average impactrating of GIC-fostering practices on the environmentaldevelopment of organizations (2.32), the studied managers opined that GIC had a moderate effect on the environmental development of organizations. The managers did not consider all practices as equally important, which justifies the adopted Hypothesis 1. The ones they considered as major were activities related to GHC-development, i.e., showing green behaviors in the workplace (such as paper and energy savings) and environmental knowledge.

Furthermore, a correlation was identified between the rates of importance of individual practices contributing to GIC formation from the point of view of corporate environmentaldevelopment and their implementation in the studied enterprises. Hypothesis 2 was positively verified. It was found that practices assessed as more important to the environmental development of anorganization were more often implemented. It is necessary to strengthen the importance of practices leading to GIC accumulation among managers. The broader the manager's knowledge about GIC, the more involved the manager becomes in the management of capital.

Empirical studies have demonstrated that there is gap in the scope of implementation of GIC-fostering practices. Polish enterprises do not implement the full range of activities supporting the implementation of environmental goals. We can conclude that implementation of the GIC model is in the initial phase. Further research to identify the reasons behind the limited implementation of the GIC model in Poland is required. One of the possible causes may be the deficit of tools used to measure, monitor, and present GLC. No commonly accepted and universal model of GIC measurement has been developed. This could be an impediment to the rating of the level of GIC in enterprises and a barrier to effective green intellectual management. Terminological issues continue to be unorganized, generating difficulties in monosemantic GIC definition, identification, and external reporting. The principal limitation is, however, the fact that the value of GIC is hard to assess, for it is composed of a number of intangible assets, which are challenging to quantify. Green intellectual capital measurement is imperative to effective GIC management. Hence, the tools and methods of GIC measurement, as well as further investigations into its role in the development of sustainable organizations, require correction. Finally, it is essential to enhance manager competences by incorporating green intellectual capital management in university programs in economics.

This research study focuses on the identification of managerial views, concerning the role of green intellectual capital in pursuance of corporate environmental goals. It contributes both to theory and practice, by identifying a gap in the implementation of GIC-fostering practices. This research article identifies the underlying impediment to GIC applications to achieve environmentalorganizational goals, i.e., underestimating actions supporting GIC accumulation. It suggests the need to change managerial attitudes in that respect. The conducted research raises awareness aboutthe importance of managerial GIC competence development for a better use of intangible green asset potential to create sustainable enterprises. It suggests the need to disseminate knowledge about GIC through, inter alia, the inclusion of the issue in the curricula of economic schools of higher education.

7. Limitations and Future Research

When analyzing the presented research outcomes, one should also consider the limitations of the analyses. The latter include high subjectivity of respondents' opinions based on convictions rather than any certain activities undertaken in the field of GIC accumulation and the limited research sample. Another issue is a more qualitative approach to the evaluation of GIC impacts on environmental performance, not taking into account objective quantitative measures, which are often difficult (or even impossible) to design due to GIC specifics. Furthermore, one should keepin mind that some managers donot havesuitable competencies to conduct reliable evaluations on the effects of activities leading to GIC accumulation, concerning the accomplishments of theorganization's environmental goals.

However, the research findings open up new research areas. Amongst them, strategic and operational factors thatdetermine the range and effectiveness of implementing GIC-fostering practices in order to improve corporate environmental performance. The research will be continued in the future, having regard for a more extensive and precisely selected research sample and measurements using more objective quantitative indicators. Future research may also encapsulate an assessment of the maturity of green intellectual capital management with inter-sectoral comparisons.

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Appendix A

Table A1. List of GIC indicators.

Activity Number	Symbol	Activity
1	HC1	Employees have environmental knowledge.
2	HC2	Employees care about the environment in the workplace (e.g., paper or energy saving).
3	HC3	Employees develop environmental knowledge and skills through training.
4	HC4	The environmental knowledge and skills of employeesare systematically assessed.
5	HC5	Employees receive additional awards for the implementation of ecological projects.
6	HC6	The responsibilities ofemployees include environmental protection tasks.
7	HC7	The organization applies penalties to employees who do not comply with environmental protection regulations.
8	HC8	The company stimulates the development of green competences.
9	HC9	Employees are informed about their environmental performances.
10	HC10	Environmental knowledge and skills are considered in recruitment.
11	HC11	Green competences are important criteria for assessing applicants.
12	OC1	The organization has an information system on the implemented pro-ecological activities.
13	0OC2	The organization's strategies take environmental objectives into account.
14	OC3	The company implements an environmental management system.
15	OC4	The company employs a specialist in environmental management.
16	OC5	The company implements the principles of employee behavior in relation to environmental protection.
17	OC6	Environmental audits are systematically implemented in enterprises.

Table A1. *Cont.*

Activity Number	Symbol	Activity
18	OC7	The company implementsa motivation system to achieve environmental goals.
19	OC8	The company has environmentally-friendly technologies.
20	OC9	The company builds a green corporate culture.
21	OC10	The company runs an environmental analysis of the product life cycle.
22	OC11	The organization creates conditions that stimulate the sharing of ecological knowledge.
23	OC12	The mission of the organization considers environmental values.
24	RC1	The principles of environmental protection are followed in the process of product distribution.
25	RC2	An important criterion in selecting a business partner involves applying the principles of environmental protection.
26	RC3	The organization encourages clients to be pro-ecological by developing green marketing.
27	RC4	The organization decides to collaborate with suppliers that meet the environmental criteria.
28	RC5	The organization publishes reports on the environmental impact of its activities.
29	RC6	The company attaches importance to the creation of a green image.
30	RC7	The organization supports environmentally-friendly initiatives in the area.

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Article

Model Analysis of Eco-Innovation for National Decarbonisation Transition in Integrated European Energy System

Viktor Koval [1,*], Oksana Borodina [2], Iryna Lomachynska [3], Piotr Olczak [4], Anzor Mumladze [3] and Dominika Matuszewska [5]

1 Institute of Market and Economic-Ecological Researches, National Academy of Sciences of Ukraine, 01030 Kyiv, Ukraine
2 Institute of Industrial Economics of the National Academy of Sciences of Ukraine, 03057 Kyiv, Ukraine; borodinaoksana1306@gmail.com
3 Faculty of Economics and Law, Odessa I.I. Mechnikov National University, 65000 Odessa, Ukraine; i.lomachynska1@onu.edu.ua (I.L.); anzor.mumladze@gmail.com (A.M.)
4 Mineral and Energy Economy Research Institute, Polish Academy of Sciences, 31-261 Cracow, Poland; olczak@min-pan.krakow.pl
5 Department of Thermal and Fluid Flow Machines, Faculty of Energy and Fuels, AGH University of Science and Technology, 30-059 Cracow, Poland; dommat@agh.edu.pl
* Correspondence: victor-koval@ukr.net

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Abstract: Consolidation with European social, economic and environmental programmes in the framework of Ukraine's integration into the European energy space has become extremely important given the growing threats to energy security and should become the basis for greening regional and national innovation systems in the context of decarbonisation, the minimisation of carbon emissions and the transition to alternative energy sources. The comparison of the regions of the country by the level of enterprise innovation and the extrapolation of these results to the share of such enterprises in the total number of industrial entities in the regions helped identify their lack of correlation and emphasised the lack of stable dependence between industrial development and innovation activity. The methodology of the article includes a number of general scientific, special and interdisciplinary methods that allowed the screening of areas for the most favourable economic development, taking into account the synergistic component of regional development and achieving the research goal. The aim of this article is to analyse the innovative component of regional and national economic development for the implementation of decarbonisation and green energy transition in Ukraine, as well as substantiate the world's leading imperatives and national directions for effective integration into relevant European programmes. An analysis of Ukraine's rating status in several international indices of environmental efficiency and innovation activity in the regions showed the lack of correlation between regions of Ukraine, which actualises the search for the most effective drivers of economic development. At the same time, the consolidation of efforts of national stakeholders of innovative development in a country with relevant European institutions, particularly in the direction of greening regional economic systems, will ensure the development of innovative regions and industries, which will in turn be drivers of related territories and industries while ensuring a synergistic effect.

Keywords: ecology; innovative development; decarbonisation; energy efficiency; "green" transition; sustainable development

1. Introduction

The growing impact of the ecological footprint on the environment from activities in the energy sector indicates the need to modernise and increase the level of implementation of environmentally sustainable technologies, which makes the search for ways to transition to national decarbonisation particularly relevant. The purpose of modernisation is to build such an energy system based on the intensification of clean production and the smart specialisation of regional development, which promotes the development of innovative (environmentally sustainable) technologies that significantly increase the share of renewable energy in the overall production structure. For Ukraine, given the current conditions of European integration, the focus should be on the threats and risks of energy and administrative decentralisation and mechanisms for their appropriate response in the context of the integration of the national energy system with the EU energy system. Despite the reduction in sulphur dioxide emissions in Ukraine in 2018–2020 to 20% annually, mainly due to the replacement of renewable energy production of electricity by heat generation capacity, there is still a need for further national decarbonisation of Ukraine's energy sector through environmental modernisation.

The proclamation of the new Green Deal Strategic Plan by the European Union in December 2019 [1] marked a new stage in its development, which is a significant transformation of public consciousness, and its implementation requires fundamental and ambitious goals to address pressing climate and environmental issues. Decarbonisation, minimisation of carbon emissions and transition to alternative energy sources—the central elements of the Green Deal—will be the basis for a number of fundamental transformational transitions, measures for regulatory adaptation and the introduction of protection mechanisms. As a political framework, this European agenda is a response to the challenges of global climate change, environmental pollution and, in light of its initiatives, the positioning of the European Union as a world leader.

Ukraine was chosen as the focus of the study, because after the accession of the Ukrainian energy system to the European ENTSO-E, the energy space became one, creating conditions for mutual strengthening and collective security throughout the region. In recent years, Europe has radically changed its policies regarding fossil fuels. The EU produces approximately one-third of its electricity using local renewable energy resources. The analysis of the role of energy systems in economic transformation to achieve sustainable development is a subject of research interest for European researchers [2]. Thus, the trend of the increasing share of renewable energy in the Ukrainian energy balance is promising.

The current composition of the national energy balance devotes more than half to nuclear generation; however, it is planned to gradually increase the weight of "green" energy to 25% based on the transformation of the energy balance in favour of low-carbon energy sources and the development of new energy technologies that can be used to achieve carbon neutrality. In the structure of the country's own production, the largest shares were: nuclear energy (35.1%), natural gas (27.8%), coal (22.4%) and renewable energy sources (RES) (10.3%). In the structure of total RES production in 2020, the largest share was occupied by biofuels and waste (75.4%). In the structure of electricity production, hydropower was the largest share of RES, but its share decreased by 16.3 percentage points, and, at the same time, the share of solar energy increased by 11.8 percentage points, wind energy increased by 3.3 percentage points, and biofuels increased by 1.2 percentage points [3].

The electricity market in Ukraine has a surplus, so the benefits to European consumers, namely, receiving cheaper energy than in Europe, as well as reducing dependence on Russian energy, are obvious. The stability of the Ukrainian energy system represents an additional reserve of stability for Europe.

In accordance with the strategic course enshrined in the Constitution of Ukraine to attain full membership in the EU and Ukraine's international obligations, the concept of "green" energy transition by 2050 was formed in Ukraine [4].

At the same time, the large-scale process of global support for Ukraine during the military conflict opens up prospects for its early integration into the European energy system, the transformation of its own energy market by carrying out balanced measures, and general economic integration with the EU, especially since national integration intentions coincide with European resource opportunities.

As one of the largest energy markets in Europe, Ukraine's energy market is primarily in need of integration into the European energy system and decarbonisation to ensure the country's energy security. This study highlights the existing resource and innovation trends in the greening of national and regional ecosystems, particularly in the energy sector of Ukraine's economy.

This study identifies the most relevant prerequisites and factors for greening innovation systems at the national and regional levels in the postwar reconstruction of Ukraine's economy, taking into account the latest integration changes in relations between Ukraine and the EU, as well as between Ukraine and the world. The second section is devoted to the analysis of literature sources, both for the ecological component of regional systems (Section 2.1) and for the environmental regulation of alternative energy sources (Section 2.2). Section 3 illustrates the research methodology, consisting of conceptual principles of integration and European environmental programmes (Section 3.1), the method of screening areas for the most favourable development of Ukraine's postwar economy (Section 3.2) and examples of their application (Section 3.3). The fourth section of the article is aimed at examining innovative components of the sustainable postwar development of Ukraine's economy, such as decarbonisation and "green transition" (Section 4.1), with a review of a number of global innovation indices and the analysis of regional innovation development in the country. This section also contains a study of the impact of state regulation on the process of decarbonisation/adaptation in the region (Section 4.2) and applied models of decarbonisation of energy-intensive sectors (Section 4.3). Finally, the findings include the main results of a study on achieving a carbon-neutral level in Ukraine's economy.

2. Literature Review

2.1. Research Review on the Environmental Component of Innovative Regional Systems

The last decade has been marked by significant interest in scientific circles worldwide in terms of combating climate change and greening national economic systems. For example, van den Berg, Hof and van Soest studied the implications of different approaches to effort sharing on national carbon budgets and emission trajectories [5]. Extensive coverage of the impact of environmental and energy aspects on economic development in the studies of Olczak et al. [6–8] highlighted the issue of regional financial subsidies of sectoral programmes. The main result of the assessment of the impact of bioenergy on sectoral decarbonisation [9,10] is the fact that almost all scenarios of development and transformation of EU energy by 2050 contain forecasts of strategic long-term development of bioenergy, implementation of the "green transition" and decarbonisation of energy-intensive sectors.

Driven by the scientific interest in the ecological component of innovative regional systems, research [11,12] has revealed that in a decentralised model of government in Ukraine, the formation of effective policies for regional eco-innovation will be one of the important endogenous factors in achieving sustainable development.

Sectoral energy efficiency measures and the investment component for their implementation [13] and industrial "green" transformation on the way to decarbonisation [14] have shown that they are the keys to achieving the energy independence of communities and a competitive economy.

Legal and regulatory aspects of greening and compliance with the regulatory regulations of processes [15–17] allowed the substantiation of recommendations for improving regulations, particularly the movement of energy cooperation in Ukraine, and improving the effectiveness of energy efficiency policies and energy security.

Studies have also analysed the impact of support mechanisms on decarbonisation [18–20]. The findings indicate that instruments such as capacity markets can slow the process of decarbonisation in countries that are highly dependent on fossil fuels [21–23]. However, supporting renewable sources and the hydrogen economy can accelerate this process in these regions [24–26].

At the same time, we should note the lack of research on national and regional greening, decarbonisation and the impact of decentralisation processes on energy efficiency, especially given the challenges of the postwar organisation of the country's structural policy and significant changes in identifying leading industry drivers of Ukraine's effective development. The system of decarbonisation needs to be systematised and analysed, with the conclusion that a comprehensive, integrated model is needed in modern Ukrainian conditions.

2.2. Ecological Regulation of Energy Consumption

In addition to environmental or social problems, which are associated with a significant increase in the world's population and have a negative impact on the environment, another problem that encourages countries to actively use renewable energy sources is the depletion of natural resources.

The ecological preconditions for the problems of the depletion of natural resources and environmental pollution are identical, and the ecological footprint of society exceeds the planet's ability to regenerate [27].

EU member states and other countries using economic methods to achieve environmental security have the opportunity to implement strategic environmental goals of sustainable development, which, according to research, helps to approximate economic methods of environmental management [28]. At the same time, there is currently no unified approach to selecting economic tools in environmental management in the EU; each country independently determines the appropriate instruments and approaches to environmental regulation in the energy sector [29].

The implementation of the European experience in Ukraine, particularly the mechanism of environmental taxation, is a difficult process, given the differences between European and Ukrainian approaches to taxation. In the EU, the vast majority of the objects of taxation are energy resources, vehicles and certain groups of goods, and the main principle is indirect taxation. In Ukraine, the object of taxation is the volume of emissions with harmful effects on the environment, and the established rent for the use of natural resources is a fiscal rather than an eco-incentive tool [30].

However, despite the significant amount of research in the field of environmental regulation of energy consumption, the relationship between research on the environmental component of the economy, the sustainability of the energy sector and the regulation of eco-innovative energy consumption remains controversial and little studied.

Despite a number of scientific works and achievements in the theory and practice of using tools to stimulate the mechanisms of renewable energy in a decentralised environment, some issues need further study. It is necessary to study models of decarbonisation, systematise their advantages and disadvantages and make proposals for a hybrid integrated approach to energy decarbonisation policy in Ukraine, which would combine existing models and have a national orientation, given the force majeure of Ukraine's war-torn economy. Research and proposals on renovation programmes in energy-intensive sectors, primarily in the coal industry in the old industrial regions of Ukraine, are relevant.

3. Methodology

3.1. Sectoral Study of Greening the Economy in the Energy Industry

Sectoral energy efficiency analysis includes a number of models, such as energy systems analysis (ENPEP, MESSAGE), energy and electricity demand (MAED, ENPEP), environmental impact of energy facilities (SimPacts, WASP-IV, ENPEP) and financial analysis of energy systems (FINPLAN). They are designed to analyse and forecast future energy needs and require time intervals to study the conditions and objectives of the countries where implementation is planned. Key conditions for the development of meaningful scenarios are: the application of systematic procedures to ensure the internal consistency of initial assumptions, especially those on social, economic and environmental factors, and a clear understanding of the dynamic nature of modelling, the interdependence among assumptions, the evaluation of results, plausibility criteria and changes to initial assumptions.

To model the sectoral development of the energy industry, this study used econometric methods of simulative modelling, in particular, the rapid diagnosis of the importance and share of innovative enterprises in the total number of industrial enterprises in Ukrainian regions. This study contained elements of cluster analysis and panel modelling as a justification for the relevance of the greening policy of national and regional ecosystems, taking into account the international status of Ukraine as a member of many international agreements and projects, including the European Green Deal [1], the transformation of coal regions (fair transition), the Paris Agreement [31] and the Climate Goals of Ukraine until 2030 [32].

The idea that the relationship between the greening of the energy sector of the national economy and the national security of the state (through energy security) is direct has been empirically substantiated. At the same time, the desire to liberalise the national energy sector will reduce the level of state influence as a regulator of ensuring the necessary level of greening of the energy sector, addressing the vast majority of energy security issues. State support for the development of "green energy" motivates companies to participate in eco-transformation.

Simultaneously, the input conditions for the current energy state of Ukraine, given energy integration and military action, are so unique that they require special elements of analysis that can effectively take them into account. This study uses a conceptual and analytical model of comprehensive support for the implementation of renewable energy, which can become an innovative component of the sustainable postwar economic development of Ukraine.

3.2. Screening Method

In order to select the direction for the most favourable development of the postwar Ukrainian economy, a comparative analysis was conducted to compare the impacts of several project initiatives on sustainable regional development. We selected region-leaders of innovation-active enterprises, which can become a model for the proactive development of Ukraine, taking into account the initial crisis conditions. The screening method highlights the areas of effective postwar development: this is the direction of fair transformation of old industrial coal regions, provoked by the closure of coal mines and related infrastructure. In addition, the focus is on the movement of energy cooperation, which, in the context of decentralisation and the acquisition of a number of financial powers by urban communities, can become a driver of local development.

3.3. Mathematical Modelling

The method of applied concretisation of the research results was illustrated by considering the energy cooperative movement in Ukraine and its relationship with the large-scale decentralisation process and the acquisition of a number of powers and rights by local communities to manage their own budgets. It has been proven that the convenience of cooperative organisational and legal forms is due to their flexibility and variability. Simultaneously, the basic resource base for the use of biofuels in agricultural regions of the country is indisputable. The development of energy cooperation is complex, as it has an impact on the revival of processing processes in agriculture and the organisation of the process of organic waste disposal, which is environmentally friendly and economically rational.

The authors' conceptual-analytical model of the complex support of mechanisms for the introduction of renewable energy is formalised by methods of mathematical logic. Thus, in order to achieve the goal of developing mechanisms for the implementation of renewable energy at the regional and local levels, a system of organisational and economic, fiscal, institutional and regulatory measures was applied.

This study also covered the issues of legal, social and infrastructural organisation of the process of transformation of coal enterprises in a city of constituent entities in old industrial regions.

Analysis of the legal, social and infrastructural organisation of the process of the transformation of coal enterprises was performed using cities as subjects in industrial regions. Thus, the fair transformation of coal regions should create a framework for public–

private partnerships between central government, local communities and investors. As part of the renovation programmes of mono-regions, not only should support be provided to miners from liberated coal enterprises, but opportunities for education and retraining and new jobs for young people and the unemployed should also be created. Thus, the structural transformation of the economy of old industrial coal regions involves direct investment in new infrastructure in these regions, the development of new industries and the mitigation of unemployment.

4. Results

4.1. Decarbonisation and the "Green Transition" as an Innovative Component of Sustainable Economic Development of Ukraine

A significant step towards Ukraine's European integration was the full connection of the Ukrainian energy system to the ENTSO-E continental European energy system in March 2022, which will secure the Ukrainian energy system in the face of technological, economic and foreign policy risks. The synchronisation of power systems has been carried out since 2017 and demonstrated to be comprehensive and systematic in nature in testing, static and dynamic stability and other technological measures.

The European course for the transition to a low-carbon economy is a list of actions agreed upon by all stakeholders of the process, which should lead to the separation of the socio-economic development of the country from emissions of harmful greenhouse gases (GG). Moreover, anthropogenic factors of harmful emissions of greenhouse gases from vehicles can be represented as a function:

$$TC = P \cdot G \cdot (E \cdot C_{EN} + C_{NE}) \quad (1)$$

where TC—anthropogenic greenhouse gas emissions, tons of CO_2-eq.; P—population, people; G—consumption of goods per capita, units/person; E—energy intensity of production and consumption of goods, GJ/unit; C_{EN}—specific greenhouse gas emissions per unit of energy used in the production and consumption of goods, including emissions from the production of energy, as well as in the production, processing and transportation of fuel for energy production, tons of CO_2-equivalent/GJ; and C_{NE}—specific non-energy GG emissions per unit of good consumed, tons of CO_2-eq./unit.

Calculated according to this principle, the anthropogenic factor of harmful carbon emissions of CO_2 allows us to state that the problem of greenhouse gas emissions such as carbon dioxide and methane is a priority for the central and southern regions (Figure 1, Table 1).

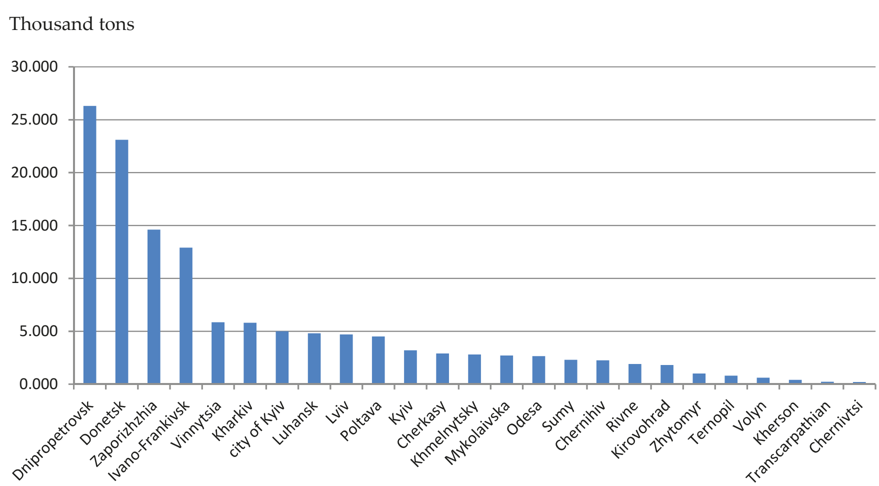

Figure 1. The impact of anthropogenic factor CO_2 emissions in the regions of Ukraine in 2021 [33].

The priority of solving problems to minimise such anthropogenic pressure on the regions is illustrated in Table 1.

Table 1. Priority of solving problems of anthropogenic factor of CO_2 emissions into the atmosphere by region of Ukraine.

The Order in the Queue to Resolve the Issue	1	2	3	4	5
Emissions of carbon dioxide into the atmosphere	Centre	South	East	West	North

For Ukraine, especially in the conditions of postwar economic recovery, measures of the synergetic effect of solving problems in key areas are extremely important. Against the background of the unconditional priority of military and civil protection measures, it is necessary to note the real progress in foreign policy and economic processes between Ukraine and the EU and between Ukraine and the world, which has developed over several years and considered only potential scenarios.

At the end of February 2022, the Ukrainian power system was disconnected from the power systems of Belarus and Russia in a test format and underwent technical measures to integrate it into the ENTSO-E continental European energy network as soon as possible and harmonise regulations [32].

It should be emphasised that the process of preparation for the integration of Ukraine's energy system into the EU energy system was carried out for six years and received financial confirmation in the form of 700 million euros of investment [34]. Ukraine has been provided opportunities for crisis assistance from Europe, which is extremely important during wartime. The long-awaited event will attract investors, as Ukraine can count on financial assistance from European partners to rebuild its war-torn infrastructure, and foreign partners have already stated their readiness to provide assistance, with at least 100 billion euros from the EU [35] and 32.5 billion from the USA [36]. Such investment funds, in addition to rebuilding destroyed infrastructure and critical social facilities, should be directed to the most profitable and environmentally friendly production, which can be drivers of postwar economic recovery.

It should be noted that in recent years, Ukraine has implemented several programmes and strategies aimed at reducing the harmful effects of human economic activity on the environment. For example, these areas are reflected in relevant legislative and regulatory acts, such as the Ukrainian law "On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the period up to 2030" and the Strategy for Environmental Safety and Adaptation to Climate Change for the period up to 2030.

A separate component is the greening of Ukraine's energy sector in the context of the Green Deal in the EU. Ukraine's implementation of the Green Deal principles in its own legal and economic environment, especially given European opportunities and the desire to integrate Ukraine in most areas as a result of Russia's military actions, will be an indisputable catalyst for economic modernisation. Measures will be especially urgent and appropriate in the context of the reconstruction of enterprises and infrastructure after the end of hostilities.

Among the policy documents of environmental orientation in Ukraine, we must highlight the Strategy of State Environmental Policy of Ukraine until 2030, the Strategy for Environmental Security and Adaptation to Climate Change until 2030, and regional environmental programmes.

These documents are intended to outline the transition of the Ukrainian economy to an ecologically oriented decarbonised (low-carbon, "green") path of development, which involves the rational use of natural resources. However, despite a significant number of efforts by the state in this direction, at present, the quality and speed of economic transformation on the way to greening cannot be called satisfactory, as demonstrated by relevant indicators. Thus, according to the International Environmental Performance

Index (EPI-2020) [37], on the basis of ranking by 32 criteria, Ukraine took 60th place out of 180 countries in 2020 (Table 1).

The analysis of the leaders of the EPI rating shows a steady trend in its dynamics. The top rankings are traditionally occupied by European countries with a high standard of living (high-income group economies) and significant investments in environmental projects (Figure 2). For example, in 2020, the top five were Denmark, Luxembourg, Switzerland, the United Kingdom and France, where sustainable development programmes are successful and stable.

The Global Innovation Index (GII) 2021, generated for 131 countries, is based on 80 indicators of resource importance in the context of this study. According to the index, Switzerland took 1st place in 2021, Britain was in 4th place, Denmark was in 6th place, France was in 11th place, and Luxembourg was in 18th place. Ukraine was in the 49th position in this rating. That is, the correlation between innovation and the environmental efficiency of the state is indisputable.

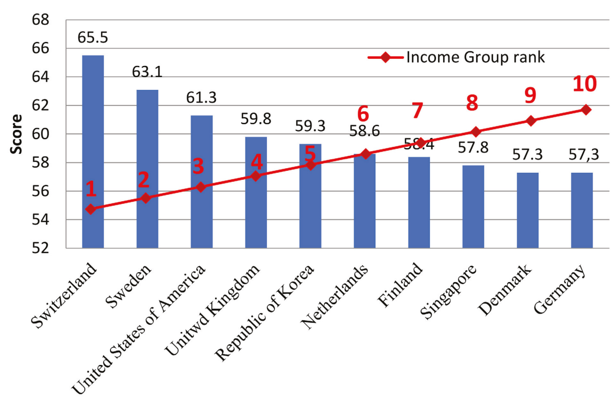

Figure 2. Top ten countries according to the GII-2021 Global Innovation Index. Reproduced with permission from [38]. Copyright 2021, World Intellectual Property Organization.

According to the GII, Ukraine improved only three indicators in 2021: creativity, scientific knowledge, and human capital and research (Figure 3).

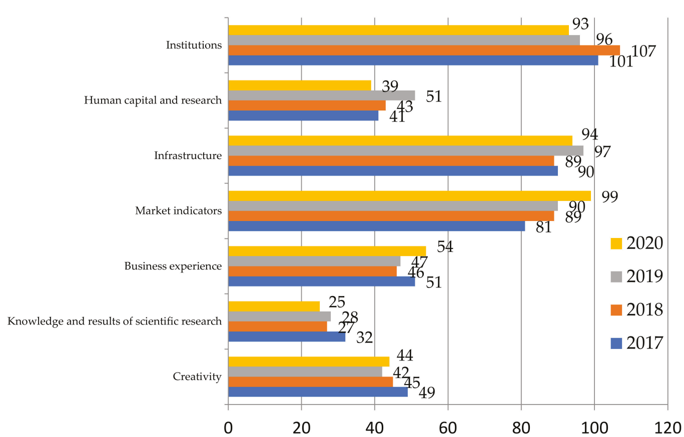

Figure 3. Dynamics of GII indices for Ukraine in 2017–2021. Reproduced with permission from [38]. Copyright 2021, World Intellectual Property Organization.

At the same time, Ukraine's ranking has worsened in the category of lower-middle-income countries, declining in comparison with 2020. In addition, Ukraine's place in the annual Bloomberg Innovation Index [39] in 2018–2021 only deteriorated and is determined by the following indicators (Figure 4).

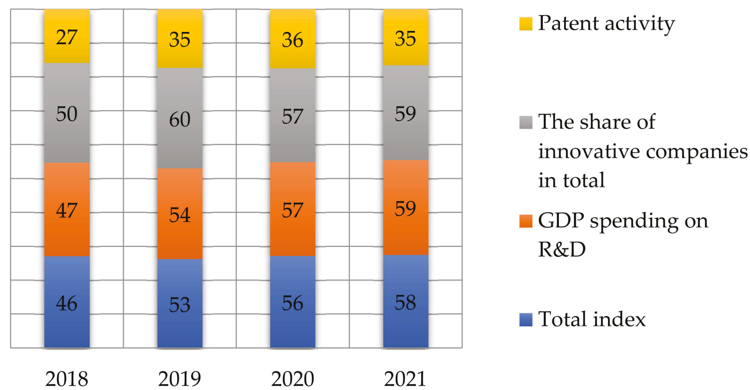

Figure 4. Ukraine's place in the Bloomberg Innovation Index in 2018–2021. Adapted with permission from [39]. Copyright 2021, European Commission.

Thus, innovative transformation of the economy is a necessary strategy for Ukraine to rebuild the infrastructure destroyed by hostilities, and clustering in this sense is an auxiliary and powerful mechanism for development at regional and local levels.

According to studies [40–42], the innovative development of the region is determined by a number of interrelated factors that promote each other during innovation, including the following factors:

- Continuous and sustainable growth of the socio-economic level of the region, based on innovative entrepreneurial activity, smart specialisation of the region, a significant level of competitiveness, adaptation to market changes, and flexible response to infrastructure challenges and political conditions;
- Constant self-development based on the constant growth of social needs of the region, which must be ensured by constant commercialisation of innovations, and as a consequence, the formation of new social needs of higher quality and the cyclical nature of further innovative development;
- Causal relationships, which are reflected in the interaction and motivation of regional development stakeholders.

Simultaneously, according to the data on industrial activity in the regions of Ukraine, it is possible to confirm a significant differentiation among regions by the criterion of the number of such enterprises and the existing features of regional innovation development [43,44].

For the period 2018–2020, the statistics for the regions of Ukraine regarding the number of innovatively active industrial enterprises are shown in Table 2, where regions are highlighted in green if they showed growth over the past three years.

Thus, the stable growth of innovative enterprises over the past three years has been demonstrated by the Ukrainian regions Vinnytsia, Poltava, Cherkasy and Ternopil, which are mostly agricultural, which is another argument for focusing investments in the energy cooperative sector based on biofuels.

Table 2. Regions of Ukraine by number of innovation-active enterprises [33].

Regions	2018	2019	2020	+/− 2020 before 2019	+/− 2019 before 2018
	...	...	...	...	...
Vinnytsia	25	28	31	3	3
Volyn	14	11	12	1	−3
Dnipropetrovsk	71	64	75	11	−7
Donetsk	23	27	24	−3	4
Zhytomyr	19	24	15	−9	5
Zakarpattia	12	9	10	1	−3
Zaporizhzhia	36	47	41	−6	11
Ivano-Frankivsk	28	22	28	6	−6
Kyiv	54	41	56	15	−13
Kirovohrad	26	20	20	0	−6
Luhansk	5	11	10	−1	6
Lviv	44	44	60	16	0
Mykolaiv	14	22	14	−8	8
Odesa	25	33	30	−3	8
Poltava	30	32	35	3	2
Rivne	8	20	19	−1	12
Sumy	25	23	23	0	−2
Ternopil	20	29	35	6	9
Kharkiv	119	116	96	−20	−3
Kherson	14	13	14	1	−1
Khmelnytsk	11	10	15	5	−1
Cherkasy	29	30	31	1	1
Chernivtsi	9	7	13	6	−2
Chernihiv	15	11	22	11	−4
City				0	0
Kyiv	101	88	79	−9	−13
	...	...	...	...	...

Simultaneously, the absolute number of industrial innovation-active economic entities in the region does not illustrate the level of regional innovation development, which can be represented by the relative share of innovation-active industrial enterprises in the region at the end of the reporting year.

In general, in Ukraine, as shown in Figure 5, the share of innovative enterprises in the total number of medium and large-business industrial enterprises (codes B, C and D according to the Classifier of Economic Activities) does not exceed 2.5%. This indicates an extremely low technological level of industry in Ukraine.

In addition, the leading regions in the number of innovation-active enterprises do not coincide with the leading regions of the index. The leaders here are the Ternopil, Kharkiv, Sumy, Cherkasy and Kirovohrad regions. The Dnipropetrovsk region is in ninth place, and the Donetsk region is at the bottom of the list. Thus, in Ukrainian regions, there is no stable dependence on the level of industrial development and the level of innovation activity, which, moreover, undergoes significant fluctuations in statistics, even from year to year.

In the sectoral structure of total expenditure by area of innovation, the leaders are the sectors that represent the processing industry of all technological segments, for example, the food industry in the low-tech sector, metallurgical production in the medium-low-tech sector and the production of pharmaceuticals in the high-tech sector (Figure 6).

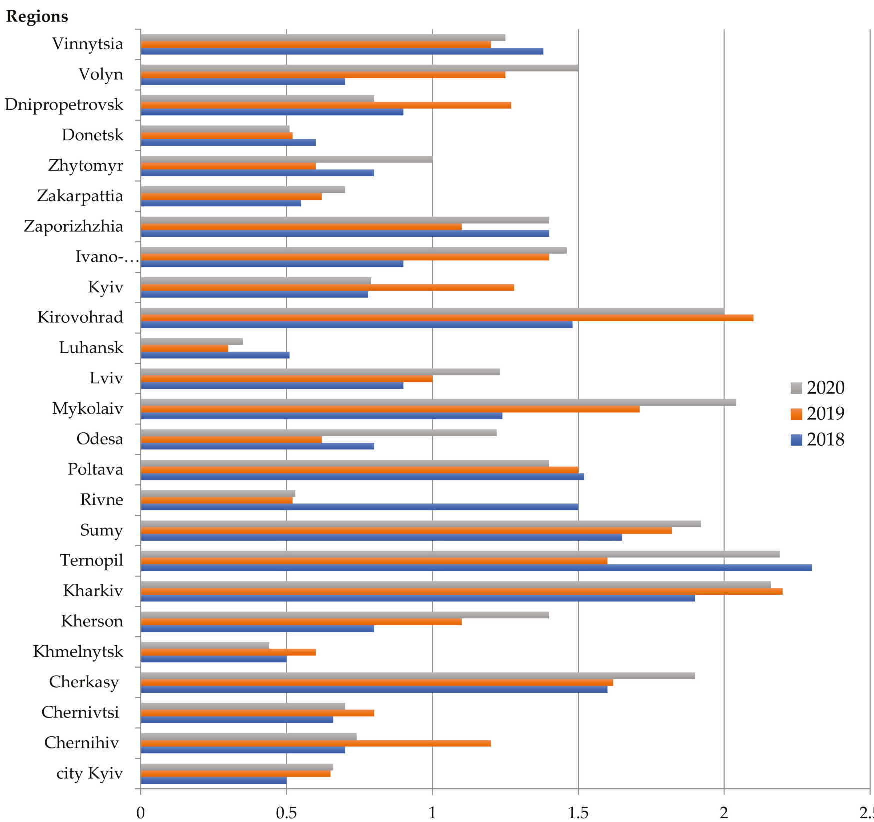

Figure 5. The share of innovation-active enterprises in the total number of industrial enterprises by region at the beginning of 2021, % [33].

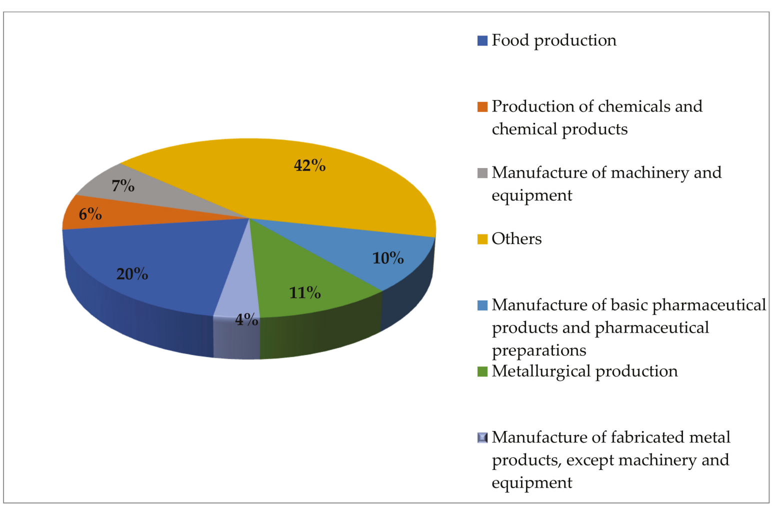

Figure 6. Structure of total costs by area of innovation, % [44].

An effective indicator of the environmental friendliness of regional economic systems is an integrated indicator of the effectiveness of environmental management, which is calculated using a linear function according to the formula:

$$I = \sum_{i=0}^{3} \binom{n}{k} Ci\ Ii \quad (2)$$

where Ii—integrated ecological characteristic; Ci—weight coefficient of integrated indicators.

The integrated indicator of the effectiveness of environmental management provides a comprehensive assessment from the standpoint of compliance with objectives based on integrated environmental characteristics calculated by groups of indicators.

Therefore, solutions to problematic environmental issues, particularly climate issues, can be achieved through the intensive implementation of technological innovations and the effective management of the latter. An example of such implementation is "green" technologies, which, together with similar models, should be applied primarily to production processes in the real sector of the economy in order to minimise harmful effects on the environment. Innovation itself can form a breakthrough in consciousness and cause the rethinking of the usual processes and technologies, which, in turn, is a necessary factor for the greening of economic activity, even in the absence of public support.

Undoubtedly, the most significant level of innovation in regional development is reflected in the indicators of the sales of innovative products because they form the gross regional product and reflect the end result of innovation.

Simultaneously, the situation in Kyiv is consistently ahead in these indicators in terms of regions. In addition, the analysis in the current study allows us to state that innovative products by region did not determine the regional sales volume and, as a consequence, were not a crucial component of gross regional product.

4.2. Influence of State Regulation on the Process of Decarbonisation/Adaptation in the Region

The state's influence on the management of innovation development in the region is currently significant. At the same time, the state plays the role of facilitator in the initial stages of regional development and later transfers these functions to the relevant institutions of innovative development. It should be noted that the state and executive authorities are among the stakeholders in the processes of decarbonisation and adaptation, and assessing the feasibility and possible consequences of their regulation requires the creation of hybrid model complexes that combine climate modelling, energy modelling, economic modelling and investment in the development of certain technologies and directions. Currently, we can discuss two groups of models for different stakeholders because they all need to consider climatic factors in their activities. The first group assesses the scale of climate change and how humanity can adapt to it (adaptation scenarios), and the second group examines how to resist climate change itself (decarbonisation scenarios). At the same time, each group of stakeholders is concerned with specific questions (Table 3).

Approaches to modelling different sectors of the economy are universal, but owing to the focus of research on energy issues, we consider modelling tools focused on the energy sector. Such models can be divided into two major categories: top-down and bottom-up (Figure 7, Table 4), as well as integrated related models.

The methodological gap in approaches to the implementation of decarbonisation has stimulated the emergence of hybrid-related approaches that combine the technological clarity of upward models with microeconomic realism and the macroeconomic feedback of downward models. The linking of models was achieved through iterations with feedback between models.

It should be emphasised that the list of integrated models of decarbonisation currently used in the EU in the energy sector includes several examples, such as: PRIMES, GAINS, GLOBIOM-G4M, PROMETHEUS, CAPRI and POLES. These integrated models have a variety of targets in methodology, time horizons, sectoral coverage and input–output data.

Table 3. The main stakeholders of the decarbonisation process. Adapted with permission from [31]. Copyright 2018, United Nation.

Stakeholder	The Question Answered by the Related Model Complex
National regulators and central executive bodies	How and with what speed can the economy be decarbonised as efficiently as possible for the country?
Regulators at the international level	How and when will most countries in the world be able to achieve the goals of the Paris Agreement?
Financial sector	What are the possible consequences of the complete cessation of funding for carbon-intensive projects?
Business community	How can a company be decarbonised as effectively as possible? How can a company's real assets be adapted to climate change?
National climate organisations and climate activists	What are the possible consequences for the world in the event of non-acceptance of mitigation of climate change?
Population	How will decarbonisation/adaptation methods affect incomes, health and living standards?

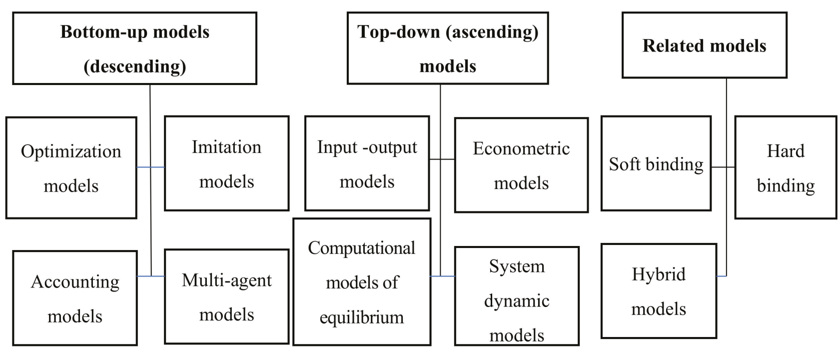

Figure 7. The classification of decarbonisation models focusses on the energy sector. Reprinted with permission from [42]. Copyright 2009, Boehringer, C.; Rutherford, T.

An analysis of the possible application of models of the decarbonisation of Ukraine's economy in the projected postwar period of development makes it possible to state the need for an integrated approach and the use of hybrid models.

After all, models of rigid bonding are ill-suited for modelling in crisis and force majeure conditions, which are the conditions for the recovery of an economy destroyed by hostilities. Soft binding often provokes interference, namely, differences between the results of energy flow models, prices and technologies within a particular region. Noise control is difficult because most useful sets of common measurement points are non-exclusive.

4.3. Applied Models of Decarbonisation of Energy-Intensive Sectors

In recent years, Ukraine has begun to implement a model of regional development for fair transformation.

According to the Concept of the State Target Program for Fair Transformation of Coal Regions of Ukraine for the period up to 2030, approved by the Resolution of the Cabinet of Ministers of Ukraine dated 22.09.2021 № 1024, the concept of "fair transformation" is interpreted as "a model of regional development to all residents, including workers who will be affected by the process of abandoning fossil fuels (liquidation of production facilities, closure of coal mining enterprises, etc.)" [32].

Table 4. Advantages and disadvantages of decarbonisation models.

Type of Decarbonisation Model	Functional and Structural Features	Disadvantages and Shortcomings
Descending models	Economists and governments commonly use descending models. These models focus on aggregating macroeconomic sectors. They are usually characterised by a simplified presentation of components and therefore do not fit the definition of sectoral policy. Their scope is to assess the impact of energy and climate policies on socio-economic sectors, such as social growth and social welfare, employment, etc. A top-down approach may also consider interdependence between sectors or countries.	Descending models lack technological details and are limited to modelling financial policy instruments. This study has methodological limitations. The parameters of elasticity and autonomous efficiency in descending models were estimated based on empirical data.
Rising models	The ascending approach is to develop engineering models with a detailed description of the technological aspects of the energy system and how they may develop in the future, which allows the determination of sectoral policies. Energy demand is usually set exogenously, and models analyse how this energy demand should be met at minimal cost. However, the bottom-up approach does not consider the link between the energy system and macroeconomic sectors, thus ignoring the impact on these sectors.	Traditional ascending models describe technologies, but they realistically reflect the economic decisions made by enterprises and consumers when choosing technologies and do not reflect the potential feedback of macroeconomic equilibrium.

In this context, the formation of a national Green Deal is a critical priority for Ukraine. A national feature of this area is environmentally harmful coal. Ukraine has historically formed certain socio-economic clusters around the coal regions—Donetsk, Luhansk, Dnipropetrovsk, Lviv-Volyn and Transcarpathian basins. However, the reduction in the share of coal energy should be gradual based on the formation of an appropriate alternative to this type of economic activity, using the experience of China, the Czech Republic, Germany and Poland in terms of diversification in the industry. Global examples of the harmonious transformation of coal regions demonstrate the strategic course of events and significant impact on the economy. Therefore, for Ukraine, which is fairly new to the process of coal industry transformation, these processes should be reflected and adjusted in the national Green Deal.

Difficulties with the transition to a decentralised electricity market in Ukraine are both objective (regulatory) and locally subjective.

The Ukrainian situation requires urgent action at the highest level of government. Thus, the Government of Ukraine announced the creation of four revival funds for the restoration of property and infrastructure, economic transformation, debt service and repayment, and support for affected businesses [45]. The proposed funds combine two trends: national, to obtain funds for development through the relevant state institution, and European, to obtain funding through the relevant fund.

In addition, Ukraine has negative or neutral trends in the development of alternative energy and energy cooperation, provoked by the instability of the regulatory environment, the passivity of the business environment and public awareness of the existing benefits of the green energy market. The fragmentation and imperfections of the current legal framework worsen the situation.

Simultaneously, developed agriculture in Ukraine can and should become the basis for the development of bioenergy. The energy cooperative movement is currently in its infancy in Ukraine [46].

The flexibility and variability of cooperative organisational and legal forms determine the convenience of their use. Thus, an energy cooperative can unite energy producers or consumers or act in both roles simultaneously to produce and consume energy (that is, the cooperative prosumer) or to accumulate (aggregate) energy from other producers [47].

Renewable energy, as a new technology, needs to implement appropriate support mechanisms: political, legislative and economic [48,49]. The models represented in this study, using the apparatus of mathematical logic, can be interpreted as follows: to achieve the goal of developing mechanisms for the implementation of renewable energy at the regional and local levels (development of mechanisms for the implementation of renewable energy at regional and local levels), a set of ten organisational, economic, fiscal, institutional and regulatory measures was applied (Table 5).

These measures belong to many methods for the effective stimulation of investment inflow to renewable green energy (methods of effective stimulation of investment inflow to renewable green energy).

Table 5. Correspondence of mechanisms to support renewable energy and their formalised presentations.

The Name of the Event	The Essence of the Event	Formalised Term in Equation (3)
Adoption of laws regulating the conditions for access to energy systems for installations of renewable energy sources (RES)	Adoption of laws regulating access to energy systems	Law^{en}
Establishment of special guaranteed tariffs for the purchase of electricity produced from RES and obligations for energy networks to purchase electricity	Transition to renewable energy sources (RES)	Es^{tar}
Establishment of a mandatory share of electricity produced from RES in the balance of electricity sold by power grids	Establishment of special guaranteed tariffs for the purchase of electricity produced from RES as well as obligations for energy networks to buy this energy	Es^{mand}
Financing research activities leading to a reduction in renewable energy cost	Establishment of a mandatory share of electricity generated from RES in the balance of electricity sales of power grids	Fin^{res}
Establishment of state and other institutions to promote renewable energy, implement special programmes and demonstrate projects	Funding for research activities that reduce RES costs	Es^{state}
Preferential loans for purchasing renewable energy equipment and partial returns on investment for consumers	Establishment of state institutions for the promotion of RES and implementation of special projects	$Loans^{pref}$
Accelerated depreciation of RES equipment	Preferential loans for purchasing RES equipment and partial returns on investment for consumers	Dep^{ac}
Organisation of public support and the introduction of voluntary forms of support, such as the purchase of green energy by consumers as well as the transparency of information on the share of clean electricity in the balance of energy networks	Accelerated depreciation of RES equipment	Pub^{sup}
Subsidising investment in renewable energy	Organisation of public support and introduction of voluntary forms of support, such as consumer purchases of "Green Energy" as well as transparency of information on the share of clean electricity in the balance of energy networks	Inv^{sub}
Tax exemptions and tax rate reductions	Subsidising RES investments	Tax^{ex}

In this case, the formalisation of the conceptual and analytical model of integrated support mechanisms for the implementation of renewable energy has the following form (Formula (3)), and definitions of terms in the formula are given in Table 5.

$$Dev^{re} \approx \left\{ Law^{en} \cup Es^{tar} \cup Es^{mand} \cup Fin^{res} \cup Es^{state} \cup Loans^{pref} \cup \ Dep^{ac} \cup \ Pub^{sup} \cup \ Inv^{sub} \cup Tax^{ex} \right\} \in METHOD^{ge} \quad (3)$$

where Dev^{re}—achieving the goals of developing mechanisms for the implementation of renewable energy at the regional and local levels; $METHOD^{ge}$—methods for the effective stimulation of investment inflow to renewable green energy.

It should be noted that some of the measures to stimulate the mechanisms of renewable energy have already begun to be implemented under current conditions in Ukraine. For example, the announced onset of tax reform will certainly contribute to the effective implementation of the proposed conceptual and analytical model. In addition, the revolutionary step of connecting the Ukrainian energy system to the European ENTSO-E system will ensure the stable operation of the Ukrainian energy system in wartime and in the postwar period, as well as the development of energy generation and investment.

5. Conclusions

Summarising the results of the study, we note that the European experience of socio-economic development demonstrates a systematic and integrated approach, including state-of-the-art measures to achieve a climate-neutral Europe. Recent events: Considering Ukraine's application for EU accession under the accelerated procedure, the development of Ukraine after the military conflict requires non-standard solutions to improve the regulation of energy security and nature management.

Unfortunately, in the Ukrainian region, at the beginning of 2022, innovative products have not yet been a significant component of indicators such as gross regional product (GDP) and gross sales. Simultaneously, the state's involvement in the management of innovation processes in the region and their facilitation has a significant impact on the level of innovative regional development.

The environmental goals of achieving a carbon-neutral level of the economy and the decarbonisation of energy-intensive industries involve the introduction of balanced and effective approaches to coordinating financial investments in relevant segments, the formation of a legal and regulatory framework, the use of available resource potential and integration prospects, and the state's environmental facilitation. For example, the decarbonisation of green energy to alternative energy sources can have significant financial implications for households. Simultaneously, the negative consequences of effective state measures of regional greening, as well as decentralisation, can be a positive vector for the development of communities and territories.

The comparative analysis of decarbonisation models conducted in this study allowed the systematisation of its advantages and disadvantages, on the basis of which, in turn, the methodological gap in approaches is evident. These factors are the basis for the development of a hybrid integrated approach to energy decarbonisation policy in Ukraine, which would combine existing models and have a national orientation, taking into account the force majeure circumstances of the recovery of Ukraine's economy. This course of events is actualised by the peculiarities of Ukraine's integration into the European energy system and the prospects of accession to the EU both on a general basis and under the accelerated procedure.

The results of the current study should be considered within certain limitations, which can be addressed in future studies. Thus, the uncertainty of the economic situation caused by hostilities produced methodological imperfections in the study, namely, the limited ability to conduct a thorough analysis using mathematical modelling. In addition, objectively limited access to statistics on the regions of Ukraine requires the adjustment of the survey results, provided that these data are available.

The most effective way to develop the Ukrainian economy will be the development of innovation-active regions and industries, which, in turn, will be drivers of the development of related territories and industries while ensuring synergies. The transition to an environmentally friendly, green economy is a multi-layered process that is not quick and painless. Thus, given the global trends in the framework of green energy transition, it is important to consider planning the development of innovation-active industries and regions of the state.

At the same time, it is necessary to take into account the legal and infrastructural preconditions typical for Ukraine, namely: the social and economic weight of the coal industry; the comparatively low cost and significant share of nuclear energy; obstacles and shortcomings in the decentralisation of the electricity market; negative trends in the development of renewable energy; asymmetry in the distribution of energy resources at the regional level; and the initial position in the development of the energy cooperation movement, but also a strong agricultural sector as a basis for the development of bioenergy, making it possible to state the available resource potential for creating a synergetic impact in various sectors of Ukraine's economy.

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Evaluating the Transition of the European Union Member States towards a Circular Economy

Joanicjusz Nazarko, Ewa Chodakowska and Łukasz Nazarko *

Faculty of Engineering Management, Bialystok University of Technology, Wiejska 45A, 15-351 Bialystok, Poland; j.nazarko@pb.edu.pl (J.N.); e.chodakowska@pb.edu.pl (E.C.)
* Correspondence: l.nazarko@pb.edu.pl

Abstract: This paper presents the assessment of the European Union member states in terms of the circular economy (CE) targets, using a combination of the Data Envelopment Analysis (DEA) method and factor analysis. This approach fills in the existing knowledge gap by providing an innovative methodology of an objectivised comparative evaluation of the degree of implementation of the CE principles by the EU countries. Assessing countries' performance in achieving the goals of the circular economy is a challenge due to the lack of a generally accepted methodology, the multitude of indicators, and the insufficient data. Countries may be compared in a narrow way, according to single indicators, but a more holistic synthetic assessment of countries is also needed to determine their position against each other. In such cases, DEA may be successfully used. The study resulted in the identification of two clusters of countries with similar profiles of relative efficiency in the CE goals' implementation. It was concluded that the position of a particular country in achieving the CE aims was strongly correlated its GDP per capita. Moreover, factor analysis showed that many CE indicators are strongly correlated with each other and may be aggregated into five meta-indicators (factors): Recycling rate of general waste, Waste production, Jobs and investments, Recycling rate of special waste, and Circular material use rate. In addition to simple rankings and indication of benchmarks, the article offers a novel concept of technology competitors which was used to group units competing for positions in the ranking.

Keywords: Data Envelopment Analysis (DEA); factor analysis (FA); circular economy (CE); sustainability; sustainable development indicators (SDI); European Union (EU)

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1. Introduction

The growing impact of human activities on the environment makes the search for viable modes of sustainable development especially urgent [1]. The term circular economy (CE) has existed in the literature since the 1960s [2]. In recent years, it gained significant notability in Europe with the introduction of the circular economy concept into the policy and strategy of the European Union (EU) in 2014 (COM/2014/0398) [3] and the launch of the first Circular Economy Action Plan of the European Commission (COM/2015/0614 Final) in 2015 [4] continued by a new Circular Economy Action Plan: For a cleaner and more competitive Europe (COM(2020)0098) [5]. The growing interest in CE is also reflected by the rapid increase in the number of scientific articles and reports [6].

Transition towards the circular economy demands a whole new logic of designing economic processes and running businesses. In the traditional linear model of production and consumption, resources are mined or grown, then transformed into goods which are then used and finally turned into waste (the so called 'produce-use-dispose', 'make-take-dispose', or 'take-make-waste' paradigms). In the circular economy, materials are repeatedly recovered and recycled—they remain in circulation for as long as possible.

Despite a noticeable change in the political discourse, academic discussion, and the public awareness, the current globally dominant economic model essentially remains focused on the efforts to increase consumption constantly, which until now was always related to the increase in production and further depletion of Earth's resources. Improvement in welfare is typically associated with an increased production and consumption. Especially now, as the world is trying to cope with the economic consequences of the coronavirus pandemic and with the unfolding geopolitical crisis, it is not easy to win the public's heart by calling for the fundamental rethinking of lifestyles, and for efforts to reconcile profitability with sustainability [7,8]. As Kirchherr notes, discussions between business practitioners, policy makers, and scholars *rest upon the CE's promise to reconcile sustainability and growth* [9]. At the same time, there is no consensus, neither among scholars nor among practitioners, that the CE paradigm guarantees social well-being for this generation and the future ones [10,11]. The European Union would need to cut off its ideological roots in the trade union for coal and steel and to prioritise long-term environmental sustainability [12].

Even though a completely circular economy is not possible in complex advanced economies [13,14], some authors view the CE as the most comprehensive and mature model capable of reconciling economic growth with sustainability and even boost the competitiveness of countries and enterprises by protecting businesses against scarcity of resources [15]. It remains to be seen, however, to what extent the paradigm shift actually occurs. As long as the old linear paradigm shapes the national economic policies (in real terms, not in rhetoric figures), there will be no single country that could come close to the ideal of a truly circular economy. Transition towards a CE must go hand in hand with the shift of the innovation paradigm [16,17] towards models such as Responsible Research and Innovation [18–22], Restorative Innovation [23], or Future-Oriented Technology Analysis [24,25], focusing not only on what is marketable but what is socially desirable and environmentally viable.

A common and widely accepted framework and the standard set of indicators measuring the CE maturity are not established yet. Assessment of the transition towards a CE based on selected indicators is the content of numerous publications that include simple and complex comparisons, qualitative and quantitative evaluation approaches [26]. One of the most exploited methods to assess sustainability, comparing the ability to transform labour, capital, and energy (including from renewable energy sources) and taking into account pollutants (e.g., greenhouse gas emissions) into the GDP, is Data Envelopment Analysis (DEA) [27]. Assessment of the state of development of the circular economy is also carried out using DEA.

Beside the numerous advantages of DEA as an objective method of creating rankings, there is a serious limitation consisting of a low classification ability in the case of too large a set of indicators in relation to the number of objects. Thus, its direct application in the case of a large set of CE indicators without limiting their number does not allow the assessment of the state of transition toward a CE. Apart from the arbitrary selection, one of the popular approaches to limiting the number of indicators is the principal component analysis (PCA)/factor analysis (FA) method. It is not always possible to use them directly, as is shown in the work. The article proposes an alternative approach consisting of the selection of the representative indicators. The position of countries compared to each was analysed, and benchmarks and technological competitors were indicated. It was proven that the performance assessment approach derived from operations research may be successfully applied to evaluate the circular economy maturity.

In this paper, the authors fill in the research gap related to the lack of works evaluating the comparative performance of the EU member states in pursuing the CE goals based on the system of indicators included in the EU methodology of CE assessment. The methodological contribution of this work consists of proposing a novel approach to a comparative evaluation of the state of transition towards a CE in a given group of countries. The cognitive added value of the paper lies in the results obtained from the analysis of the EU member states according to the developed methodology.

The article is structured as follows: first, it provides a review of papers that focus on the monitoring and assessment of countries toward a CE, and the second part assesses

EU countries in terms of CE targets combining DEA and factor analysis. The article ends with conclusions.

2. Background Literature

2.1. Circular Economy and Multitude of Related Concepts

Circular economy is a concept that has not been clearly defined in the literature so far. However, different propositions share much in common and converge towards the same paradigm [28]. Kirchherr et al. (2017) [29] view the CE as a market-based economic system that supports business models implementing the ideas of reducing, alternatively reusing, recycling, and recovering materials in the production, distribution, and consumption processes. Such reorientation of the economic system at all levels (products, companies, consumers, cities, regions, countries) shall lead to the environmental viability, welfare, and social equity for the current and future generations. The circular economy is defined in opposition to the linear 'make-take-waste' model and is understood as an extension of the concept of green economy or bioeconomy [30–33] and linked to a cleaner economy, a low emission economy, industrial symbiosis [34], industrial ecology, eco-industry [35,36], cradle-to-cradle economy [37], Tech-Ökonomie [38], zero-waste economy, 'regenerative by design' economy [39], natural capitalism [40], green engineering, ecological modernisation [41], or sustainable development in general [42–46].

The bio-based CE is an economy where materials and energy are produced and derived from renewable biological sources [47,48]. Moreover, biological resources are managed in a way that their value is maintained at the highest level as long as possible [49]. Bioeconomic orientation of the CE is particularly suitable in sectors such agriculture [50], fertilizers [51], forestry [52], marine economy, pulp and paper, food production and retail [53], feedstock [54], cosmetics, biofuels, bioplastics [55], construction, furniture as well as bio-waste management [56,57], and wastewater treatment [58]. Metic et al. propose a concept of dual circularity, noting the existence of distinct, yet overlapping, thematic areas of a technology-focused CE and bio-based CE [59]. The area where 'bio' fuses with 'tech' includes, among others, such topics as microbial production, enzyme technology, and Green Chemistry [60].

Regardless of the definition, the implementation of the principles of a circular economy and the transformation towards less wasteful systems, a more effective and sustainable use of natural resources, and the reduction of pollutant emissions, including greenhouse gases, is becoming one of the key challenges worldwide [61]. Institutional, economic, environmental, organisational, social, technological, supply chain related drivers, barriers, and critical success factors determining the transition to a CE are discussed from different perspectives and at different levels of analysis [62]. Changing the economic systems is not possible in the short term horizon, and the practices that lead to the implementation of the circular economy postulates are introduced gradually [63]. Monitoring the progress of the performance at micro, meso, and macro levels [64] towards the circular economy is a complex and demanding task, mainly because of the multidimensionality and vagueness of the concept [65,66].

2.2. Macro and Meso Levels of CE Analysis

At the macro and meso levels, researchers study sectoral or spatial (national, regional [67], municipal/urban [68,69]) aspects of CE. Those aspects were divided by Martinho and Mourão [70] into the following categories: (1) efficiency and sustainability [71–73], (2) policies, governance, and management [41,74–78], (3) product life-cycle [79,80], (4) resources and waste [81,82], (5) innovation and opportunities [83], (6) sectoral topics, (7) bioeconomy. Mhatre et al. [84] offer an exhaustive list of CE-oriented activities characteristic to different sectors of national economies. Those activities are, among others, related to: bio-based materials, by-products' utilisation, cascading materials, community involvement, design for disassembly, design for modularity, down-cycling, eco-design, eco-labelling, element recovery, energy recovery, extended producer responsibility, bio-chemicals' extraction, functional recycling, green procurement, high-quality recycling, incentivised recycling, material substitution, optimising packaging, product as a service, refurbishment, adaptable manufacturing, restoration, reuse, redistribution and resell, sharing, take back and trade-in, upcycling, maintenance and repair, virtualisation.

2.3. Micro Level of CE Analysis

At the micro level, forward-looking enterprises and organisations anticipate the emerging shift towards the CE and try to transform their operations with the aim at boosting innovation, penetrating new markets, and securing customer loyalty. Interface of entrepreneurship and the CE is an extensively explored topic [85]. Incentivising adoption of CE activities by companies (with a special focus on small and medium enterprises [86]) is also a priority of the European Union [87]. Public sector entities are also evaluated against the circularity criteria, especially with regards to public procurement procedures, internal process and operations, and public service delivery [88]. Eco-innovations [89] and new business models are proposed and validated in various sectors [90–93]. Discussion on incorporating digital technologies (Industry 4.0, Big Data, Internet of Things, Artificial Intelligence, Blockchain) into CE frameworks is currently a dynamic field [94]. Interaction between governmental policies and different business models conducive to the CE is also analysed [95].

Four macro-categories of business models aligned with the CE paradigm are distinguished: net-zero emission innovation, servitisation, sharing, product life extension, product residual value recovery [96,97]. In the CE assessment of single organisational entities, such aspects as greenhouse gas emissions, air pollution, nitrogen release, phosphorus release, water pollution, release of harmful substances, biodiversity loss, real estate maintenance, transport, space/land usage, and the procurement of electricity, energy, food, and other materials, are considered [37]. Intangible aspects of business alignment to CE principles labelled as values, mission, culture, or mindset are also studied [98].

Several frameworks of CE assessment applied at the macro level may also be used at the micro level, in single businesses and non-profit organisations: Life Cycle Assessment (LCA), social life cycle assessment (S-LCA), BS 8001:2017 Standard [99] material flow analysis (MFA), Life Cycle Sustainability Assessment (LCSA), Ecological Footprint (EC), Product Circularity Data Sheet [100]. Accounting and accountability reporting models are also indicated as important mechanisms through which enterprises and stakeholders can measure the progress, costs, and gains from the transition towards a CE [101,102]. The focus here is clearly on fulfilling certain requirements rather than benchmarking (understood as a specific management practice oriented at achieving excellence described in [103]) and comparison with other entities [104]. Depending on the chosen CE assessment approach, different groups of intended end-users may be identified: specific organisations, entities from a particular sector, managers, designers, customers, policy makers [105].

2.4. CE Metrics and Indicators

One important step towards CE mainstreaming is the development of suitable indicators that would help measure the state of transition in both absolute and relative/comparative terms [26,65,106–108]. Research on CE metrics and indicators is ongoing at all levels of analysis (micro, meso, macro), with different indicators trying to capture different dimensions of sustainability (environmental, economic, social) and core principles of the CE ('reduce, reuse, recycle, recover, remanufacture, redesign') [109]. Examples of a quantitative analysis of the CE in the European Union concern individual member states [110,111], groups of member states [112,113], regions [114,115], economic sectors [116,117], or all EU member states [118–125].

The recommended indicators measure different aspects of the CE at the company, regional, and national level [126]. Measures proposed by the EU to progress towards a circular economy at the EU and national level are composed of a set of key indicators that cover production and consumption, waste management, secondary raw materials, and competitiveness and innovation [127]. In the typology of the European Environment Agency (EEA), the indicators are divided into five groups: descriptive indicators, performance indicators, efficiency indicators, policy effectiveness indicators, and total welfare indicators [128]. Different methodologies of clustering and classification are proposed, both conceptual and empirical, to deal with the humongous number of available sustainable development indicators (SDI) [65,129–134].

2.5. DEA Method in the Evaluation of CE Goals Achievement

The DEA method plays an important role in comparative performance assessment. It allows the comparison of the efficiency of countries, regions, organisations, enterprises, and other entities characterised by the same set of inputs and outputs. DEA is broadly applied in various fields of public policy and business endeavours. It is recognised as a useful instrument of efficiency improvement and competitiveness increase [135].

The conducted literature review led to the identification of the fields of DEA application to circular economy problems. (Table 1).

Table 1. DEA applications in assessing the implementation of the circular economy.

No	Year	Objective of the Study	DEA Model	Publication
1	2019	Evaluation the eco-efficiency of the circular economy system in coal mining area Shanxi Province (China)	SBM-Undesirable super-efficiency model	Liu et al. [136]
2	2020	Measuring countries' performance in managing and exploiting their municipal solid waste	multiplier DEA model with weight restriction	Giannakitsidou et al. [137]
3	2021	Investigating efficiency performance and the dynamic evolution of industrial circular economy in Yangtze River Delta region (China)	Malmquist index based on network DEA	Ding et al. [138]
4	2021	Assessment and the monitoring of the cities and regions through the 'lens' of European Green Capital (ECG) indicators, using the available ECG data	CCR DEA	Amaral et al. [139]
5	2021	Assessing the efficiency of different sectors in the UAE based on sustainability and circularity objectives	CCR DEA	Bagheri [140]
6	2021	Appraisal and investigation of the performance of China's regional industrial CE systems	network DEA	Chen et al. [141]
7	2021	Comparison of the circular efficiency within the Visegrád Group and efficiency of Visegrád Group countries to the European Union 28 average	CCR and BCC DEA SBM	Lacko et al. [142]
8	2021	Evaluation of Chinese city urban circular economies under large datasets and fuzzy conditions	fuzzy non-radial DEA with undesirable factors	Wang et al. [143]
9	2022	Development of a Waste Management Composite Index (WMCI) as a Circular Economy indicator	Benefit-of-the-Doubt DEA	Milanović et al. [144]

The identified DEA applications concerned the assessment of CE implementation on the country (No 2, 7, 9), regional (No 4, 6), city (No 4, 8), and industrial sector (No 1, 3, 5, 6) levels. Study objectives and deployed DEA models are presented in Table 1. None of the reviewed works tackles the challenge of evaluating the comparative performance of the European Union countries in the implementation of the CE principles on the basis of a system of indicators as stipulated by the EU methodology of CE assessment (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions on a Monitoring Framework For the Circular Economy). The presented paper fills in this research gap and offers a comprehensive approach to a comparative analysis of the EU states' performance in achieving the goals of the circular economy.

3. Methods

Data Envelopment Analysis (DEA) is a linear programming technique that allows for studying the relative efficiency of decision-making units (DMU). The development of the method was initiated by the publication of Charnes, Cooper, and Rhodes (1978) [145] which was based on previous work by Farrell (1957) [146] and his concept of the 'best practice frontier' determined by the most effective units in the analysed set of units. Since its development, the DEA has become one of the most popular nonparametric benchmarking methods for measuring efficiency. A constantly expanding bibliography of the DEA method confirms its usefulness in analysing the efficiency of facilities of any complexity from almost all sectors of the economy.

The DEA method considers efficiency as the ability to produce maximum outputs at a minimum cost. Inputs and outputs must be clearly specified for each j unit in a set $(j = \{1, \ldots, j_O, \ldots, n\})$ as the vector of measurable attributes: $x_j = (\ldots, x_{ij}, \ldots), i = \{1, \ldots, r\}$ and $y_j = (\ldots, y_{rj}, \ldots), r = \{1, \ldots, s\}$. In this work, the variable return to scale super-efficiency DEA (SE-BCC) model by Andersen and Petersen [147] was employed:

$$\begin{gathered} max\phi j_O, \\ \sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{ij_O}, i = 1, \ldots, m,\ j \neq j_O \\ \sum_{j=1}^{n} \lambda_j y_{rj} \geq \phi y_{rj_O}, r = 1, \ldots, s,\ j \neq j_O \\ \sum_{j=1}^{n} \lambda_j = 1,\ \lambda_j \geq 0. \end{gathered} \tag{1}$$

The efficiency score ϕ of unit j_O is determined by finding a weighting vector $\lambda_j = (\ldots, \lambda_j, \ldots)$ that solves the linear programming problem. Decision-making units which achieve $max\phi \geq 1$ $(max\phi \geq 100\%)$ are efficient.

DEA determines the efficiency but also allows indicating the benchmarks: units whose linear combinations of input and output vectors are the pattern to follow. Moreover, in order to divide units into groups, the concept of technological competitors can be used. The term technology in the DEA method is used in the sense of vectors of empirical inputs x_j and outputs y_j. Technological competitors in the DEA method should not be viewed as rivals for resources or outcomes, but rather as rivals for a position in the ranking. Technological competitors may be defined by solving the DEA model formulated with the exclusion of effective objects [148]. The idea is presented in Figure 1. In the standard DEA model, the frontier is formed by units A, B, and C, and they are considered as fully, 100% efficient. In the SE-DEA model, for example, to assess the efficiency of B, this unit is excluded from the constraints; the frontier consists of A and C, so that B achieves efficiency higher than 100%. Its competitors are A and C. Efficient units B and C are the benchmarks for E, but after their exclusion, D and F are the technological competitors. The concept of technological competitors allows the grouping of objects on the basis of similarities, not the target.

The main drawback of DEA is that the ability to classify units as efficient or nonefficient decreases together with the increase in the number of attributes. The preferred number of attributes should be 3–5 fewer than the number of units [149]. It may be said that determining the inputs and outputs is one of the most difficult and challenging stages in the efficiency analysis with DEA. The choice of the analysed attributes has a huge impact on the results, but there are no formal rules that would clearly define what should be inputs and outputs in DEA models. Their selection depends on the specificity of the decision-making units and their goals, data availability, and researchers' intuition, experience, and subjective choices. Some previous works suggest establishing a list of inputs and outputs by removing variables whose exclusion causes the least changes in the efficiency scores, removing variables strongly correlated with those left in the model (those that do not significantly affect the information measured by conditional variances and partial correlations), combining DEA with principal component analysis and replacing original variables with principal components. Another approach is the Rough Sets concept of reductions to limit the number of attributes [150]. In this paper, factor analysis is applied. It is due to the fact that the correlation coefficients between variables are not very strong, whereas the principal components have negative values, which cannot be directly included in DEA.

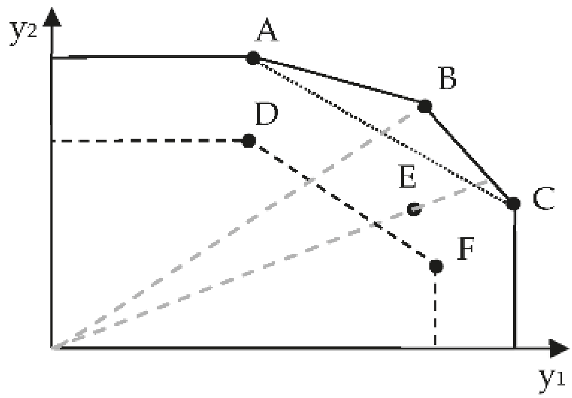


Figure 1. Frontiers in standard and super efficiency DEA models and the concept of technology competitors.

Factor analysis is a method to study the structure of multivariate observations and identify relationship between variables. By assuming that certain groups of variables represent the variability of the latent factors, a large number of variables can be reduced to a smaller set. The factor analysis for the standardised observed variable y_r ($r = \{1, \ldots, s\}$ where F_k, $k = \{1, \ldots, K\}$ denotes the factor, a_{rk} factor loadings, ε_r unique factors can be written as follows:

$$y_r = a_{r1}F_1 + a_{r2}F_2 + \ldots + a_{rK}F_K + \varepsilon_r \quad (2)$$

In order to obtain the simplest interpretation of individual factors, the factor loadings matrix can be rotated. It is assumed that the variance of y_r is the sum of common and unique variance:

$$Var(y_r) = h_r^2 + d_r^2, \text{ where } h_r^2 = a_{r1}^2 + a_{r2}^2 + \ldots + a_{rK}^2 \quad (3)$$

Cluster analysis was also used to discover the state of transition to a CE. The aim of cluster analysis is to classify objects into groups (which are not defined a priori) based on the density or distance between objects. There are several types of clustering techniques. The K-means model using Euclidean distances was employed in the research. Mathematically, assuming K as the number of clusters, n as number objects, y_j values of unit j, and μ_j as the centroid of cluster k, the objective function is:

$$min \sum_{k=1}^{K} \sum_{j=1}^{n} \|y_j - \mu_k\|^2 \quad (4)$$

Following the choice of the research methods and the set of CE-related indicators, a step-by-step research procedure was established. Figure 2 presents a flow chart of the conducted study.

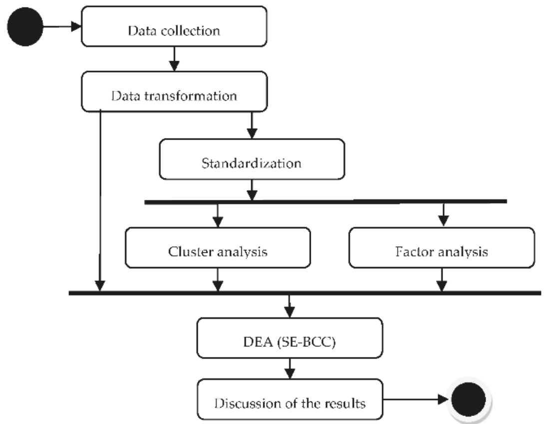


Figure 2. Research process.

4. Data

EU policies, initiatives, and assessment tools relevant to the monitoring and evaluation of the CE can be found in Europe 2020, Sustainable Development Strategy/Sustainable Development Goals, Euro indicators (PEEIS) and European Pillars of Social Right [151]. A similar set of indicators with the following focus areas of material input, eco-design, production, consumption, and waste recycling was also proposed by the European Environment Agency [152]. The indicators monitoring the CE are not unique to the CE only but are present in other UE frameworks. It is because the CE is not a closed system but directly or indirectly influences the economy, and thus the CE assessment relies both on direct and indirect indicators [153].

In this article, the EU CE monitoring framework intended to track the progress of CE implementation at the member states' level was used. The indicators' set represents 4 dimensions: production and consumption, waste management, secondary raw materials, competitiveness and innovations. According to the EU, they allow the European Commission and other policy makers to monitor the progress and evaluate the effectiveness of the EU members and inform stakeholders about current trends.

The indicators proposed by the European Commission to measure the CE development are in different units (percentage, absolute, or per capita). The first stage was to verify availability of data and their transformation to obtain comparable indicators and consistent interpretation. Indicators whose values are aggregated for the whole EU or are not collected directly (but estimated on the basis of different categories of waste) as food waste or whose interpretation without other information are problematic (e.g., about EU or non-EU exports and the dominant industry) as trade in recyclable raw materials was not included.

Table 2 includes the original data (from the EU methodology) and the 16 variables selected for further analysis (P1, P2, P3, W1, W2, W3, W4, W5, W6, W7, W8, S1, C1, C2, C3, C4) of the 27 EU counties, along with descriptive statistics. The data come from the publicly available Eurostat database (up-to-date on 17 March 2022) and cover mainly 2019 and 2018. Taking different years was possible due to the assumption that there were no radical changes in the economies of individual countries in recent years.

Table 2. EU CE monitoring framework data table.

Area	Indicator	Original EU Indicator and Unit	Indicator Used	Abbrev	Average	Max	Min	Std Dev
Production and consumption	EU self-sufficiency for raw materials, aluminium	Aggregated for the EU (percentage)	Not available					
	Green public procurement	N/A	Not available					
	Waste generation	Generation of municipal waste per capita (kg per capita)	Capita per generation of municipal waste (capita per kg) 2019	P1	2.071	3.571	1.185	0.509
		Generation of waste excluding major mineral wastes per GDP unit (kg per thousand euro)	GDP unit per generation of waste excluding major mineral wastes (thousand euro per kg) 2019	P2	15.820	37.037	1.548	8.405
		Generation of waste excluding major mineral wastes per domestic material consumption (percentage)	Domestic material consumption per generation of waste excluding major mineral wastes (percentage) 2019	P3	105.734	208.333	33.670	47.296
	Food waste	Estimated (million tonnes) based waste category, hazardousness, and NACE Rev. 2 activity	Not available					
Waste management	Recycling rates	Recycling rate of municipal waste (percentage)	Recycling rate of municipal waste (percentage) 2019	W1	39.500	66.700	8.900	14.547
		Recycling rate of all waste excluding major mineral waste (percentage)	Recycling rate of all waste excluding major mineral waste (percentage) 2018	W2	50.630	82.000	10.000	17.502
	Recycling/recovery for specific waste streams	Recycling rate of packaging waste by type of packaging: Recycling rate of overall packaging (percentage)	Recycling rate of overall packaging (percentage) 2018	W3	64.070	85.300	35.700	9.059
		Recycling rate of packaging waste by type of packaging: Recycling rate of plastic packaging (percentage)	Recycling rate of plastic packaging (percentage) 2018	W4	41.104	69.300	11.100	12.110
		Recycling rate of packaging waste by type of packaging: Recycling rate of wooden packaging (percentage)	Recycling rate of wooden packaging (percentage) 2018	W5	36.193	90.600	0.000	21.802

Table 2. *Cont.*

Area	Indicator	Original EU Indicator and Unit		Indicator Used	Abbrev	Average	Max	Min	Std Dev
		Recycling/recovery for specific waste streams	Recycling rate of e-waste (percentage)	Recycling rate of e-waste (percentage) 2018	W6	44.578	83.400	20.800	12.751
			Recycling of biowaste (kg per capita)	Recycling of biowaste (kg per capita) 2019	W7	69.556	189.000	0.000	51.458
			Recovery rate of construction and demolition waste (percentage)	Recovery rate of construction and demolition waste (percentage) 2018	W8	86.296	100.000	24.000	17.518
Secondary raw materials	Contribution of recycled materials to raw materials demand	End-of-life recycling input rates, aluminium (percentage), aggregated for the EU			Not available				
		Circular material use rate (percentage)		Circular material use rate (percentage) 2019	S1	9.367	30.000	1.300	7.010
	Trade in recyclable raw materials	Imports from non-EU countries (tonne)			Picture of trends in the markets for secondary raw materials (No clear interpretation)				
		Exports to non-EU countries (tonne)			Picture of trends in the markets for secondary raw materials (No clear interpretation)				
		Imports intra-EU (tonne)			Picture of trends in the markets for secondary raw materials (No clear interpretation)				
Competitiveness and innovation	Private investments, jobs, and gross value added related to circular economy sectors	Gross investment in tangible goods—percentage of gross domestic product (GDP)		Gross investment in tangible goods—percentage of gross domestic product (GDP) 2018	C1	0.140	0.250	0.020	0.049
		Persons employed—percentage of total employment (percentage)		Persons employed—percentage of total employment (percentage) 2018	C2	1.824	2.720	1.130	0.419
		Value added at factor cost—percentage of gross domestic product (GDP) (percentage)		Value added at factor cost—percentage of gross domestic product (GDP) (percentage) 2018	C3	0.977	1.560	0.360	0.230
	Patents related to recycling and secondary raw materials (number)			Patents related to recycling and secondary raw materials (number per million capita) 2016	C4	0.589	2.443	0.000	0.620

Source: https://ec.europa.eu/eurostat/web/circular-economy/indicators/monitoring-framework (accessed on 17 March 2022).

5. Research Results

The introductory examination of the collected data included the substantive and statistical analysis presented in Table 2, and the attempt to group countries. Standardisation was carried out, and countries were grouped via cluster analysis to assess the countries' development (missing data were supplemented with an average value). As a result of applying the cluster analysis procedure selected in the previous stage P1, P2, P3, W1, W2, W3, W4, W5, W6, W7, W8, S1, C1, C2, C3, C4 (missing data were supplemented with an average value), two groups were obtained (Table 3).

Table 3. Results of cluster analysis.

Cluster 1	Cluster 2
Belgium, Czechia, Denmark, Germany, Ireland, Greece, Spain, France, Italy, Luxembourg, Netherlands, Austria, Portugal, Slovenia, Finland, Sweden	Bulgaria, Estonia, Croatia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Romania, Slovakia

What is worth noting is that it is impossible to indicate a group of leaders in terms of all variables (Figure 3). Cluster 1 has high values for P2, W1, W2, W3, W5, W7, W8, S1, C4, and, respectively, low values for P1, P3, C1, C2, C3. Furthermore, variables W4 and W6 do not differentiate clusters.

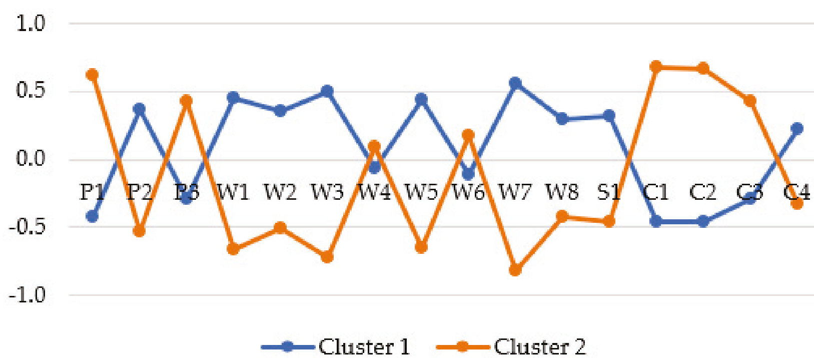


Figure 3. Means of CE monitoring indicators in the obtained country clusters.

Although GDP per capita was not included in the dataset, the clustering was generally conducted on the basis of it. In the second cluster, the average GDP per capita amounts to 14,486.4 euro, and the minimum value is 6840 euro. Treating Greece, the Czechia, Portugal, and Slovenia as exceptions and excluding them from the first cluster, the highest GDP in the second cluster (24,530 euro) would be even lower than the lowest value in the first cluster. In the first cluster, the mean is 36,233.3 euro per capita. Thus, it is justified to conclude that the indicators of the circular economy are primarily influenced by GDP. In Figure 4, the leaders are presented in terms of each indicator.

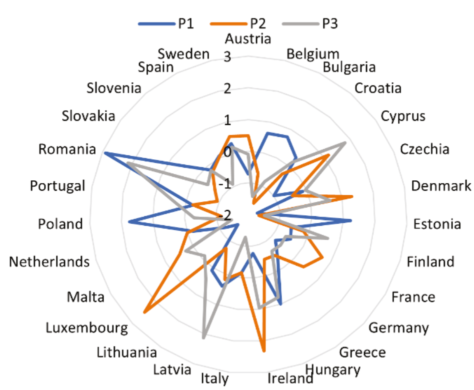
It is impossible to indicate obvious leaders on the basis of the presented data. Nevertheless, it is possible to point at leaders with respect to particular (sets of) indicators. The following countries can be distinguished: Romania in the case of P1 and P3, Luxembourg and Ireland in the case of P2, and Latvia in the case of P3. Similarly, for W1—Germany, W2—Slovenia, W3—Belgium, W4—Lithuania W5—Belgium, W6—Croatia, W7—Austria, and there are no pioneers in the case of W8. If one takes into account factor S1—it is the Netherlands, C1—Slovakia, C2—Lithuania and Latvia, C3—Croatia, C4—Luxemburg.

The DEA method allows for assigning ratings to the analysed countries. Its usefulness and adequacy are proven in many studies. Assuming a constant, identical level of inputs for each European country, weights for outputs can be adjusted to maximise the assessment of environmental performance. However, applying the DEA method to all variables does not differentiate the scores at all. The number of variables (16) is too high as compared to the number of countries (27).

To limit the number of units, the principal component method is often suggested in the literature [154]. PCA is a data space reduction method that is based on linear relationships and usually on standardised variables. However, as mentioned earlier, the values of the main components attain negative figures, which is not accepted in the DEA method.

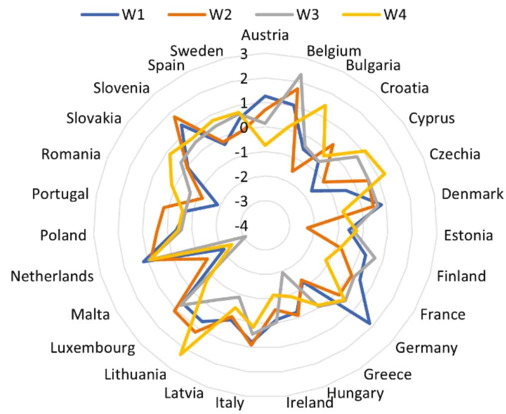
Factor analysis describes variability among observed variables with a lower number of unobserved factors. The five factors have eigenvalues greater than 1 and explain almost 75% of the variance (Table 4). Nevertheless, the use of the vector of factor values as well as the vector of components is not possible due to the output of the negative values. For this reason, a non-standard approach was used. After factors were determined, the most correlated variables were selected as representatives.

Factor 1 contains W1, W2, W3 but also three more variables with factor loadings over 0.5: W4, W5, W7. It represents the recycling rate but excluding the recycling rate of e-waste (W6) and construction and demolition waste (W8). The W6 and W8 build factor 4—recycling waste of special products. Factor 2 can be named waste generation because it has the highest factor loadings for the generation of municipal waste per capita and the generation of waste per GDP, P1 and P2, respectively. The opposite signs of P1 and P2 may suggest the following relationship: the higher generation of waste per GDP the smaller generation of waste per capita. In Factor 2, C1 (gross investment in tangible goods as percentage of GDP) also has a factor loading higher than 0.5. Factor 3 represents C2 (persons employed as percentage of total employment) and C3 (value added as percentage of GDP). It is related to investments. Considering Factor 5, one notices that S1 (circular material use rate) and P3 (generation of waste per domestic material consumption) have the higher factor loadings with opposite signs. Generally, the division of variables is consistent with the area indicated by the EU methodology. Thus, the following indicators were selected as the representatives of each discovered factor: P2, W2, W6, S1, C3. Next, the DEA scores were calculated for the representatives. Results of the computation are presented in Table 5 and in Figure 5.

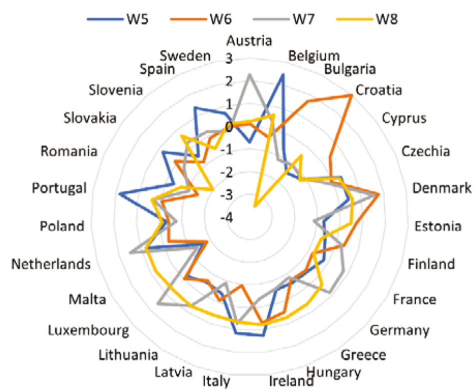


(**a**)

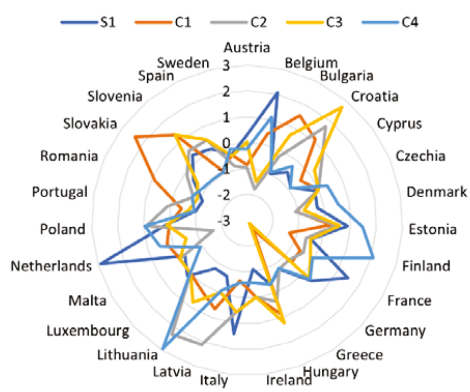
Figure 4. *Cont.*



(**b**)



(**c**)



(**d**)

Figure 4. Visualisation of standardised CE monitoring variables, respectively for variables: (**a**) P1, P2, P3; (**b**) W1, W2, W3, W4; (**c**) W5, W6, W7, W8; (**d**) S1, C1, C2, C3, C4.

Table 4. Factor loadings (Biquartimax normalised). Extract: Principal components. Numbers in red mark the indicators forming the respective meta-indicators (factors). For each factor, the indicators with the highest factor loading are marked in bold.

	F1	F2	F3	F4	F5
	Recycling rate of general waste	Waste production	Jobs and investments	Recycling rate of special waste	Circular material use rate
P1	−0.1794	−0.8420	0.0409	0.0483	−0.0363
P2	0.1523	**0.8826**	−0.0481	0.0221	−0.1499
P3	−0.2738	0.2630	0.1540	0.0154	−0.7471
W1	0.7776	0.2142	0.1171	0.0453	0.4002
W2	**0.8460**	0.1362	0.2218	0.2781	0.0925
W3	0.7068	0.0807	−0.4156	−0.3396	0.2546
W4	0.5439	−0.5090	−0.0093	−0.3471	−0.2454
W5	0.5787	−0.0989	−0.4793	0.0811	0.0482
W6	−0.0392	0.1628	0.3346	**−0.7862**	0.0946
W7	0.6738	0.4775	−0.1077	0.1181	0.3176
W8	0.1634	0.3932	0.0716	0.7374	0.1488
S1	0.4016	−0.0922	−0.1189	0.2770	**0.7625**
C1	0.1116	−0.5431	0.4971	−0.1685	−0.1191
C2	−0.1094	−0.1237	0.7425	0.0646	−0.3739
C3	0.0367	−0.0637	**0.9181**	−0.1790	0.0470
C4	0.0384	0.3112	−0.0558	−0.1122	0.6769
Variance explained	3.252	2.726	2.280	1.655	2.206
Contribution	0.203	0.170	0.143	0.103	0.138

Table 5. DEA analysis.

Country	Code	Score	Benchmarks	Technological Competitors
Croatia	HR	145.80%		Denmark, Slovenia
Netherlands	NL	129.80%		Belgium, Luxembourg
Luxembourg	LU	129.60%		Denmark, Ireland, Netherlands
Slovenia	SI	117.80%		Belgium, Croatia, Luxembourg
Belgium	BE	110.90%		Netherlands, Slovenia
Denmark	DK	106.10%		Croatia, Ireland, Luxembourg
Ireland	IE	104.90%		Croatia, Denmark, Luxembourg
Italy	IT	98.60%	Croatia, Luxembourg, Netherlands, Slovenia	Austria, France
France	FR	96.30%	Croatia, Luxembourg, Netherlands	Austria, Italy

Table 5. *Cont.*

Country	Code	Score	Benchmarks	Technological Competitors
Lithuania	LT	91.30%	Belgium, Croatia, Slovenia	Austria, Italy
Estonia	EE	90.20%	Croatia, Netherlands	Bulgaria, France
Austria	AT	89.90%	Belgium, Croatia, Luxembourg, Netherlands, Slovenia	Cyprus, Hungary, Italy, Lithuania
Germany	DE	88.70%	Croatia, Luxembourg, Netherlands	Poland, Spain
Cyprus	CY	88.10%	Croatia, Luxembourg	Austria, France
Spain	ES	84.70%	Croatia, Luxembourg, Netherlands	Czechia, Germany
Hungary	HU	84.40%	Croatia, Luxembourg, Netherlands, Slovenia	Bulgaria, Cyprus, Italy, Lithuania
Czechia	CZ	84.00%	Belgium, Croatia, Luxembourg, Slovenia	Germany, Poland, Sweden
Bulgaria	BG	80.00%	Croatia	Estonia, Hungary
Malta	MT	79.90%	Croatia, Luxembourg, Netherlands	Germany, Sweden
Poland	PL	79.90%	Belgium, Croatia, Netherlands, Slovenia	Czechia, Germany
Portugal	PT	77.70%	Belgium, Croatia, Luxembourg, Slovenia	Latvia
Sweden	SE	76.80%	Belgium, Croatia, Luxembourg	Finland, Germany
Latvia	LV	75.90%	Croatia, Luxembourg, Slovenia	Portugal, Slovakia
Slovakia	SK	73.90%	Belgium, Croatia, Luxembourg, Slovenia	Latvia
Finland	FI	70.80%	Croatia, Denmark, Luxembourg, Netherlands	Sweden
Romania	RO	51.70%	Croatia, Luxembourg	Romania
Greece	GR	51.20%	Croatia, Denmark, Netherlands	Greece

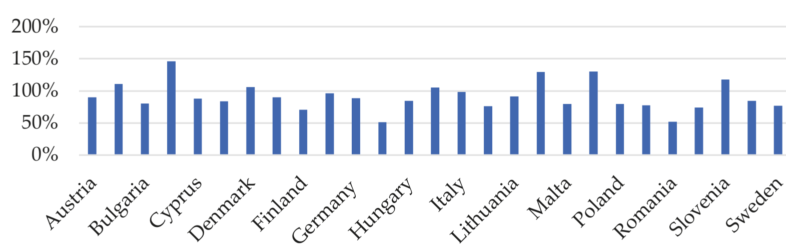


Figure 5. DEA results.

Taking into account the generation of waste, recycling rate of all waste, recycling rate of e-waste, circular material uses rate, and the value added, Croatia, Netherlands, Luxembourg, Slovenia, Belgium, Denmark, Ireland are the leaders among EU countries. The lowest performers, Greece and Romania, reach slightly over 50% efficiency.

The concept of technological competitors was used to group the countries (listed in Table 5), which is illustrated in Figure 6 with an additional indication of the direction of dependences.

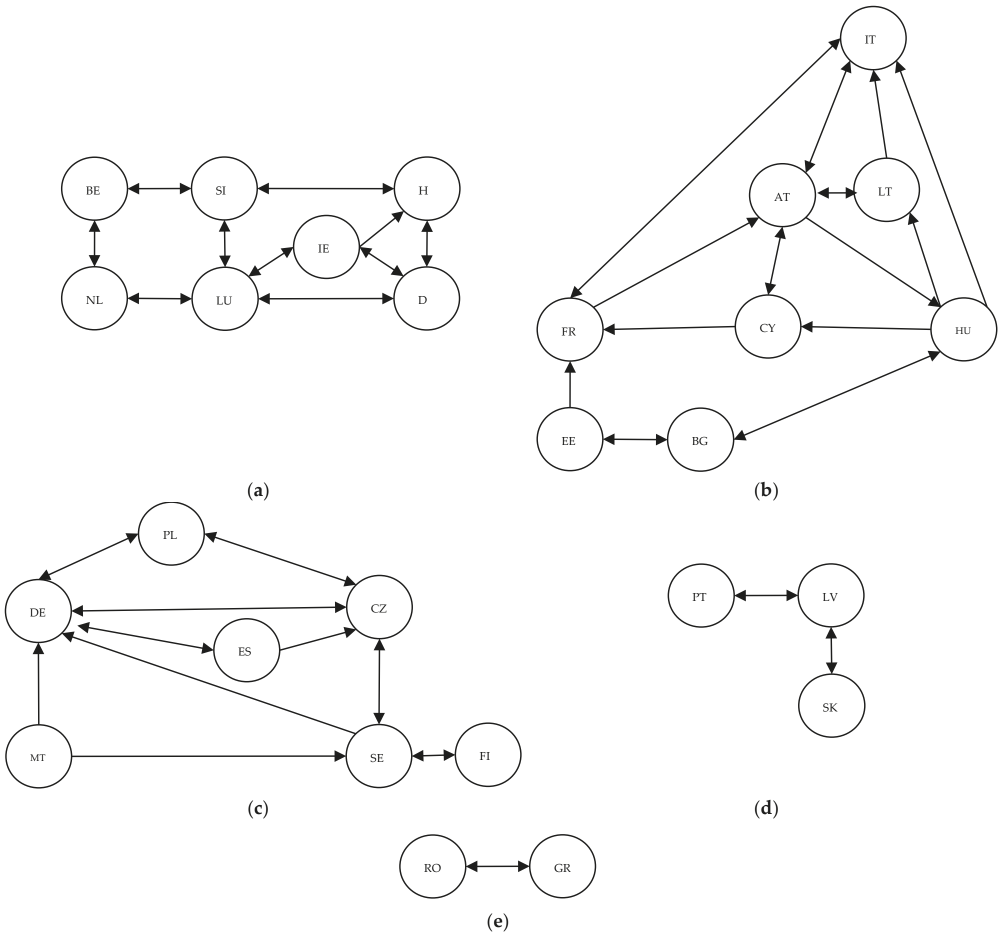


Figure 6. The competition of effective objects graph. The first graph (**a**) gathers competitors in the group of 100% efficient states. The next one presents the countries that may switch places with slight changes in data. The groups are as follows: (**b**) Estonia France, Cyprus Hungary, Austria, Italy Bulgaria, France Hungary, Lithuania; (**c**) Germany, Malta, Poland, Spain, Sweden, Czechia, Finland; (**d**) Portugal, Slovakia Latvia; € Romania, Greece. Designated groups connect countries with similar effectiveness. Group (**b**) includes countries with efficiency from 80.00% to 98.60%; group (**c**) from 70.08% to 88.70%; group (**d**) includes countries from 73.90% to 77.70%; group (**e**) consists of countries with a score slightly above 51%. The grouping allowed for the identification of similar countries that are in a sense dependent on each other in terms of the final assessment. After excluding 100% effective ones, changes in the characteristics of countries within the groups would affect the score of the remaining ones.

6. Discussion of Results

Over the past few years, the concept of the circular economy gained increasing attention around the world as a way to counteract climate change and save resources. A CE could help overcome pressures on resources arising from the estimated growth of the global population. It is hoped that transition to a CE would result in new economic opportunities [155], new jobs (in terms of type and numbers), higher productivity [156], and the improved quality of life for all thanks to the environmental recovery, health benefits, and less pressure on land and Earth's resources.

The necessity to change the economic model and to decouple growth from resource consumption is of interest not only to politicians, but also to average European citizens. As research results indicate, most Europeans believe that environmental protection is very important to them personally [157].

Whereas the general interest in the CE is well reflected in the bulk of scientific publications, the specific issue of measuring the performance of countries in achieving a CE aims is not yet sufficiently grounded in the literature. This paper is a contribution to the discussion on CE metrics and measurement. It presents a methodology of an objectivised comparative assessment of the degree of implementation of CE principles in the EU member states. The proposed approach is based on the DEA method supported by factor analysis. Circular Economy Indicators published by the European Statistical Office (Eurostat) [158] served as the input data.

The conducted calculations and the analyses performed on their basis suggest that the position of a particular country in achieving the CE aims is strongly correlated with its GDP per capita. The fact that richer economies are more advanced in achieving CE aims may indirectly imply that the implementation of CE principles requires investments and expenditures that poorer countries are unable to bear. Apparently, transition towards the CE requires costly modern technology, perpetual knowledge generation, and advanced infrastructures [23].

Factor analysis shows that many CE indicators are strongly correlated with each other and may be aggregated into meta-indicators (factors) and represented by one indicator that displays the strongest correlation with a given meta-indicator. In this situation, it is reasonable to limit the number of CE indicators, which will simplify the CE statistics and the assessment of countries' standing in achieving CE goals.

Comparative performance assessment of the EU member states allows for splitting them into three groups of countries with a similar relative efficiency in the CE goals' implementation: (90%, 130%), (70–90%), (50–70%). This shows a certain stratification within the EU when it comes to CE goals' implementation.

Thanks to the competition graphs, it is possible to indicate optimal technologies (i.e., CE indicator values) of technological competitors of particular countries so that they achieve the results at least equal to the one of the reference country.

Limitations of this approach should also be pointed out. Firstly, the obtained country ranking depends directly on the chosen evaluation criteria. Therefore, it is important that the adopted indicators are well justified on scientific grounds and are reflective of the key aspects of CE. Secondly, with 27 countries under evaluation, the number of assessment criteria should not exceed the 6–9 range. Such limitation requires a significant decrease in the number of indicators chosen from the list of the UE Circular Economy Indicators. DEA analysis results are sensitive to the choice of input and output variables. Therefore, the CE indicators should be selected diligently, and various combinations of variables should be tested for stability of results [159]. Thirdly, results obtained with DEA may be sensitive to outliers; hence, the data should undergo preliminary screening with regards to their homogeneity. Fourthly, one should keep in mind that the results change in time; thus, the static assessment of particular countries at a given point in time should be complemented with the dynamic evaluation of the change of their performance in time.

The indicated limitations are a good guidance as far as possible future research directions are concerned. The authors intend to examine the sensitivity of various combinations of CE indicators included in the country assessment, carry out simulations to evaluate the impact of outliers on the result stability, and look into the changes in CE performance of particular countries over a certain period of time.

Some policy implications may be derived from the study results. The objectivity and scalability of the DEA approach to the evaluation of CE implementation make it a suitable approach to comparing the effectiveness of CE policy packages [78] beyond the European Union. For example, benchmarking of OECD or G20 countries [160] with the use of the proposed approach is feasible. Such an internationally adoptable comparison tool will be necessary when the CE attains the status of a global policy [161,162]. Moreover, the CE agenda should not be used as an instrument of a disguised domination perpetrated by the richer countries with the aim of preserving their competitive advantage. The CE policy must not create winners and losers [163].

7. Conclusions

The contribution of this paper is manifested by the development of a robust methodology of a comparative assessment of the state of transition towards a Circular Economy in given countries with special focus on European Union members. The methodology allows for the determination of the level of a country's relative performance as well as the disclosure of the sources of its inefficiencies. Comparative analysis of this kind, performed on a regular basis according to a unified methodology, may serve as an instrument of refining the CE indicators and improving policy coordination of EU and member states in striving for ambitious CE goals. The paper also aims at promoting DEA applications in measuring relative performance of particular countries in spheres that are subject to common policies.

The results show a strong correlation between CE indicators and a certain degree of sensitivity to slight data changes. Moreover, it is impossible to select a leading country or group of countries superior to others with respect to all studied variables. In consequence, if the proposed approach is ever used to determine the streams of funding to particular EU member states, there exists a risk of manipulating the input variables and input data to serve particular interests. Transparency in this respect will be of critical importance.

The study shows that countries with higher GDP per capita perform better in terms of CE goals. This implies that poorer countries require tailored support measures oriented at the general modernisation of their economies accompanied by an increase in the efficiency of their production factors.

The journey towards a CE is only starting. There is a clear need to develop and refine tools of an objectivised assessment of countries with regards to their progress towards the CE. This paper makes a contribution to this global effort.

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Article

Achievement of Sustainable Development Goals through the Implementation of Circular Economy and Developing Regional Cooperation

Natālija Cudečka-Puriņa [1], Dzintra Atstāja [1,2,*], Viktor Koval [3,*], Māris Purviņš [1], Pavlo Nesenenko [4] and Oleksandr Tkach [3]

[1] Department of Management, BA School of Business and Finance, LV-1013 Riga, Latvia; natalija.cudecka@inbox.lv (N.C.-P.); maris.purvins@ba.lv (M.P.)
[2] Legal Department, Faculty of Law, Rīga Stradiņš University, LV-1007 Riga, Latvia
[3] Institute of Market and Economic-Ecological Researches of the National Academy of Sciences of Ukraine, 65000 Odesa, Ukraine; tkach_rada@i.ua
[4] Odesa National Economic University, 65000 Odesa, Ukraine; nppod@ukr.net
* Correspondence: dzintra.atstaja@rsu.lv (D.A.); victor-koval@ukr.net (V.K.)

Abstract: Circular economy is a tool based on the inclusion of environmental, social, and governance performance (ESG) in decision-making to achieve sustainable development goals (SDG). In recent years, it has become clear that business-as-usual has nothing to do with sustainability, and alternative business models, primarily on technological grounds, must be implemented to mitigate the damage caused by significant and unpredictable effects of climate change. The current situation requires unprecedented and urgent changes to policies and business development models. The current research aimed to target on industrial symbiosis as one of the business models of the circular economy. It evaluated the benefits of symbiosis and the fostering of cooperation between industries and, consequently, has a major impact on resource efficiency ratios. The research is based on quantitative and qualitative research methods, including a literature review, assessment, and application of the triangulation method. As a result of this research, the authors realized a matrix for the development of regional or cross-country industrial symbiosis that can be used by policymakers to foster the development of symbiotic interconnections on a wide scale. The authors also recommend the development of the Baltic University Program (BUP) network center of excellence and methodological justification for industries to engage in industrial symbiosis (IS).

Keywords: circular economy; European green deal; industrial symbiosis; sustainability; transformation

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1. Introduction

Sustainable development objectives and main principles have been at the core of European policymaking for a long time, being firmly anchored in a range of European Treaties and put forward in key projects, initiatives, and sectoral policies [1,2]. Combining the tasks of socio-economic development and environmental conservation through the priority development of green technologies and considering social, environmental, and economic factors constitute the aim of implementing the concept of sustainable development. Institutional impact with the goal of introducing innovative transformations that minimize the impact on nature and compensate for the weakness of the market for the development of activities for the transition to sustainable development includes the following universal areas: public financing; environmental taxation; improvement of legislation; development of international cooperation in the field of rational environmental management.

During the last decade, a very ambitious policy has begun in Europe to minimize the amount of waste to be disposed of by rethinking the process of waste disposal and improving recycling, recovery, reuse [3–6]. For these countries, industrial symbiosis could become a good mid-term solution to save resources and move towards a circular economy on a landfill basis [7,8].

The COVID-19 pandemic, which began in 2020 is likely to have a negative impact on all European Union (EU) member states and the EU's overall progress towards achieving the SDG goals [9,10]. On the other hand, this situation has been a motivator for economies to reconsider their further development and in some cases even to foster the development of circular economy strategies or guiding documents.

The circular economy is of particular value to the energy sector for a range of reasons. Basically, all EU and a range of non-EU countries have set already very ambitious targets towards net-zero, and this means that not only business as usual is obsolete, but also our daily habits as a society will have to be reshaped. The energy transition has also become a crucial issue especially in 2022 for the EU countries.

In addition to that, energy transition will be underpinned by a boost in recycling capacities, fostering the market for recycled materials (as it thus becomes possible to conserve primary critical resources). The net-zero itself will also require the boost of clean technologies. Last, but not least, the use of renewable energy means that a solution will have to be found on recycling or reuse of earliest generation renewables (solar, wind turbines) and new technologies are required to make the new renewables more durable and recyclable.

Taking into account the current vulnerable times and the simultaneous necessity for a prompt action to foster transition to the circular economy, the authors have undertaken research to assess the possibility of implementation of regional or cross-country industrial symbiosis (IS), to identify current obstacles and develop a methodology that could be used by policy makers or practitioners in order to successfully implement industrial symbiosis.

1.1. The Essence of Circular Economy

It seems that "circular economy" has recently become the most important and discussed topic, especially within the European Union member states. The circular economy appeared in the literature through three main activities-the so-called 3R principles, namely: reduction, reuse, and recycle [10–13]. In addition, the basic principles of the circular economy include the following: rational environmental management through stock optimization, counteracting negative environmental externalities; circulation of natural resources along ecological and technical material flows; non-waste organic production; adaptability to external conditions by using the optimal business model; circular design when creating new products at the development stage with the improvement of the composition and technology of the product.

Ensuring a sustainable production cycle, considering existing resources, is directly related to economic development, which in the circular economy model increasingly depends on the consumption of these resources [14].

When analyzing existing research on the circular economy, the leader is obviously China with over 40 case studies. This is logically explained by the fact that the country continuously faces huge environmental, human health, and social problems. This is the first country so far, having in force a circular economy law. In contrast, the European Union is paying significant attention to this issue but so far, the circular economy has been seen as a recommendation and not mandatory.

As explained by Heck (2006) [15] circular economy (CE) means reducing resource use and reducing the load on natural sinks. The CE concept is a central part of the environmental economy and industrial ecology (IE) which is expected to lead to more sustainable development [16–19].

Sustainable development is made possible by adhering to its principles of recycling and reuse (circular economy), the use of renewable materials or their joint consumption (sharing economy), the reduction of carbon dioxide emissions, and the use of renewable raw materials of plant origin (low carbon economy) [20–22].

As emphasized by George et.al. (2015), recycling is considered to be a significant aspect of most developed economies. It is also an important objective of policy, so the concept of the circular economy has to be incorporated into theoretical considerations [23].

The circular economy is a concept for changing and adopting new habits and completely new systems for the use of primary resources and raw materials [24–26].

The circular economy model is mainly associated with waste disposal, which has the following relationships: production of products from waste; recycling; regeneration; and recovery. Moreover, the key advantages of CE are namely: the transition to the cyclical nature of value chains capable of continuous reproduction; increasing the eco-efficiency of production and more environmentally friendly products through the technological process; and service products through sharing models [27].

1.2. Green Deal and Sustainable Finances

The European Union has created the Green Deal as a green growth program, and such requires behavioral changes in citizens (as consumers), businesses, and decision-makers, both with the EU and beyond its borders. Nowadays, sustainability is one of the most challenging global issues, affecting not only individuals but also organizations, both of those operating in the financial and non-financial sector, from small- and medium-sized enterprises (SMEs) to large commercial companies and governmental institutions [28]. The keys to ensure the long-term competitiveness of the EU wide economy are sustainability and the transition to a more resource-efficient, low-carbon circular economy, which increases the well-being of the population due to social justice, on the one hand, and the reduction of anthropogenic impact on nature and the depletion of natural resources [29]. The main aspects and essence of the implementation of the CE in socio-economic development are competition, increase in jobs, poverty alleviation, resource efficiency.

The implementation of green technologies (especially by business entities) should not be "greenwashing" as a type of environmental marketing, since misleading information about sustainable development is of growing interest from consumers and investors. It is important to develop the level of corporate, social, and environmental responsibility of business entities depending on the results of their economic activities, that is, the volume of profitability and its level as indicators of economic efficiency and sustainable management. Sustainable development, first of all, is a process of harmonious development of a person and an ecosystem, with the help of which public welfare is improved, negative externalities are minimized, conditions are created for the introduction of resource-saving technologies, economic growth is observed along with the preservation of the natural environment. Currently, these trends are supported by most developed countries, they are a guide for the further development of the socio-economic system and contribute to an increase in investment in environmental projects and innovations. The creation of resource-saving technologies, on the one hand, is capital-intensive, however, in the long run, it has improved efficiency and reduces risks for business, society, and the state. More often, sustainable development is a combination of the natural environment and automated innovation systems that, if properly used, have a sufficiently long lifespan and are capable of modernization. Becoming the first climate-neutral continent by 2050 requires significant investment from both the public and the private sector. Public finance needs to lead the way, private actors need to provide the scale [30].

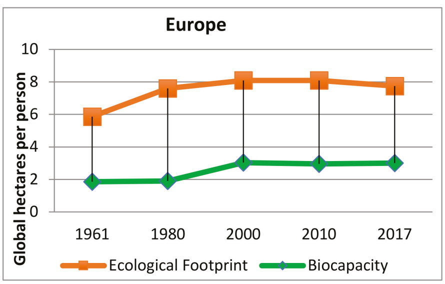
The ambitions are high, the goals are challenging, but the question is–how will member states and in particular how businesses be able to meet these targets? A substantial shift in business models as well as in business thinking and consumer behavior is required and moreover support from the state and the EU in terms of funding is essential.

This is why the EU has already been working since 1997 in order to develop a range of documents covering sustainable development, the circular economy, and now green deal aspects [31,32]. Sustainable finance involves investing and making financial decisions that take into account the consequences and impact of investments on the environment.

Socially responsible investment helps to reduce the negative impact of the activities of an organization that meets the principles of sustainable development.

Therefore, the transition to a circular economy is possible thanks to the financing and insurance of companies in this area, as well as on the basis of a strategy for sustainable financing, which is based on the inclusion of environmental, social, and governance performance (ESG) in decision-making to ensure sustainable development.

The transition to a policy of managing the rational use of resources and optimizing consumer behavior requires a balance, considering the necessary conditions for the development of the economic system as a backbone element. In this regard, the concept of "Earth Overshoot Day" has gained popularity, the introduction of which was associated with a response to an increasing anthropogenic impact (for example, emissions of carbon dioxide waste into the atmosphere) on natural resources with the impossibility of their full recovery over a certain period against the backdrop of aggressive consumer behavior. As a result, there is an ecological deficit associated with an exaggeration of the ecological footprint over the biocapacity of the territory (Figure 1).



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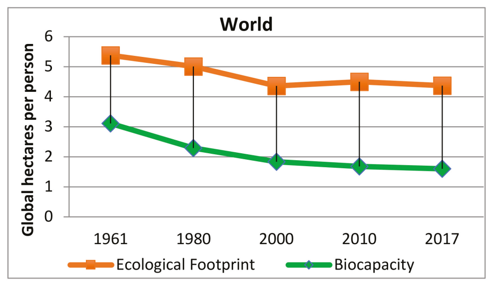

(**b**)

Figure 1. Ecological Footprint vs Biocapacity (gha per person): (**a**) The ratio of Ecological Footprint and Biocapacity in European countries; (**b**) The ratio of Ecological Footprint and Biocapacity in the World [33–35].

A distinctive feature of the ecological footprint and biocapacity is the level of ecological deficit (decrease in ecological assets or increase in waste) and ecological reserve (excess of the biocapacity of the region over the ecological footprint). The ecological footprint is characterized by the biocapacity of the region's environmental assets in the production process using natural resources and the resulting waste (carbon emissions) from these activities. In turn, the biocapacity of a region is determined by the productivity of its environmental assets for waste absorption and the ability of ecosystems to recover. Ecological footprint and biocapacity are measured in global hectares (with average global productivity). Figure 1 shows the values (gha per person) for more than 50 years, where in the World (b) since 1961 more than 1.7 times the resources were required, and before 2000 this figure reached more than 2 times. In Europe (a), the opposite is observed, where the ratio peaked in 1980 by almost 3 times and decreased to the world average only by 2017.

The calculation of the ecological footprint can be represented by the following formula [36]:

$$\text{EF} = \sum \frac{T_i}{D_w} \times \text{EQF}_\text{i} \quad (1)$$

where it is the annual number of tons of each product and consumed in region, Dw is the average annual average annual production yield of each product "i", and EQFi is the equivalence factor for each product "i".

Biocapacity is calculated in terms of constant gha as follows [37]:

$$BC = \sum A_i \times YF_i \times EQF_i \quad (2)$$

where A_i represents the bioproductive area, and YF_i, and EQF_i, are the country-specific yield factor, the world average intertemporal yield factor, and the equivalence factor for each product "i".

Earth Overshoot Day characterizes the level of overspending of resources and leads to the need to use the concept of sustainable development, considering the specific features of the economic system and the need to increase the ecological reserve, which is necessary in industrial regions where its biocapacity does not exceed the ecological footprint [38]. The concept of sustainable development is aimed at achieving balance and coherence, uniting all transformational processes in the social sphere (Goals 1–6), the economic sphere (Goals 7–12), and the environmental sphere (Goals 13–17). At the same time, meeting the conditions for sustainable development is possible when implementing appropriate models of sustainable development, the main one of which is to ensure a balance between the economy and the environment and responsibility. In our opinion, as already stated above, the paradigm of sustainable development of the system in the future should consider specific features and should be based on the current level of development of productive forces. At the same time, a model of the circular economy is being formed with the ability to take into account the transformation of production factors and the value chain focused on sustainable development.

2. Methodology

The research is based on quantitative and qualitative research methods, including a literature review and assessment on the circular economy and industrial symbiosis. The methodology includes conceptual research including analysis of normative, jurisprudence, doctrinal, theoretical, and scientific sources. It reflects on different theories of change relating to ethical behavior, social responsibility, and sustainability transformations. According to Mileva (2018), the method of triangulation (also known as qualitative-quantitative method) was applied to ensure the validity of the study. Meaning that the data obtained from seven industrial symbiosis cases from literature reviews, empirical data, and empirical data were assessed from articles with interviews of those who work with the practical aspects of IS. A theoretical framework which stemmed from the literature review on IS, frameworks the data collection and assessment in all parts of the study [39].

Various methods have been used to measure the actuality of the topic. In this case, we used the current keywords and their application over time, see Figure 2. The Google Ngram Viewer demonstrates how user-selected words or phrases (Ngrams) have appeared in a corpus in a graph over the selected years 1990–2019. It is easily and transparently perceived because the graph on the *x*-axis shows the year in which the selection group was published, while the *y*-axis shows the frequency with which the searched keyword was found in the publications.

A search for the term "industrial symbiosis" revealed that the number of publications was rising moderately since 1992 until a significant surge began in 2006 but since 2018 onwards a decline was observed.

Observing the frequency of the term "green deal", in a separate graph, it can be concluded that the insignificant increase was from the mid-1990s until 2005, when it rose sharply, to 0.000000300% in 2013, followed by a slight decline and a rise again, starting with the year 2016. Unfortunately, due to the scale, it does not stand out significantly in the overall schedule.

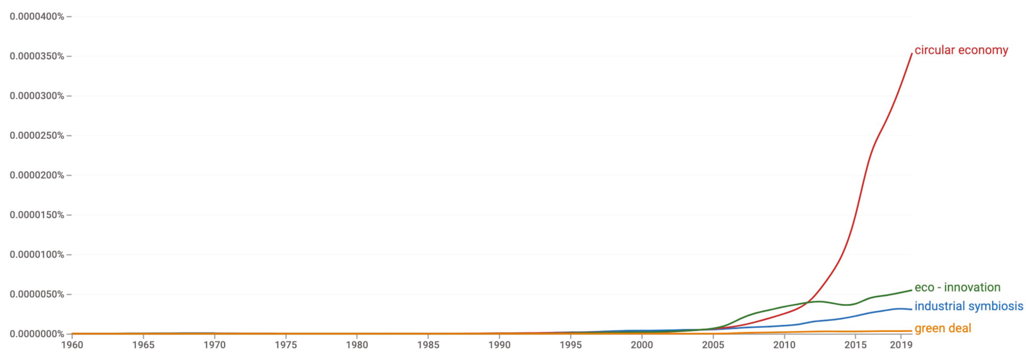

Figure 2. The frequency of using the terms "industrial symbiosis", "green deal", "circular economy", "eco-innovation" (Ngram Viewer). Reprinted from Ngram Viewer [40].

In describing the frequencies of the term "circular economy", the term has been used moderately but dynamically since 2001 but has been growing rapidly since 2012. A clear increase starts in 2013 when it reaches 0.0000350% in 2019.

Surprised by the graphic representation with the search for "eco-innovation", the frequency of the term has been increasing moderately from 1992 to 2004. Since 2006 there has been a sharp increase to 0.00000400% in 2012, then a decrease again until 2015, when the frequency increases again, to 0 00000550% in 2019.

Ngrams showed a dynamic development in publications, according to the search term "sustainability". This is not included in the graph, as it differs sharply from the ones described above—from 0.00024% in 1990 to 0.0140% in 2019. After identifying keywords and the evolution of domains of the literature, the authors analyzed articles and relevant documents. The analysis determined the application of the keywords based on their relevance to the research topic. Results were used to build a theoretical framework and identify a research problem statement, which has created the basis for the critical literature review [40–42].

The main purpose for the authors was to assess the Baltic University Program member-countries and on a benchmark of the European members, to develop a set of recommendations for development and improvement possibilities within SDGs (in particular focusing on SDG No. 8, 9, 11, and 12) and circular economy for the BUP non-EU member countries.

The research was focused on benchmarking the following countries: Czech Republic, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Slovakia, and Sweden. Figure 3 depicts the theoretical framework that served as a basis for the research. Nowadays the EU produces more and more ambitious documents and the business-as-usual path will no longer be valid, sooner than one could have imagined some five years ago.

This is why businesses, as well as entire country economies, must look for ways to adapt to changes more efficiently. Common projects by region of industrial symbiosis in the EU are presented in Table 1.

The development of industrial symbiosis is associated with risks that can be caused both at the national and cross-country levels, which are associated with the impact on the competitiveness of its participants as well as on the state of the environment (Table 2).

Despite the systematic development of industrial symbiosis, policy and economic are identified as the most influential risks and the main obstacles (Table 3).

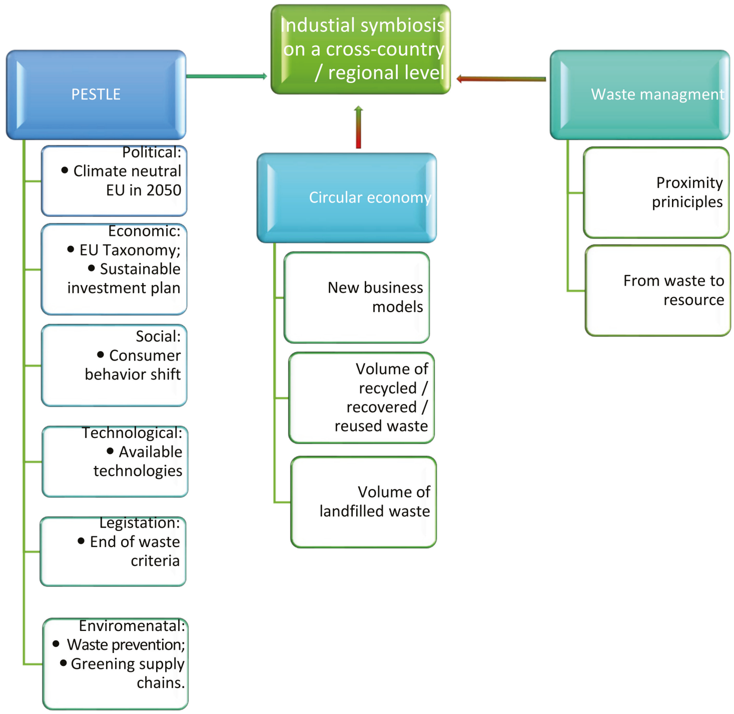

Figure 3. The theoretical framework of the research.

Table 1. Common projects by regions of industrial symbiosis in EU.

Title of Project	Characteristics
Baltic Industrial Symbiosis	The project aims to create conditions for the development of territories in the Baltic Sea region using the resources of companies from different industries, for example secondary resources or materials/waste from one company as a resource for the next company.
Kujala Waste Centre	The project aims to optimize waste recycling, treatment, and disposal in Finland.
Pécs-Kökény Waste Management Centre	The project aims to improve the planning and management of waste in the municipalities of Hungary with the reduction of waste to landfill and its further processing into energy.
Kalundborg Symbiosis	Public and private industries across sectors both in sharing surplus resources (energy, water, and materials) with each other to reduce CO_2 emissions.

After an extensive literature research, analysis of existing case studies and relevant information, including PESTLE, the authors developed the dependent variable "Industrial symbiosis on a cross country/regional level". The independent variables are namely: PESTLE, Circular economy, and Waste management. The Circular Economy here includes as well national or regional strategies and supply chains [43]. The Waste management independent variable focuses on waste prevention and waste management proximity principles as well as on the idea to re-capture all the valuable resources from waste.

Table 2. Risk assessment and mitigation for industrial symbiosis establishment.

Risk Source	**Risk Description**		**Mitigation Actions**
	National	**Cross-Country**	
Transportation	Developed road network is required	Long-distance becomes cost ineffective;	Development of IS networks in cross-border regions, thus developing the rural areas
No End-of-waste criteria		Lack of possibility to use waste as resource	Development of EoW criteria, or cross-country agreements for particular IS
Bureaucratic boundaries	Lack of knowledge	Legislative differences, lack of expertise	Adoption of best practices from other countries; Development of cross-country expert working group
Financial	Lack of knowledge for financing attraction;	High bureaucratic burden; High competition.	Promotion and explanation of available funding and application criteria.
Green public procurement	Social inertia-low credibility in green public procurement benefits	Lack of regulations; Possible lack of stable product supply	Promotion and prioritization of Green public procurement nation wide and on EU level
Environmental taxes	Lack of significant economic benefit, while waste management costs are quite low	Lack of regulations, promoting energy and resource efficiency.	Review of environmental taxes, so that IS would be much more economically efficient
Knowledge	Lack of knowledge of neighboring companies, industries, and their activities.		Development of company and resource mapping on a regional level.

Table 3. Obstacles for development of industrial symbiosis.

Type of Risk	**Risk Assessment**	**Risk Level**	**Risk Mitigation**
Geographical	Long-range transportation required, that loses the value of the resource during the transportation.	Moderate	Cross-country symbiotic connections can be in place for the materials that do not lose value over distance.
Policy	Cross-border shipment legal requirements; Different approaches on national level to permit issuance and difference in control mechanisms; Need to merge legislation in certain aspects to ensure industrial symbiosis; Potential bureaucratic issues.	High	The involvement of corresponded governmental institutions is a must in development of cross-country industrial symbiosis. Taking into account the Green Deal and economies of scale, this is a potential field for development of neighboring country cross-policy solutions.
Economic	Lack of stable demand-supply network; Low price for primary resources; Market immaturity; Lack of high-quality material for symbiotic exchange.	High	On national level it is required to align the policy framework to foster development of symbiotic exchanges. National strategies have to incorporate symbiosis as one of the solutions for resource efficiency
Social	Lack of credibility in industrial symbiosis; NIMBY syndrome.	Low	By promoting policy planning documents and general country's development trends, this risk is likely to disappear as the society will acquire the necessary knowledge and comprehension of why development in this direction is crucial for the country.

The Authors developed the following research questions:

RQ1. Can industrial symbiosis on a cross-country level improve the resource consumption ratios?

RQ2. What are the main obstacles to the implementation of industrial symbiosis on a regional and cross-country level?

The design of the theoretical framework also leads to the definition of a research gap: lack of a harmonized method towards reaching a circular economy approach through IS. This gap is identified both on cross-country and even regional level within one country and leads to a significant obstacle for transition towards circular economy on the EU scale.

In the subsequent sections of the research the authors provide an overview of the conducted research, revealing the main results and findings as well as the most significant conclusions.

3. Results

The assessment of development and sustainable development by EU Member States is carried out using the Eco-Innovation Index (Eco-IS), the results of which allow a comprehensive approach to the use of the benefits of eco-innovation and processes [44–46].

Stimulation of sustainable development based on the country's Eco-IS can be distinguished by certain factors (Figure 4) [47–49]. The economic system is posed to extract as much value from given resources as possible [50] and the key point here is to make this process as much eco-efficient as possible and to enhance regional cooperation where possible. However, at the same time, the main barriers to regional cooperation in the field of eco-innovation are namely: institutional barriers; fiscal restrictions; imbalance between the technosphere and the biosphere associated with regional differences in the industrial sector.

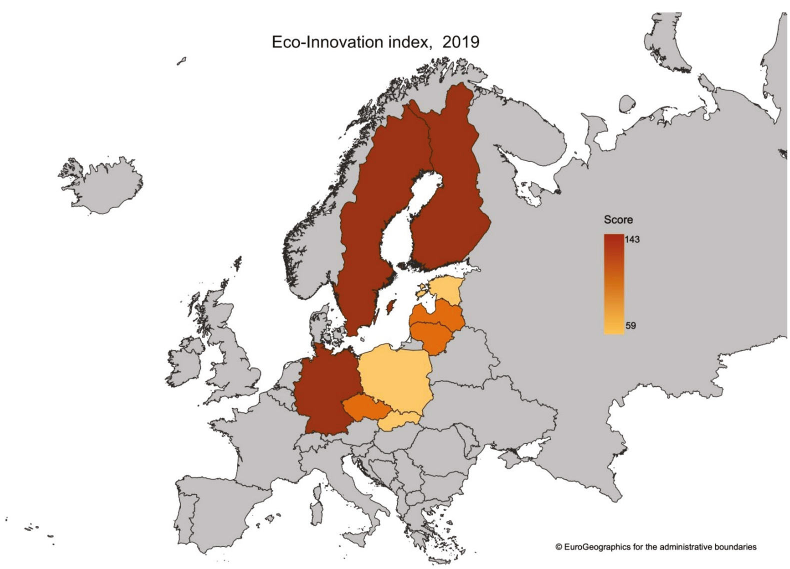

Figure 4. Eco-innovation index of BUP EU-Member States. Reprinted with permission from [51].

Solving the problem of climate change mitigation in the direction of counteracting carbon dioxide emissions and rational environmental management is possible thanks to the development of climate-regulated ecosystems and the mechanism for ensuring the development of a circular economy at the state and regional levels. This is because at the regional level, local authorities form the demand for waste processing products (for example, secondary processing or biogas) and track the carbon footprint in urban areas.

In any case, business models of the circular economy are local because of the following: products for recycling (e.g., waste) are predominantly generated in a certain area (the need to reduce their transportation costs and reduce CO_2 emissions); sharing mainly uses products that are locally located due to the impracticality of their delivery (the same costs, emissions, and additional waiting time for delivery) from other regions. The above indicates that the development of a circular economy is possible with the ability of regional cooperation (organs of local government, business, and the population). The clusters help understand the status of eco-innovation in EU countries and identify possible cooperation partners.

As the authors chose to analyze only the BUP EU member states, represented in Figure 4, they can be clustered as follows:

- Cluster 1: Eco-Is 59-73-Poland, Slovakia, Estonia;
- Cluster 2: Eco-Is 82-96-Lithuania, Latvia, Czech Republic
- Cluster 3: Eco-Is 123-143-Germany, Finland, Sweden.

Here it is necessary to mention that the EU-28 average Eco-innovation index is 109 (based on the ratio over the time frame 2021–2021), meaning that we have Cluster 2 with the Eco-Is reaching the EU average and Cluster 3 with three countries which significantly over performed the average figures and which thus can be motivators for others to catch up.

Further on, when turning to industrial symbiosis, it is necessary to assess one of the Eco-IS composing indicators, i.e., resource efficiency. Eco-innovation is expected to have a positive influence on resource efficiency in two ways: it can boost the economic value, and lead to a decrease in the pressure on the environment [44].

It is notable that the resource indicator is also covered by the circular economy indicators and the demand for material extractions due to consumption in the public sector, households, and businesses in the EU [44,52,53]. Figure 5 gathers three indicators and shows that the leader in resource productivity in terms of Eur/kg is Germany, followed by Sweden.

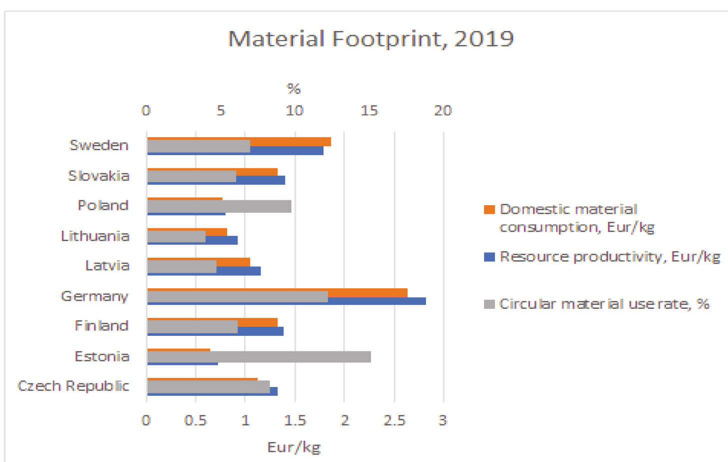

Figure 5. Material Footprint of BUP EU-Member States [44,52,53].

The concept of sustainable competitiveness is to find a compromise approach in order to balance economic growth, environmental issues, and the sustainability of society [54,55].

The efficiency of the development of the country and its industries is mainly expressed in terms of economic production, but for a deeper analysis, indices are used that allow a balanced approach to assess the competitiveness of the national economy (Figure 6). The countries are grouped because it is the BUP of the EU-Member States for which the analysis is being carried out. In this regard, it is rational to use a competitiveness model based on the sustainable competitiveness index, which allows for a more comprehensive coverage of all indicators and an assessment of the effectiveness of economic development (the root) (Figure 7) [56].

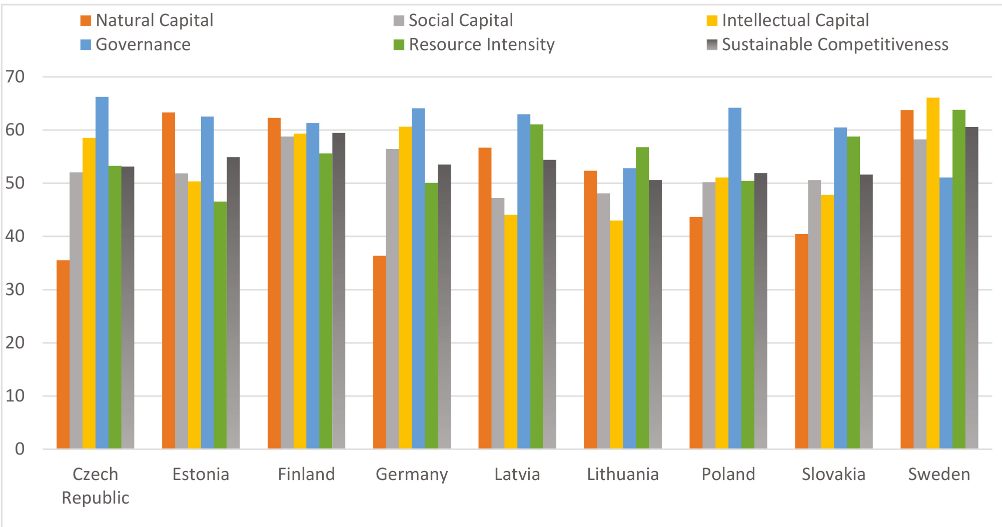

Figure 6. Indicators of economic efficiency in sustainable development of BUP EU-Member States [44,52,53].

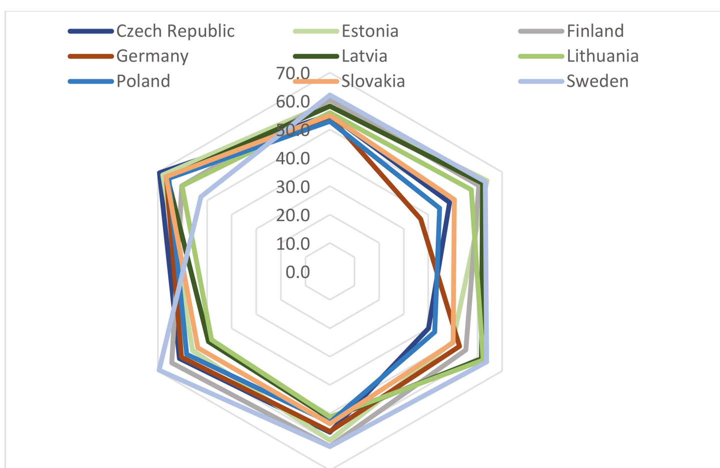

Figure 7. Sustainable Competitiveness Index 2020 of BUP EU-Member States [44,52,53].

Industrial symbiosis is not only a technological or logistical system; it transcends the boundaries of various systems, and it is also a social system [39]. Businesses that have successfully shifted to sustainability have encouraged participation in industrial symbiosis [57]. Industrial symbiosis allows businesses to maximize the use of resources by recycling [58] and in particular by diverting waste from landfills, reducing its generation, and seeking alternative application to production residuals or by-products, which will lead to increased efficiency of resource use and reducing greenhouse gas emissions in industries [59].

It is quite notable that according to research carried out by Domenech et al. (2019) [57], the mapping of industrial symbiosis in Europe revealed the absence of any type of network in parts of the countries analyzed in the present research. In particular it tackles such countries as the Czech Republic, Poland, Lithuania, Latvia, and Estonia. This is why the authors consider it even more evident that such networks need to be developed in the near future (Figure 8).

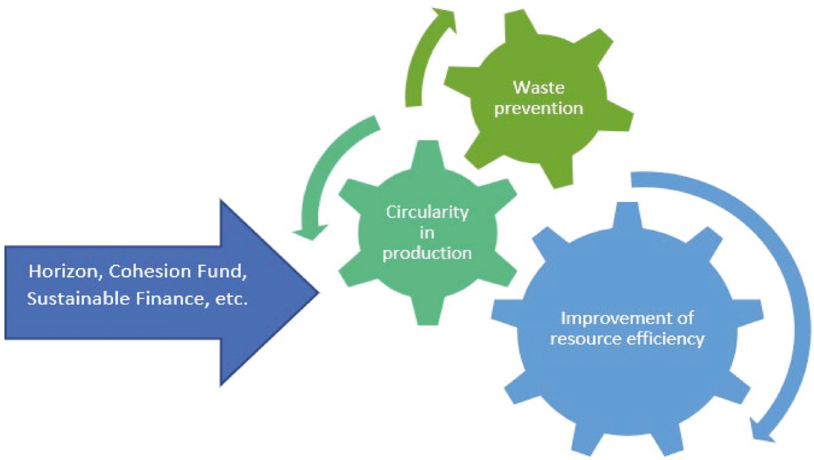

Figure 8. Benefits of cross-country industrial symbiosis and potential funding sources.

Sustainability and value creation are significant challenges for businesses' analysis of IS on a regional basis [58]. According to recent research [57,59], there were no industrial symbiosis networks reported in Slovakia, Poland, Lithuania, Latvia, or Estonia in 2018. It has to be noted that in Poland and Slovakia there have been some attempts, but mostly short-term, using H2020, Interreg or other European, national, or regional financing and they did not manage to commercialize after the termination of the projects.

It is vital to mention that the lack or the availability of industrial symbiosis networks is surely also dependent on a range of issues like political will, cooperation of the countries on a range of other issues, availability of resources, the willingness of the industries to undertake such start-up projects, and the willingness to continue any grant-based projects in order to develop them in the long-run. Another important aspect is the geographic location of different facilities and distances between them, as geographic proximity is said to be a key characteristic of resource reuse and recycling practices in terms of industrial symbiosis.

3.1. Existing IS Projects on a Cross-Country Level

The functioning of ecosystems due to industrial symbiosis can be represented as an eco-network in which materials circulate, the economic value of which increases, and the economic activity itself is directed towards zero waste and, as a result, reduces the anthropogenic impact. Industrial symbiosis in different countries pursues the same goal related to the realization of not only economic benefits but also environmental benefits through the circular exchange of resources, but also, in recent times, through smart specialization.

Smart specialization is being developed by the European Commission as one of the strategies for achieving the SDGs based on the methodologies of combining science, technology, and innovation. The key to the implementation of industrial symbioses is public–private partnership for the sustainable development of production in the transition to a circular economy based on the use of recycled materials in production and the use of green technologies in value chains that use fewer natural resources. It is in industrial symbiosis ecosystems that efficiency depends on the optimal use of resources (locating on the same production site; sharing production infrastructure; use of waste or by-products) and at the same time producing less waste and CO_2, which allows the parties involved to receive additional income by reducing production costs and reducing environmental taxes [59–61].

The main projects by region are presented in Table 1. The authors decided to limit the projects to the EU, as according to recent research [62], the EU is leading in number of publications and practical projects in the field—with 48 studies published (Table 1), followed by China with 12 and the USA only 5. In developing countries, the potential for involving secondary resources in the industrial symbiosis of enterprises is not fully used, which is associated with the capacities of the production infrastructure.

3.2. Main Risks Associated with Industrial Symbiosis

Based on the undertaken research of the current successful industrial symbiosis projects (Table 1) and the literature review performed under the Methodology and Result sections, the authors developed a risk assessment matrix for the establishment of cross-country IS (Table 2).

This matrix was developed from the perspective of a company that would like to analyze the possibilities for shifting to symbiotic exchange creation with potential cooperation of companies.

Based on the data in Table 2 the authors performed a risk calculation, applying risk severity from 1 to 5 points and the likelihood of risk from 1 to 5. Further on, gathering the results, a ranking of risks was undertaken, which is depicted in Figure 9.

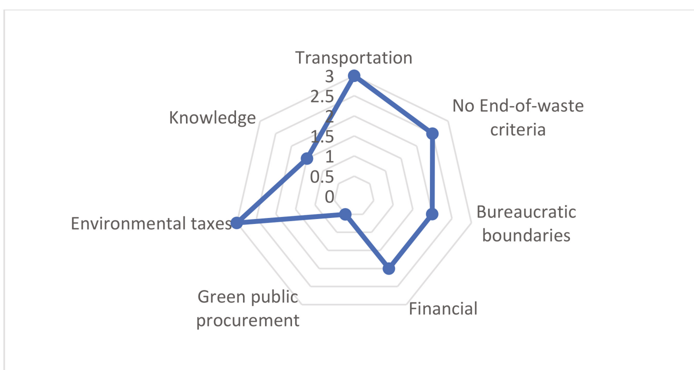

Figure 9. Risk calculation for establishment of IS.

It was concluded that the main risks for the establishment of cross-country IS are transportation, lack of end of waste criteria, and environmental taxes. The authors see that the current development tendencies are tending to decrease these risks, as countries currently are actively seeking different circular economy elements, to boost national economies and to foster the transition to circular economy [63,64]. In this respect it is recommended at state level to actively monitor the best practices of IS as well as to focus on the establishment of national and cross-country IS, thus also developing not only the urban, but also the rural areas, offering more green jobs and developing regional infrastructure [65,66].

In addition to the risk assessment from a company's perspective, the authors have also identified a range of obstacles in the development of industrial symbiosis that stem from the PEST analysis. Basically, here the authors have chosen the PEST analysis, substituting technology for geography. Table 3 below depicts the results of the evaluation.

4. Discussion

The next section of the research article is devoted to result description and discussion. It summarizes the most critical research findings and discusses how they relate to two essential topics, well-being and risk awareness. During the research the authors analyzed different approaches to industrial symbiosis (based on the theory of CE, SD, and IE) and what could be considered of utmost importance, in developing the above depicted matrix, which reveals the cooperation possibilities between main stakeholders–clients, government, partners, society, and financial stakeholders (Figure 10).

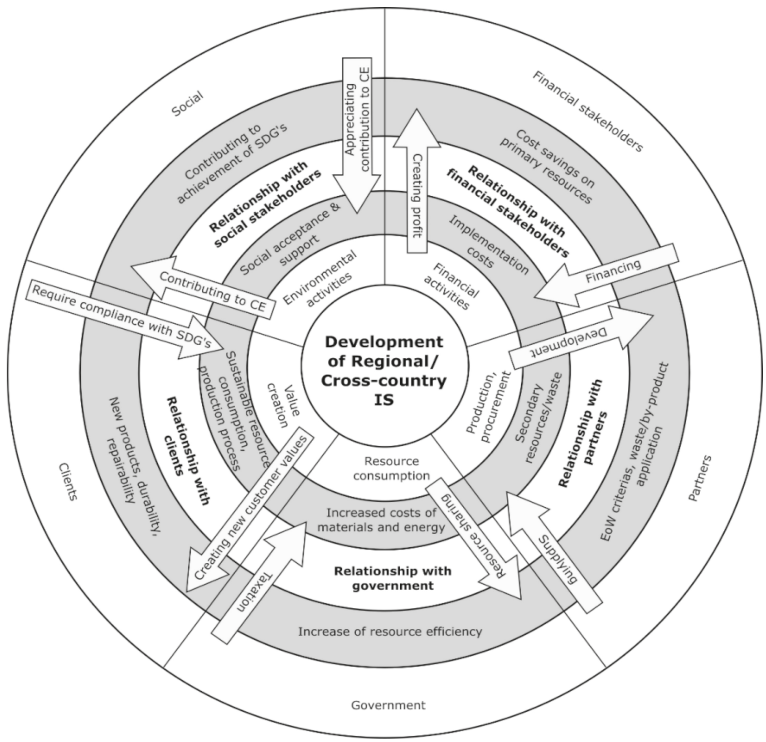

Figure 10. Matrix for development of regional or cross-country IS.

The matrix depicts the main areas of interest of each of the stakeholders and their impact on potential regional/cross-country industrial symbiosis. The matrix also incorporates the undertaken risk assessments and reveals the cooperation matrix involving all of the stakeholders. Basically, this matrix can be used as a tool for country policymakers to develop a national IS strategy framework and to reveal all the benefits for each of the stakeholders while it is also a crucial tool in the potential development of the BUP level cross-country IS cooperation platform. Integration of industrial systems to achieve the goals and principles of sustainable development achieves an effect in the case where there is an interaction of all participants in industrial symbiosis and in elements of the external environment.

However, the role of the government remains unchanged within the framework of IS, since it is based on the model of public-private partnership, where the state reflects the guarantor of economic security and invests, while in turn, the private sector actively attracts other stakeholders. However, only in the joint and mutual deepening of the processes of creation and exchange of knowledge between the stakeholders of industrial symbiosis in the context of their transition to a circular economy can it help them implement policies to achieve SDGs [67].

The implementation of IS at the regional level should be harmonized with the main municipal policies and programs aimed at increasing the value of residual resources with reference to urban systems based on recursive organic modernization and eco-innovation, which is the basis of sustainable economic development. Regional features of interaction between enterprises located in the same territory determine the possibilities for the development of a circular economy in the future due to geographical, environmental, socio-economic, and natural conditions [68–70].

5. Conclusions

Climate change poses unprecedented challenges for the world's socio-economic and ethical issues of responsibility towards mitigating these impacts. While science is warning of the need to act urgently on climate change (e.g., IPCC AR6 WGII), societies are also responding to global challenges. The United Nations' Sustainable Goals have addressed the whole spectrum of health, poverty/economy, environment, and peace/cooperation. The authors concluded that currently there is a range of risks associated with the implementation of industrial symbiosis. A wise national strategy alongside cooperation with neighboring countries, in particular BUP member states, can result in development of a unified approach to solving the resource efficiency issues as well as to improvement of sustainable competitiveness, material footprint, and also as a consequence, the eco-innovation index.

It is obvious that the circular economy is becoming the new normal and a change in social mindset is crucial, as well as transformation of national legislation that will focus on keeping the existing resources within the economic cycles for as long as possible and avoiding them to become waste. The authors conclude that BUP is a very successful cooperation program which has been developed in the field of education, but it is worth considering the possibility to foster its development and broaden the cooperation fields by, for instance, including a pilot project of industrial symbiosis cooperation.

The matrix for the development of regional or cross-country IS is considered to be a very useful tool for policy makers as well as for potential centers of excellence as it can be applied as a roadmap for decision-making and to facilitate certain practical aspects of regional or cross-country IS development. In future research, the authors plan to provide the developed matrix for approbation in one of Latvia's planning regions in order to analyze its practical application. The authors have developed a range of recommendations based on research that could be analyzed more in-depth within future research namely: development of a cross-country center of excellence on industrial symbiosis and thus summarizing a range of recommendations for policy-makers in order to foster symbiotic exchange at regional and cross-country levels; gathering currently existing best practices of regional industrial symbiosis cases that would form the basis for a comprehensive methodology, so that all the involved stakeholders would be able to see tangible benefits from this business model and become economically engaged in fostering its implementation.

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energies

Review

Review of Possibilities for Evaluating the Performance of an Organization in the Aspect of Greenness

Ilona Skačkauskienė * and Juliana Smirnova

Department of Management, Faculty of Business Management, Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania
* Correspondence: ilona.skackauskiene@vilniustech.lt

Abstract: Due to the increasing relevance and importance of sustainable development pursuit, it can be assumed that organizations are striving to develop in a green direction. This is not only related to raising awareness of modern society but also to legal regulation and strategic documents for achieving the goals of sustainable development at the international level, especially affecting certain fields of activity such as energy or manufacturing. It is noticed that there is still a lack of definition in the scientific literature of what kind of organization is considered green. Therefore, it is appropriate to create a green organization benchmark against which organizations can assess their current level of greenness and identify areas for improvement. This research aimed to choose the most suitable approach for developing a green organization benchmark by examining the methods for evaluating an organization's performance in terms of greenness according to defined attributes. Applying the methods of systematic and comparative analysis of scientific literature and strategic documents, content analysis, grouping, and synthesis, it was determined that the approach of resources of an organization can be considered the most suitable for creating a green organization benchmark. However, it is reasonable to supplement it with an evaluation of external environmental factors.

Keywords: green organization; performance evaluation; sustainable development goals; resources; value chain; management functions

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1. Introduction

In the modern world, global society is increasingly focused on the pursuit of sustainable development. This is evidenced by the active involvement of public figures, such as Greta Thunberg and James Hansen, and organizations of global significance such as the OECD and the UN, as well as countries around the world, in tackling the challenges of economic development, social welfare, and environmental quality. The importance and relevance of the pursuit of sustainable development are further supported by a number of strategic documents and directives at the international level, such as the European Green Deal, the Paris Climate Change Agreement, the EU Biodiversity Strategy, the "From Field to Table" strategy, the European Climate Pact, the European Climate Law, the European Industrial Strategy, GreenComp: European Competence Framework for Sustainable Development, and others. In 2015, the UN approved the Sustainable Development Agenda 2030 [1], which sets 17 Sustainable Development Goals, covering the areas of improving the social environment, economic development, environmental protection, and cooperation. All UN member states are committed to implementing these goals [2]. It can be stated that mentioned strategic documents and directives especially affect certain fields of activity, such as energy or manufacturing, where organizations are directly related to net-zero global commitments, that means cutting greenhouse gas emissions to as close to zero as possible, with any remaining emissions re-absorbed from the atmosphere, by oceans and forests [3]. According to [3], the energy sector is the source of around three-quarters of greenhouse gas emissions today and holds the key to averting the worst effects of climate change. Replacing polluting coal, gas, and oil-fired power with energy from renewable sources, such as wind or solar, would dramatically reduce carbon emissions [3]. The energy sector is responsible for more than 75% of the EU's greenhouse gas emissions, so increasing the share of renewable energy across the different sectors of the economy is therefore a key building block to reach the EU's energy and climate objectives of cutting greenhouse gas emissions by at least 55% (compared to 1990) by 2030 and becoming a climate neutral continent by 2050 [4]. The relevance of the pursuit of sustainable development is also confirmed by the active localization of international strategic documents at the national level. For example, based on the set of recommendations for Sustainable Development Goals [2], the implementation of the sustainable development goals in Lithuania at the national level is ensured by legal regulatory measures and at least 52 strategic documents, which include national-level strategies, development and prevention action programs, institutional plans, and recommendatory guidelines. The sheer volume and content of such documents suggest that the implementation of the sustainable development goals should be considered high priority when determining the direction of legal regulation and state policy-making. It should be noted that both the instructions of strategic documents and legal regulatory measures, as well as the growing awareness of people's resolve to pursue the sustainable development goals, influence the aspirations of modern organizations to transform themselves toward the implementation of sustainable development priorities [5–7]. It is noted that green organizations can be considered as one of the measures to achieve the sustainable development goals [8]. Organizations' willingness to develop in a green direction is stimulated not only by the organization's own pursuit of sustainable development, but also by certain benefits, such as increasing the organization's competitive advantage [9,10] and a positive impact on operational profitability [9,11]. Although much scientific research is currently devoted to the development of organizations in a green direction, it is noticeable that there is still a lack of definition of what kind of organization is considered as green [12,13]. It can be noted that topic of green organization is not still widely discussed in the scientific literature. Search for the studies on the topic was conducted among Scopus and Web of Science scientific databases using keywords "green organization" OR "green organisation" OR "green company" since 1990 (All fields). The search on the Scopus database resulted into 37 publications on the topic since 1990. The search on the Web of Science Core Collection database resulted into 41 publications on the topic since 1992. Search results in both databases show growth of publications on the topic since 2017 (see Figure 1).

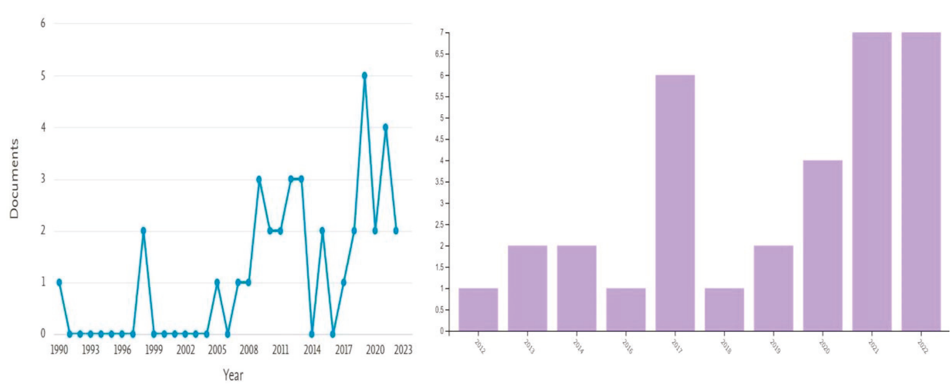

Figure 1. Publications on the topic in the Scopus (**left**) and Web of Science (**right**) databases since the year 1990 (source: Scopus and Web of Science search analysis tools).

To compare with, other search was conducted in order to analyze the number of publications with keyword "green" in the field of social (and closely related) sciences since 1990. The search on the Scopus database (Subject Area: Social Sciences) resulted into 16,028 publications on the topic. The search on the Web of Science Core Collection database (Web of Science Categories: Economics or Business or Business Finance or Social Sciences Interdisciplinary or Management) resulted into 5839 publications on the topic. It is noticed that term green is used by the scholars defining different areas of organization's performance. It can be assumed that there is a lack of constant studies of an organization as a whole in the aspect of greenness. While analyzing the research made on the level of greenness of the organization in the scientific literature it is noticed that most of the research focuses on the more detailed aspect of the greenness of certain elements of the organization or on increasing the greenness, and lacks a systematic approach to the interrelationships of these elements with other elements of the organization [14,15]. According to previous research [8,15] on the topic of green organization done by the authors of this review, it can be assumed that there is a need for a tool that can be used by organizations to assess their current situation in terms of greenness and to determine developmental directions. Therefore, it is reasonable to create a green organization benchmark against which organizations can assess their current level of greenness and identify areas for improvement. It is also noticed by the authors of this review that the topic of green organization from perspective of creation of green organization benchmark is not very studied by scholars yet. Thus, guidelines for the development of green organization benchmark are not provided in the scientific literature. After studying a number of scientific literature sources authors of this review decided to develop green organization's benchmark by evaluating the performance of an organization in terms of greenness. For that purpose, it is first necessary to choose the most suitable approach for evaluating performance of an organization in order to create a green organization benchmark, which would be applicable for organizations with different fields of activity (energy, manufacture, services, etc.). The most suitable approach chosen for evaluation of performance of an organization in terms of greenness will be used as a basis for further creation of a green organization benchmark and its approval in companies will be conducted as a follow-up to this study in the future.

The purpose of the research is to examine the methods of evaluating performance of an organization, to determine their potential in the terms of ability to evaluate performance of an organization from the aspect of greenness and to choose the most suitable one for creating a benchmark.

Objectives of the research:

1. To identify the attributes based on which the suitability of the organization's performance evaluation methods for developing a green organization benchmark can be analyzed;
2. To examine a variety of methods for evaluating an organization's performance and assess its suitability for creating a green organization benchmark;
3. Based on the comparison of suitability assessment results, to choose the most suitable approach for creating a green organization benchmark.

The following methods were used for the research: systematic and comparative analysis of scientific literature and strategic documents, content analysis, grouping, and synthesis.

2. Challenges in Selecting an Approach to the Organization's Performance Evaluation in Terms of Greenness: A Literature Review

Various issues of organization's performance evaluation have been studied for several decades. It can be argued that the choice of an organization's performance evaluation system must be understood as an individual system formation for each organization [16–19]. Organizations can choose to develop their own individual performance evaluation systems or to adapt existing performance evaluation systems (models/methods). The scientific literature offers a wide variety of methods for evaluating an organization's performance. The analysis of these methods reveals that the authors of such works have identified many different objects of evaluation (see Table 1).

Table 1. The variety of methods for evaluating an organization's performance according to the objects of evaluation.

Objects of Evaluation	Author(s)
Assessment of the impact of information and communication technologies (e.g., Industry 4.0, the Internet of Things, machine learning, artificial intelligence, robotics, cloud computing) on 22 organizational performance indicators identified according to Lean Six Sigma and quality management standards (e.g., ISO)	Yadav et al. [20]
Human resources results, financial performance, non-financial performance	Khan and Naeem [21]
Management functions	Sabiu et al. [22]
Organization's establishment decisions, organizational environment, core activities, labor resources, assets, costs, solvency, investments, operational efficiency	Bivainis [17]
Leadership, people management, policy and strategy, resources and processes, people satisfaction, customer satisfaction, impact on society, and business results (European Foundation for Quality Management)	Dror [23]
Areas of activity: - Analysis of the main (production, commercial) activities (company environment, types of operational risks, organizational technical level, marketing activities, long-term tangible assets, long-term financial assets, intangible assets, short-term assets, work indicators (for employees' productivity, wages, working hours), expenses, cost—volume—profit, probability of bankruptcy, activity, and prospects) - Financial performance analysis (financial statement indicators, short-term solvency, long-term solvency, working capital, financial leverage, profit, profitability of sales, profitability of assets, capital efficiency, capital market, cash flows) - Analysis of investment activities (types of investments, current and future value of money, periodic value of cash flows, securities risk, shares and bonds, investment projects, efficiency of investment activities	Mackevičius [24]
Resources of an organization: human, financial, organizational (intangible), technical-technological	Sekliuckienė [25], Úbeda-García et al. [26], Sabiu et al. [22]
Supply chain (suggests evaluating relationships with suppliers, the information exchange process)	Giannakis [27], Baihaqi et al. [28], Alfalla-Luque et al. [29], Gawankar [30]
- Financial measures related to revenue, profit margins, or investment profitability indicators - Customer/market measures relating to the relationship between the company and its customers - Process measures that show the effectiveness and extent of continuous business process improvement in the organization - People development tools (e.g., quality of employee skills, commitment to technological leadership, and human resources development) - Preparing for future measures (e.g., excellence in strategic planning, critical partnerships and pacts, anticipation and preparation for future challenges in the business environment, and investments in new markets and technologies)	Maltz et al. [31], Tubigi and Alshawi [32]
Finance, customers, internal business processes, training, growth	Kaplan and Norton [33], Folan and Browne [34], Večerskienė and Valančienė [35]

Source: compiled by the authors.

It should be noted that the performance of an organization can be evaluated according to various objects of evaluation, such as financial indicators, quality criteria, areas of activity, resources of an organization, supply chain, and management functions.

Depending on the exact objects of evaluation, the relevant instruments for evaluating an organization's performance are selected, which some authors refer to as methods and others as systems or models. In this research, the wording *organization's performance evalua-*

tion methods has been chosen to refer to the instrument for evaluation of the performance of an organization. Ref. [18] distinguished four main groups of methods for evaluating the performance of small and medium-sized enterprises: (1) Performance evaluation, where evaluation systems are created by adapting the performance evaluation systems of large companies; (2) Performance evaluation using integrated performance evaluation systems for small and medium-sized businesses; (3) Performance evaluation using models designed to analyze specific performance evaluation issues of small and medium-sized businesses, such as performance and customer orientation; (4) Performance evaluation using performance evaluation systems that are formed on the basis of scientific research. Within the framework of this research, the methods chosen to evaluate an organization's performance are based on scientific research.

It is noticed that performance of organizations is evaluated with more and more recent approaches, taking into account contemporary global and organizational development issues. For example, Ref. [20] suggested a performance evaluation which takes into account the impact of Industry 4.0, the Internet of Things, machine learning, artificial intelligence, robotics, and cloud computing on an organization.

The scientific literature presents a wide range of methods for evaluating the performance of organizations, and in order to make an informed choice, it is necessary to determine the attributes of the analysis methods for evaluating the performance of an organization (see Table 2).

Table 2. Attributes of the analysis methods for evaluating an organization's performance.

Attribute	Kaplan and Norton [33]	Folan and Brownie [34]	Rudzkienė and Burinskienė [36]	Večerskienė and Valančienė [35]	Mackevičius [24]	Dror [23]	Derfuss [37]	Christauskas and Kazlauskienė [38]	Sližytė [16]	Sousa and Aspinwall [39]	Carlucii [40]	Venckevičiūtė and Subačienė [18]	Alfalla-Luque et al. [29]	Kozyriūtė [19]	Total
Adaptability	+		+	+					+	+		+			6
Relevance											+				1
Feasibility										+					1
Complexity (Systematicity)	+	+		+		+		+	+	+		+	+		9
Flexibility (Dynamics)		+										+			2
Consistency		+									+				2
Objectivity					+										1
Comparability											+				1
Measurability	+	+	+	+	+	+	+		+			+		+	10
Simplicity, Comprehensibility		+								+	+				3
Reliability (Validity)										+	+				2
Sustainability										+		+			2

Source: compiled by the authors. Attributes of the analysis methods for evaluating an organization's performance identified during the analysis of the scientific literature sources are marked in the table by "+".

During the analysis of the scientific literature, 12 attributes were identified, three of which may be considered more emphasized in the scientific literature than the others:

- Measurability—the possibility to select measurable evaluation indicators. Many of the analyzed scientific literature sources [16,18,19] emphasize the importance of quantitative indicators, which can be used to quantify any complex phenomenon

expressed by many indicators. A set of quantifiable indicators would allow the creation of a benchmark for a green organization—a tool that would help organizations assess their current level of greenness and identify areas for improvement by comparing the absolute values of the benchmark with the results of their performance indicators. It should be emphasized that multi-criteria evaluation methods integrating quantitative and qualitative indicators are also used to evaluate an organization's performance;
- Complexity—the ability to examine an organization as a system by assessing its elements and their interrelationships and taking into account the external environment of an organization. According to [23,29,39], complexity allows to analyze an organization in a comprehensive way, taking into account both the internal and external factors affecting the performance of an organization. Evaluating the elements of an organization not in isolation but as a whole and analyzing their mutual interactions considering the impact of the external environment provides a basis for a detailed evaluation of an organization's performance from the aspect of greenness, diagnosing strengths and weaknesses. Based on the results of such studies, reasonable solutions can be found for improving the performance of an organization and increasing efficiency;
- Adaptability—the ability to adapt an organization's performance evaluation method to organizations that are different in the nature of their activities. In order to make the green organization benchmark applicable to various organizations, consideration should be given to the possibility of adapting the benchmark to various types of organizations.

Considering the results of the analysis, it can be stated that the attributes of adaptability, complexity and measurability, which are mostly mentioned in the scientific literature, are the most suitable for assessment of organization's performance evaluation methods in order to choose the most suitable for the creation of the benchmark for the evaluation of the organization's performance in terms of greenness.

3. Research Methodology

With the aim of examining the variety of approaches to evaluating an organization's performance, assessing their suitability for the creation of a green organization benchmark, and selecting the most suitable approach for the creation of a green organization benchmark, it is appropriate to conduct the theoretical study in several stages, each of which is defined by the appropriate research method (see Figure 2).

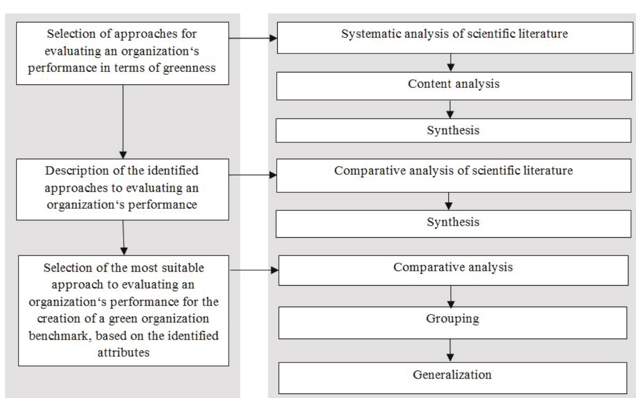

Figure 2. Methodological scheme of the research (source: composed by the authors).

In the first stage, the selection of approaches to evaluate an organization's performance in terms of greenness was carried out. To identify the approaches to evaluating an organization's performance associated with green organizations in the scientific literature, the content analysis method was applied within the framework of this study. The content analysis method allows textual information and written sources to be examined according to a selected indicator, for example, a topic that reflects certain attitudes, interests, values, norms of activity, etc. [41,42]. According to [43], in the preparation stage of the content analysis method, it is important not only to select documents for analysis but also to assess their authenticity, representativeness, meaningfulness, completeness, and reliability. Therefore, the keywords *green organization* and *performance*, which correspond to the objective of this research, were used to find information and select an approach to evaluating a green organization's performance. Ref. [43] noted that a disadvantage of this research method may be the fact that the indicator chosen for analysis (for example, a word) may be understood differently by different authors and therefore be given different meanings. It should be noted that the adjective *green* used in the scientific literature is no longer just a characteristic of the color of a physical object. As early as 2012, Ref. [44] stated that the color green can be assigned to a group of metaphorical terms in which colors are given certain meanings. According to this author, in economic terminology, the color green is associated with things that are ecological and environmentally friendly, such as green tax, green tourism, green energy, and the use of metaphorical terms in the terminology of a certain field of science is closely related to the research objects in that field. According to [45], the color green is most often included as an active element in the composition of a term to create a metaphor related to environmental protection, environmental goals, nature conservation and nurturance, and the fight against climate change (green economy, green growth). Ref. [44] identifies the concept of the adjective *green* as problematic because it has many meanings, and emphasizes that administrative language increasingly uses the adjective *green* in the sense of "ecological, conforming to the laws of nature, harmless to the environment, preserving it, produced from renewable sources" as in green accounting, green diplomacy, green energy, green electricity, green enterprise, green (environmental) tax, green product, green revolution, green public procurement, green zone. According to [46], the color green in advertising communications usually indicates that the product is natural, not artificial. In conclusion, it can be assumed that the adjective *green* may be attributed to metaphorical terms, which have different meanings depending on the research object of the scientific branch. In this research, the adjective *green* used in the wording *green organization* refers to those organizations that integrate green initiatives and practices into their activities in different areas to meet their environmental objectives, social well-being, and economic growth. The selection of scientific sources related to the green organization was focused on literature in the field of social sciences. The results of the content analysis of the selected scientific literature sources were processed according to the general features of the topic, which can be attributed to the possible methods for evaluating an organization's performance.

In the second stage, after performing a comparative analysis and synthesis of the scientific literature, the identified approaches to evaluating the organization's performance were described. *In the last stage*, a comparative analysis of the suitability of each organization's performance evaluation approach to creating a green organization benchmark was performed according to the identified attributes. After grouping, interpreting, and generalizing the results of the analysis, the most suitable approach to evaluating an organization's performance was determined to create a green organization benchmark.

4. Selection of Organization's Performance Analysis Approaches Suitable for Creating a Green Organization Benchmark

To clarify which approach to an organization's performance evaluation is suitable for the analysis of the organization's performance from the aspect of greenness, a selection of scientific literature was carried out for further content analysis. The scientific literature sources were selected in the Web of Science Clarivate Analytics database according to the search criteria: "green organization" (All fields) or "green organisation" (All fields) or "green company" (All fields), and "performance" (All fields). According to these search criteria, 60 sources of scientific literature were found. After narrowing down the search to only literature sources attributable to the categories of social sciences (Web of Science Categories: Social Sciences Interdisciplinary or Management or Business or Economics), 17 articles were selected for further analysis, 12 of which met the following criteria set for the documents selected for content analysis: authenticity, representativeness, meaningfulness, completeness, and reliability. After analyzing the content of all 12 selected articles according to the selected topic indicator, the obtained results were processed distinguishing the common characteristics of the *topic*, which can be attributed to the possible methods of evaluating an organization's performance (see Table 3).

Table 3. Determining the suitable approaches to analyzing a green organization's performance.

No.	Year	Authors	Analyzed Topic	Method of Organization's Performance Evaluation			
				Resources of an Organization	Value Chain	Management Functions	Other
1	2009	Yu et al. [11]	Resources efficiency	+			
			Sustainable value		+		
			Environmental management			+	
2	2009	Rocky J. Dwyer [47]	Performance management			+	
			Management accountability			+	
3	2010	Jennings and Zandbergen [12]	Ecological sustainability of organizations				+
4	2012	Ormazabal and Sarriegi [48]	Environmental management			+	
5	2013	Cai and He [9]	Corporate environmental responsibility				+
			Market efficiency				+
6	2015	Yusoff et al. [13]	Green human resources management	+			
7	2016	Fan et al. [5]	Green supply chains		+		
			Resource-based view	+			
8	2017	Bangwal et al. [49]	Workplace design				+
			Green building	+			
			Work satisfaction				+
9	2019	Leszczynska and Karman [14]	Green human resource management	+			
10	2020	Ormazabal et al. [50]	Environmental management			+	
			Eco-innovations	+			
			Leading green company			+	
			Maturity stages				+
11	2021	Liu et al. [51]	Green human resources management	+			
12	2021	Yoo et al. [7]	Green supply chain		+		
		Total:		8	3	6	6

Source: compiled by the authors. Possible methods of evaluating an organization's performance according to the results of conducted content analysis of each selected scientific literature source are marked in the table by "+".

Based on the results of the analysis, the following three approaches to evaluating an organization's performance related to the purpose of the research were determined: resources of an organization (adopting a resource-based view), value chain, management functions. General topics that did not fit into any or fit all of the sections of the organization's performance evaluation were assigned "Other" (for example, market efficiency, workplace design, job satisfaction, and others) and were not considered during further analysis. For a deeper analysis of the suitability for the development of a green organization benchmark, the three mentioned approaches to an organization's performance evaluation were selected for examination according to the defined attributes.

4.1. Suitability Assessment of the Approach of Resources of an Organization to Developing a Green Organization Benchmark

Organizations have certain resources at their disposal. According to [52], a resource can be considered anything that has an enabling capacity, and the concept of a resource-based approach plays a key role in helping companies gain a competitive advantage. The scientific literature provides many different classifications of an organization's resources (see Table 4).

Table 4. Organization's resources classification diversity.

Classification	Author
Physical (plant, equipment, physical technology, access to raw materials, geographical location), human (intelligence, experience, training, relationships, characteristics, and abilities of employees and managers), organizational capital (reporting structures, informal and formal planning, the company's entire organizational process), financial resources (property, debts, retained earnings)	Barney [53,54], Khan and Naeem [21]
Perceived human resources practices, clarity of organizational goals, senior management leadership, organizational adaptivity, strategic alignment, organizational autonomy	Albrecht et al. [55]
Human, financial, organizational (intangible), technical-technological	Sekliuckienė [25]
Tangible, intangible	
Labor resources, financial resources, technical (technological) resources, organizational culture	Bivainis [17]
People, money, raw materials, capital	Certo and Certo [56]
Tangible, intangible	Martín-Hidalgo and Pérez-Luño [57]

Source: compiled by the authors.

It is also noticeable that the scientific literature presents different opinions on the distribution of the components of resources of an organization, such as in the case of components of organizational (intangible) resources [58,59]. Although there are different classifications, it is possible to distinguish the main groups of resources of an organization: human resources, organizational resources, technical-technological resources, and financial resources. It can be argued that by applying a systemic approach, these resource groups can be treated as elements of the organization as a system.

The resources of an organization can be examined in various ways, one of which is through the prism of the input-process-output (IPO) concept. Interpreting McGrath's (1964) concept of IPO, Ref. [60] argues that the outcome of an "output" is determined by the "processes" to which the "input" leads. Models based on the IPO concept may differ in certain aspects but share a common "input" factor that influences the "output" factor through a "process" [61]. When applying the IPO concept, it is possible to treat resources as input and examine the output (product) obtained during the transformation process.

When evaluating the measurability of resources of the organization, it has been observed that researchers propose various methods to evaluate each resource. For example, human resources evaluation is characterized by a variety of evaluation methods. Ref. [62] suggests evaluating human resources in several stages, which include: business strategies (costs, innovation, quality); content of human resources management (resources, development, reward, relationships); human resources management processes (distinctiveness, consistency, consensus), human resources management experience (resources, development, rewards, relationships), employee attitudes (job satisfaction, motivation, organizational commitment), employee behavior (employee commitment, organizational citizen behavior, cooperation, intention to leave) and performance (productivity, growth, creativity). In addition, it has been proposed to examine human capital based on income and expenditure methods, which are based on acquired education, experience, and skills, whereby the value of each individual's human capital is calculated as income received from participation in the labor market [63,64]. Depending on the chosen objective of the organization's human resources evaluation, the selected evaluation indicators will also differ. For example, to assess the supply of employees, it is appropriate to calculate a supply level criterion based on their individual characteristics (profession, nature of work, etc.). To assess the turnover of employees, it is appropriate to calculate the employee turnover rate or the employee stability ratio [17]. It can be concluded that depending on the purpose of the evaluation, evaluation indicators can be selected for each group of organization's resources.

After analyzing the theoretical aspects of resources of an organization, an assessment of the suitability of this approach was carried out according to the established attributes (see Table 5).

Table 5. Suitability assessment of the approach of resources of an organization according to identified attributes.

Attribute	Suitability Assessment	
Adaptability	Organizational performance analysis from the perspective of resources can be applied to all organizations, as each has resources at its disposal	Suitable
Complexity	An organization can be analyzed as a system, evaluating resources as subsystems of this system, but the analysis is limited to the level of the organization's internal environment and does not consider the factors of the external environment	Partially suitable
Measurability	Evaluation indicators can be selected for each group of resources of an organization	Suitable

Source: compiled by the authors.

The analysis of evaluating an organization's performance through the approach of resources of an organization identified a disadvantage in the application of this approach: the focus of management decisions on increasing the competitive advantage. There is a consensus that the resource-based approach does not focus on the essential consequences of management decisions [65,66]. It can be assumed that such an approach may focus on the most efficient use of resources to achieve a competitive advantage. Therefore, the management decisions of an organization will be focused on profit maximization over the implementation of sustainable development goals.

4.2. Suitability Assessment of the Value Chain Approach to Developing a Green Organization Benchmark

Value is the result of the customer's continuous assessment of the organization, i.e., the customer creates and determines value through simultaneous and determines it in concurrent, repeated consumption experiences, and defines value as the subjective meaning of the repeated and accumulated consumption experiences [67,68]. According to [69], a business model essentially is the logic of value creation and the structure that implements it, as well as the operational environment of value creation logic. The scientific literature presents a variety of value chain concepts (see Table 6).

It should be noted that the value created by different organizations varies depending on the specifics of the organization's activities. For example, the steps of the chain of social value creation are the stages through which social value can be created by solving social problems, and the chain of social value creation partly provides a way of linking economic activity to the social mission [69]. Meanwhile, the added value created by for-profit organizations is oriented toward the result.

Table 6. Diversity of value chain concepts.

Definition	Authors
A set of core activities (direct production activities or activities that support the final production of goods offered to customers)	Hitt et al. [70]
The activities required to transform a product from idea to market	Jonikas [71]
A tool that divides a business into strategically important activities	Walters and Lancaster [72], Budrys [73]
Series of activities that add value to a product	Toussaint et al. [74]

Source: compiled by the authors.

There are different opinions on value chain analysis in the scientific literature. Ref. [75] proposed to examine the value chain by distinguishing between core and supporting activities. The core activities include inbound logistics activities, production, outbound logistics activities, marketing and purchasing, and service while supporting activities include corporate structure, human resources, technology development, and purchasing. According to [71], the value chain includes product development, different stages of production, raw material extraction, semi-finished products, component manufacturing and assembly, distribution, marketing, and even waste recycling. McKinsey & Company consultants propose to examine value creation through six different distinct but related groups of actions: technical progress, product design, production, marketing, distribution, and services, and specific actions are carried out in each of these groups [76,77]. Ref. [78] offer three perspectives for examining value creation:

1. Economic value centered on the efficiency of product development. For the customer, economic value is high quality at a low price;
2. Market value is about providing an attractive range of products at the right time and in the right place;
3. Suitability, which includes the customization of value-added services that benefit customers. Convenience value means that products and services are changed, sorted, and grouped in a way that is much more attractive to the customer. Customization is achieved by incorporating specific components into products to enhance the functionality desired by a particular customer.

The work of Ref. [79] emphasizes such models of product value creation for the consumer as the theory of economic profit, the consumer value model of the product development process, the risk value method, and the design structure matrix. It can be concluded that the value creation chain can be examined from different aspects, so the choice of indicators depends on the purpose of the evaluation. The analysis of the organization's performance evaluation using the value chain approach resulted in an assessment of the suitability of this approach according to the defined attributes (see Table 7).

The suitability analysis of this approach to developing a green organization benchmark identified a fundamental disadvantage; namely, the authors' opinions on the classification of green supply chain components in the context of the green value chain differ. While some authors consider the green supply chain as part of the green value chain, other authors distinguish certain elements of the green supply chain as separate components of the green value chain [80–82]. It can be said that there is no unified opinion on the definition of the value chain and the elements attributable to it, which increases the risk of inaccuracies when creating a green organization benchmark based on the value chain approach.

Table 7. Suitability assessment of the value chain approach according to identified attributes.

Attribute	Suitability Assessment	
Adaptability	Adaptable to different types of organizations, but the identified value created will vary depending on the nature of the organization	Partially suitable
Complexity	The value chain includes both internal and external environments, but the sequential nature of elements in the value chain limits the possibility of applying a systematic approach to the study of the relationships between the elements and their mutual effects	Partially suitable
Measurability	The sequence of elements in the value chain allows for determining the evaluation indicators for each element, but the value created and its evaluation depend on the nature of the organization's activities and the purpose of the evaluation	Partially suitable

Source: compiled by the authors.

4.3. Suitability Assessment of the Management Functions Approach to Developing a Green Organization Benchmark

In the scientific literature, organizational management functions are divided into general and special functions [83]. General management functions are repeated across different processes [84,85]. General management functions include planning, organizing, leading, and controlling. According to Ref. [86], although all organizations share the same general management functions, the management tends to differ due to the diversity of organizations and the diverse nature of their activities. Special management functions refer to those whose composition is determined by the specifics of the managed object's activity. The scientific literature contains a variety of opinions regarding which management functions should be considered special functions, but there is no clear set of special functions (see Table 8).

Table 8. Special management functions.

Special Management Functions	Authors
Technical, production, marketing, financial, and other functions	Gerasymchuk [87]
Special management functions include policy control, marketing management, sales control, procurement management, financial management, quality management system, human resources management, production management	Danilava [88]
Organization of the appropriate structure, support, and modification (improvement, adjustment) of optimal advertising of the assortment of consumer goods, continuous internal and systematic external control (audit) of the management	Maleca [89]
Organization policy, human resource management, production management, marketing function, the implementation function is assigned to sales managers, procurement function assigned to supply managers, financial management, the function of the quality management system	Nebelyuk and Shishko [90]

Source: compiled by the authors.

It should be emphasized that the general management functions are common to all organizations, and different evaluation methods are offered for each of the main management functions. Meanwhile, the set of special functions depends on the specifics of an organization and the nature of its activity, so the choice of performance evaluation method will therefore differ accordingly. Analyzing the indicators from the perspective of management functions, it can be stated that there are clearly defined indicators for the evaluation of special management functions in the scientific literature. For example, quantitative (e.g., financial return on marketing), qualitative, and balanced indicator analysis methods are applied when evaluating the effectiveness of marketing activities [91]. Ref. [92] claim that financial indicators of marketing efficiency are focused on profit assessment (increasing sales, increasing profits, income, and market share), whereas non-financial indicators are focused on customer satisfaction (brand awareness, consumer satisfaction, quality of goods and services, interpersonal relations, competitiveness). It can be stated that measurable evaluation indicators can be selected for the analysis of an organization's performance in terms of its management functions, depending on the nature of the organization's activity and the purpose of the analysis.

After analyzing the theoretical aspects of the management functions, an assessment of the suitability of this approach was carried out according to the defined attributes (see Table 9).

Table 9. Suitability assessment of the management functions approach based on the identified attributes.

Attribute	Suitability Assessment	
Adaptability	Universal in the context of general management functions and limited in the context of special management functions	Partially suitable
Complexity	The analysis focuses on the management of an organization's internal processes without evaluating the factors of the external environment	Partially suitable
Measurability	The evaluation indicators for special management functions will vary depending on the nature of the organization's activities	Partially suitable

Source: compiled by the authors.

Analyzing the suitability of this approach for the creation of a benchmark for a green organization, the essential advantage of the management functions approach was identified, namely the wealth of research into the individual special functions in terms of greenness in the scientific literature. Many studies are devoted to green marketing, green human resources management, and green finance. However, this aspect can also be attributed to disadvantages. Due to the strong focus on the aspects of individual special functions' greenness, there is a lack of linkage with other management functions. This allows assuming that the analysis of an individual organization's special function in the context of the whole organization can be fragmentary. Another identified disadvantage of the management functions approach is the absence of a clear set of special functions.

5. Identification of the Most Suitable Approach to Evaluating Performance of an Organization for the Creation of a Green Organization Benchmark

Table 10 presents a comparison of the suitability assessment results of the analyzed approaches to choose the most suitable approach to evaluating an organization's performance for the development of a green organization benchmark (see Table 10).

Table 10. Comparison of the analyzed approaches in terms of their suitability for the development of a green organization benchmark.

Attribute	Resources of an Organization	Value Chain	Management Functions
Adaptability	+	+/−	+/−
Complexity	+/−	+/−	+/−
Measurability	+	+/−	+/−

Source: compiled by the authors. Suitability for the development of a green organization benchmark of each analyzed approach is marked by + (suitable) or +/− (partially suitable).

Taking into account the identified advantages and disadvantages of an organization's performance evaluation approaches, it can be said that the most suitable option for creating a green organization benchmark is the approach of resources of an organization since this approach corresponds to the attributes of adaptability and measurability more than others. However, when applying an approach of the resources of an organization to creating a green organization benchmark, it was observed that this approach only partially corresponds to the attribute of complexity. Therefore, in order to address the attribute of complexity, it is suggested that the creation of a green organization benchmark based on the resources of an organization should be supplemented with an assessment of the impact of external environmental factors on the organization's activity, i.e., it is appropriate to include an assessment of the impact of general and special external environmental factors on the green organization. The general environment of an organization includes the natural, demographic, economic, social, political, legal, cultural, and technological environment, while the special environment includes consumers, competitors, and suppliers. The evaluation of the external environment is important to reduce the uncertainty of the environment and the negative impact of its changes on organizational performance. It is reasonable to include an assessment of the external environment in the creation of a green organization benchmark since certain factors in the external environment of organizations, such as legal regulation, directly and indirectly, affect the organizations' willingness to transform in a green direction, especially in certain fields of activity, such as energy or manufacturing.

6. Conclusions

Responding to the importance of the pursuit of sustainable development in modern society, it can be stated that an increasing number of organizations are striving to develop in a green direction. Therefore, a tool applicable to organizations with different fields of activity (energy, manufacturing, services, etc.) is needed to help organizations to assess the current situation in terms of greenness and determine directions for development. In this research, the aspect of the greenness of an organization's performance refers to an integration of green initiatives and practices into day-to-day activities aiming to meet its objectives of environmental, social well-being, and economic growth. It can be stated that it is appropriate to create a green organization benchmark against which organizations can assess their current level of greenness and identify areas for improvement. When creating such a benchmark, one of the important tasks is to determine the most suitable approach to evaluating an organization's performance. Thus, this research aimed to choose the most suitable approach for developing a benchmark by examining the methods for evaluating an organization's performance in terms of greenness.

After the analysis of the scientific literature, the essential attributes were defined, on the basis of which the suitability of the organization's performance evaluation approaches can be analyzed for the creation of a green organization benchmark: adaptability, complexity, and measurability. After systematizing the results of the methods analysis for evaluating an organization's performance, the three approaches suitable for the creation of a green organization benchmark were selected: resources of an organization, value chain, and management functions. It was determined that the most suitable approach to creating a green organization benchmark is the approach of resources of an organization, as this approach corresponds to the attributes of adaptability and measurability more than the other identified approaches. However, when applying the approach of resources of an organization to the creation of a green organization benchmark, it is important to consider that this approach does not include the impact of factors of the external environment. Therefore, when creating a green organization benchmark for evaluating an organization's performance on the basis of the approach of resources of an organization, it is reasonable to supplement this approach with an evaluation of factors of the external environment to address the attribute of complexity.

The strengths of this research can be defined by its relevance, novelty, and originality. The topic of the research is relevant according to nowadays actualities as the emergence of green organizations and their further development is considered one of the measures to achieve the Sustainable Development Goals. The research was conducted aiming to fill the gap in the scientific research that there is still a lack of definition of what kind of organization is considered green. The novelty of the research is defined by the decision of the authors to analyze the aspect of the greenness of an organization in terms of its performance evaluation. The originality of this research can be defined by chosen attitude to analyze the topic from different perspectives combining different research methods (systematic and comparative analysis of scientific literature and strategic documents, content analysis, grouping, synthesis) in several stages in order to identify the most suitable approach for evaluating an organization's performance in the aspect of greenness. The limitation of this research is that the Web of Science database was chosen as a basis for the search for documents on the topic. Therefore, the results of the analysis would not be comprehensive enough. However, the content analysis provided in this review paper resulted in the choice of the most suitable approach for evaluating an organization's performance for the creation of a green organization benchmark, so the purpose of the research should be considered reached.

To sum up, the essential results of this research could be described as follows. First of all, the authors suggested analyzing the aspect of the greenness of an organization in terms of its performance evaluation, which could be considered a new perspective to study the topic of a green organization. Secondly, essential attributes were defined by the authors, on the basis of which the suitability of the organization's performance evaluation approaches can be analyzed: adaptability, complexity, and measurability. In addition, the authors identified three possible approaches to evaluating an organization's performance in the aspect of greenness: resources of an organization, value chain, and management functions. The main result of this study is the choice of the approach of resources of an organization as the most suitable for evaluating an organization's performance in the aspect of greenness according to the defined attributes.

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Review

Circular Economy and Sustainability-Oriented Innovation: Conceptual Framework and Energy Future Avenue

Viktor Koval [1,*], I Wayan Edi Arsawan [2], Ni Putu Santi Suryantini [3], Serhii Kovbasenko [4], Nadiia Fisunenko [5] and Tetiana Aloshyna [5]

1 Department of Business and Tourism Management, Izmail State of University of Humanities, 68601 Izmail, Ukraine
2 Department of Business Administration, Politeknik Negeri Bali, Bali 80364, Indonesia
3 Faculty of Economics and Business, Universitas Udayana, Bali 80361, Indonesia
4 Department of Transport Construction Machinery Engineering, National Transport University, 02000 Kyiv, Ukraine
5 Department of Analytical Economics and Management, Dnipropetrovsk State University of Internal Affairs, 49005 Dnipro, Ukraine
* Correspondence: victor-koval@ukr.net

Abstract: A circular economy emerged as an alternative transition model, which is considered to be a solution to massive environmental degradation. The transition from a linear economy to a circular economy requires companies to be actively involved in more sustainable practices. For such a transition, companies must rethink, innovate on business models, and encourage sustainability-oriented innovation to deliver customer value, while simultaneously considering environmental and social aspects. On the other hand, the role of the circular economy in energy conservation and infrastructure has not been mapped out in the current literature. This systematic literature review seeks to map out the main interrelated topics of the circular economy and sustainability-oriented innovation, describing internal and external factors that need to be considered in the transition to a clean energy future. Key lines of research are identified, and suggestions for future research and for how to facilitate the movement towards a circular economy are provided. This study contributes to an enhancement of the literature by identifying priority areas regarding the circular economy and sustainability-oriented innovation to encourage future research that contributes to sustainability and environmental preservation.

Keywords: sustainability-oriented innovation; circular economy; conceptual framework; energy transition

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1. Introduction

The principle of a linear economy that prioritizes take-make-dispose has implications for increasing the volume of waste [1] and wasted resources [2], which can be reused or used as an energy source based on the creation of energy transfer infrastructure from recycled materials. Coupled with the fact that the amount of waste will increase to 2.59 billion tons in 2030 and 3.4 billion tons in 2050 worldwide, our approach to this has changed [3]. Considering that sustainable development goals on 17 main agendas involve three components (economic, social, and environmental), dependence on sustainable resource management is very essential [4].

Given the important role of organizations in preserving the environment, the circular economy concept can be an alternative for managing resources, reducing waste, and reprocessing them into high-value products [4]. Consequently, a circular economy approach benefits businesses and society as a whole with a better supply chain, low volatility of resource prices, better customer relations, and new job opportunities [5]. In the energy context, the circular economy approach can provide a new perspective because it manages waste into energy and manages resources efficiently [6].

In a circular economy, the use of waste as an energy source is one of the ways to reduce the use of fossil fuels. The circular economy has an important impact on energy conservation and energy infrastructure efforts because it provides the direction of research and development in an innovative and sustainable manner. However, the circular economy transition process related to energy in various sectors needs to be revealed through the visualization of literature mapping to obtain a comprehensive picture as the basis for making relevant research and policies [7].

The transition to a circular economy involves systemic changes aimed not only at reducing the impact of a linear economy, but also at building long-term resilience that generates new business opportunities and returns social and environmental benefits [8]. On the other hand, the circular economy has produced a significant impact on environmental improvement from the threat of degradation [8,9]. All industrial sectors have played a role in reducing the potential for damage by reducing, reusing, and recycling [10]; however, the relationship with sustainability-oriented innovation is still not well explored.

A circular economy provides an alternative in order to integrate ecological approach criteria, such as the recycling, reuse, and replacement of materials into the routine activities of an organization [11,12]. This approach involves managing the internal environment [13,14] and an eco-friendly design [14], as well as the management and recovery of corporate assets [14]. The circular economy will be successful if it starts from the internal environment by developing environmentally oriented procedures, such as green human-resource-management practices [2,15], training, and development [16], as well as an environment-based performance-evaluation system; thus, supporting intra-organizational environmental goals builds environmental ethics and improves ecological performance [17]. On the other hand, organizations implement product design process policies by considering environmental impacts because they are considered promising in achieving eco-efficiency [18,19]. In addition to environmental efficiency, eco-friendly design practices offer opportunities for companies to provide a market share with differentiated products [20] and increase global value propositions [21]. Finally, the positive impact is an increase in the ability of the organization to recover investments, resell and reuse used materials [13]. This requires companies to think strategically about how to mitigate emerging issues in order to gain greater value and is an important goal to be achieved in a circular economy [22].

In the energy sector, the impact of circular economy practices can increase energy efficiency and facilitate an increase in the quality of human life [23]. However, the increase in energy consumption raises concerns about climate change, especially when accompanied by an increase in greenhouse gas emissions [23]. Thus, adopting a circular economy strategy helps countries meet their climate change mitigation goals [24,25]. Another study states that the combination of circular economy principles and the use of renewable energy can result in a reduction of 37.5% in greenhouse gas emissions [25]. Therefore, a circular economy strategy can mitigate global climate change by increasing the use of renewable energy and changing the energy structure to be more sustainable.

On the other hand, sustainability-oriented innovation is seen as a systematic effort by organizations to promote the role of competitiveness and human and social welfare in building environmentally friendly practices [26–28]. Furthermore, sustainability-oriented innovation requires strategic sustainability behavior by implementing an integrated environmental strategy, creating an environmentally friendly culture, extending the product life cycle, and initiating an environmental management system [28]. In the available literature, innovation practices that encourage sustainability-oriented innovation occur in two ways. The first is product innovation, which introduces new product or service improvements to improve sustainable performance [29]. The second is process innovation, which requires organizations to redesign operational mechanisms for resource efficiency, energy use, and building an eco-efficiency culture [29]. As a result, there is a consolidation of organizational practices and values to achieve economic, social, and environmental goals.

In this perspective, according to emerging characteristics, research on the circular economy associated with sustainability-oriented innovation remains fragmented with numerous variations and has been investigated in different dimensions. Although a circular economy is the basis for implementing sustainability-oriented innovation, research on these two constructs is still rare [30]; however, a circular economy provides innovative solutions and promotes sustainability. Therefore, understanding the interconnectedness of the circular economy and sustainability-oriented innovation is critical to bridging an organization's transition to sustainability [31]. Previous studies have focused on the drivers and barriers to the circular economy in various industries. However, the literature on the circular economy as a sustainability-oriented innovation trigger has not been well explored. Thus, this article maps out the main research topics at the intersection of the circular economy and sustainability-oriented innovation. The combined bibliography was used to identify the main lines of research in the literature on circular economy and sustainability-oriented innovation in a broad scope and to suggest topics for future research.

2. Methods

A systematic literature review is a research design used to systematically synthesize existing research evidence in terms of searching research articles, critical reviews, and synthesis of research results to answer trending topics [32]. Systematic literature reviews are research designs that enable robust investigation into the state of the art from a particular research field [33], systematic synthesis of evidence, and critical appraisals [34], while recognizing research gaps to promote future inquiry and knowledge advancement [35,36]. This study adopts the systematic literature review approach used by recent studies to holistically assess and synthesize the progress of the current relevant literature on the circular economy and sustainability-oriented innovation [37].

A systematic literature review is a method that reviews previous studies with several stages as follows: first, identify studies and research questions; then, determine the relevant studies; third, collect and retrieve the information; fourth, synthesize the data; and finally, report the findings. This study also involved a review panel, consisting of two professors and a researcher, establishing the conceptual boundaries of this topic. Consultations were held at every level from the initial identification to the final selection of relevant studies. This consultation helped resolve differences of opinion among the authors and reach a final consensus to continue the research. We followed established protocols to ensure the replication and accuracy of our findings [32].

To achieve the research objectives, we used VOSViewer to combine the downloaded data in the form of a research information system [38,39] that was fed to Mendeley [40]. First, we searched for the keywords "circular economy" and "sustainability-oriented innovation". Considering that environmental concerns are starting to become a trend in various areas, we searched the Scopus-ScienDirect database in the following six main areas: (1) Environmental Science; (2) Business, Management and Accounting; (3) Decision Sciences; (4) Energy and Engineering; (5) Economics, Econometrics and Finance; and (6) Agricultural and Biological Sciences. A search conducted in August 2022 yielded 1832 articles. All articles went through a rigorous review process before being published. During Phase 2, we identified and analyzed articles into 1326 terms in which the minimum number of the occurrence term was 10. In this phase, we selected articles and discarded those that did not meet the criteria, such as duplication, country of research, unsuitable keywords, and inappropriate scope. In Phase 3, we performed bibliographic coupling, resulting in 402 items with seven clusters. In stage 3, we used VOSViewer software to analyze data in the form of a research information system.

Figure 1 presents the research protocols from the initial data collection process to the determination of the number of key articles, which were then researched to achieve the research objectives.

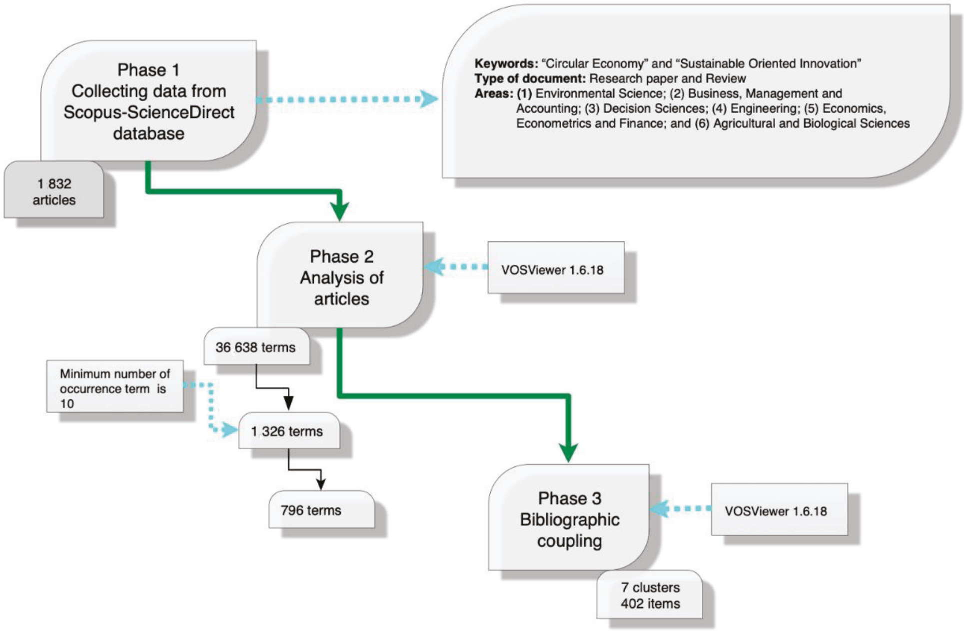

Figure 1. Research protocols of the systematic literature review.

3. Results

3.1. Descriptive Analysis

Considering the research trend in environmental management, we combined data sources from six main areas to enhance the analysis and achieve the research objectives. Figure 2 presents information that the topic of the circular economy and sustainability-oriented innovation began to be published in 2003, and then began to increase from year to year. There was especially a spike in publications in 2018 which doubled compared to that of 2017, increasing sharply in 2019 and 2021, and reaching a peak until this data was taken in 2022. This indicates that the linear transition of the economy to a circular economy has become the agenda of researchers in an effort to preserve the environment, especially in the context of the emerging need for a clean energy transition in the face of growing concerns about climate change and the need to increase access to energy [2,5,41–45].

The 1832 selected articles (Figures 3 and 4) were published in several journals including the following: Journal of Cleaner Production (939 articles—51.24%); Resources Conservation and Recycling (138—7.5%); Technological Forecasting and Social Change (131—7.1%); Sustainable Production and Consumption (126—6.8%); Journal of Business Research (88—4.8%); Journal of Environmental Management (73—3.9%); Science of the Total Environment (73—3.9%); Ecological Economics (59—3.22%); Environmental Innovation and Societal Transitions (44—2.4%); International Journal of Production Economics (41—2.2%); Industrial Marketing Management (38—2.1%); Technology in Society (35—1.8%); Waste Management (29—1.54%); and Forest Policy and Economics (28—1.5%). This provides information that this topic is a trending topic in line with environmental conservation efforts [46,47].

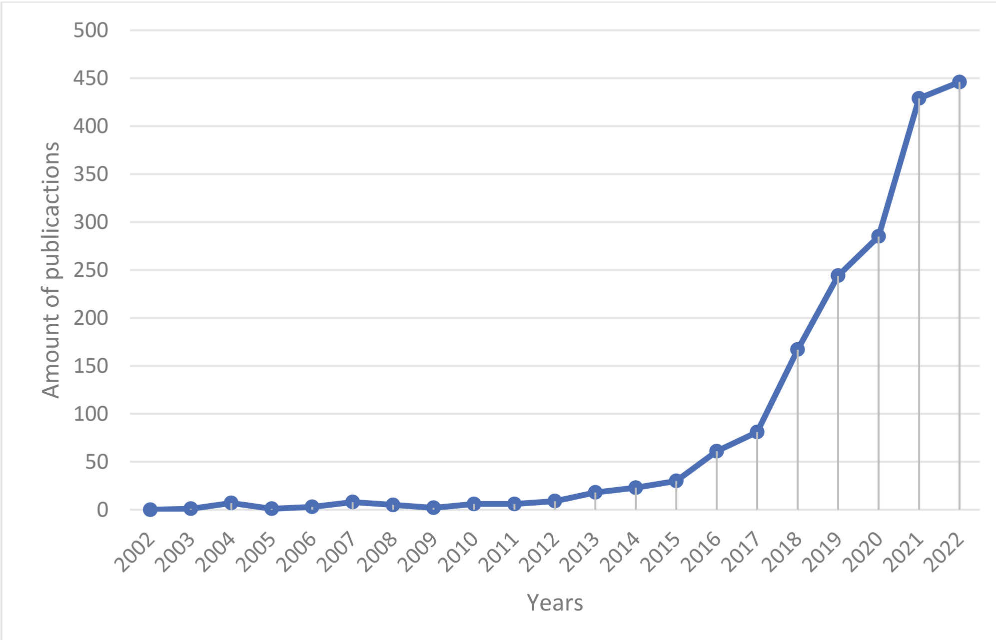

Figure 2. Annual growth in the number of publications.

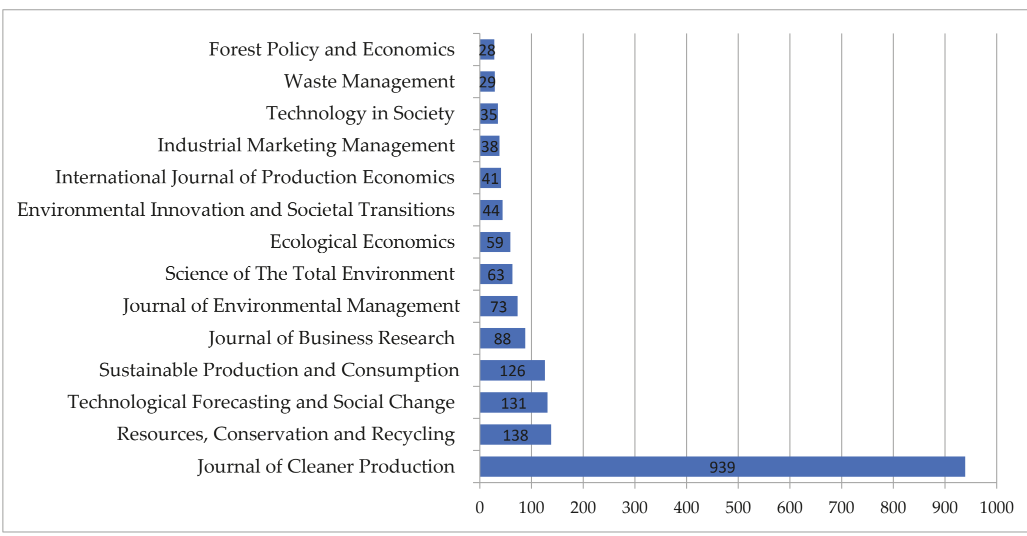

Figure 3. Journal venue for related topic.

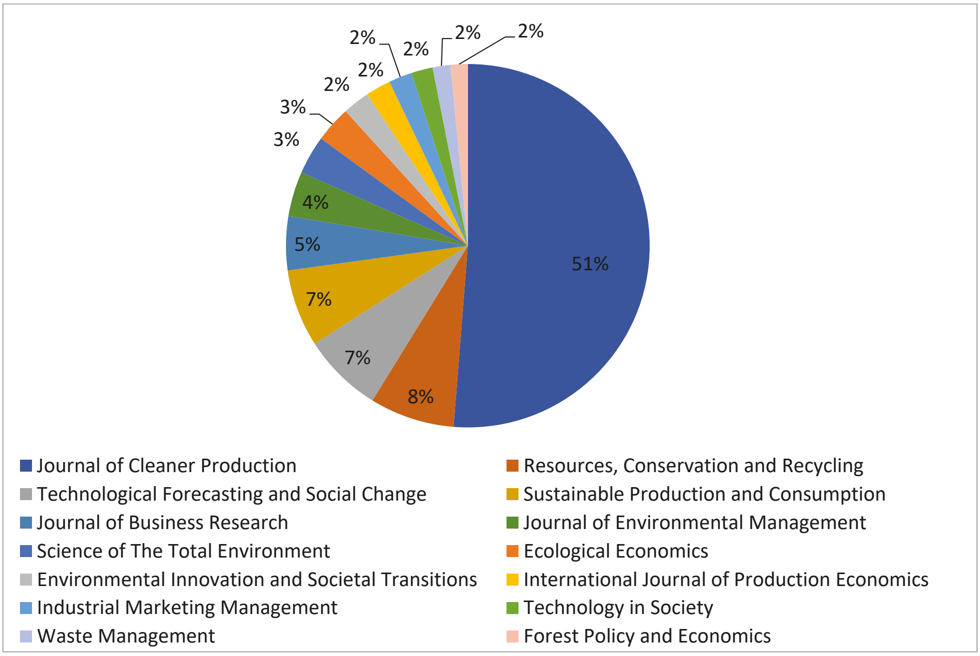

Figure 4. Percentage of article publication on journals.

Figures 3 and 4 show the increasing research on the circular economy as an alternative strategy to increase environmental awareness. This provides opportunities and challenges for every country, industry, and business entity to jointly maintain sustainability and environmental preservation. All stakeholders are involved in implementing circular economy practices. First, governments and countries that are concerned about the environment can apply for green subsidies to increase sustainable practices [48,49]. Second, for business managers, they must increase commitment to the environment, build a culture of action for sustainable development [17], and create sustainable business model innovations [50,51]. Third, there is an environment-oriented standard-operating procedure as environmental ethics guidance [2,15]. Thus, the increase in these publications is an important indication of increased environmental awareness and insight in related fields.

3.2. Bibliographic Analysis

To identify the main research themes in circular economy and sustainability-oriented innovation, we combined the bibliography of these documents with VOSviewer 1.6.18 software. All articles were analyzed by linking a minimum of three articles per cluster. The cluster network is shown in detail in Figure 5.

The results of the network visualization show that there were seven main clusters related to the two research topics. Some of the relevant items in each cluster are described as follows.

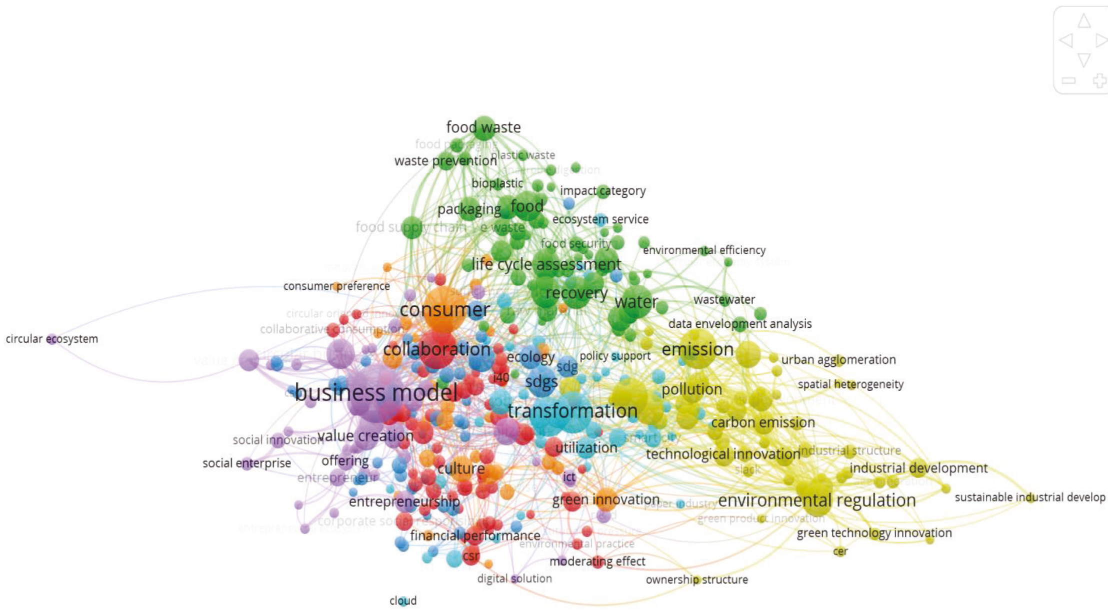

Figure 5. Network visualization of circular economy and sustainability-oriented innovation.

3.2.1. Cluster 1 (Strategic Adoption for Circular Economy)

Within this cluster, all studies contribute to the inherent need for collaboration among stakeholders to drive the circular economy in strengthening sustainability-oriented innovation. To build this agenda, big data analyses and digital transformations are needed [52], along with a strengthening of circular economy practice and collaboration to build green innovation [53,54]. On the other hand, business operations that take into account sustainability will improve the global value chain [55], thereby increasing social value and competitive advantage. The impact of this is the creation of a collaborative economy and economic performance in environmental collaboration for sustainable performance [56]. Other scholars have concluded that the circular economy concept adopted in routine organizational activities, such as green supply-chain management, waste reduction, circular economy-oriented innovation, collaborative consumption, and clean energy, will improve environmental practices in accelerating the circular economy transition [57].

3.2.2. Cluster 2 (Waste Management in Circular Economy Practices)

By implementing a circular economy strategy, environmental conservation can be conducted because it builds an integrated and systematic system for waste demolition, food waste, municipal solid waste, plastic waste, recycled material, and disposal [58]. In addition, the implementation of the circular economy has an impact on eco design [59,60] by conducting food packaging, food production, and the food supply chain. That is, the circular economy process provides stimulation on how to build environmentally friendly products [61].

On the other hand, by building environmentally oriented products, resource recovery, low carbon transition, and even waste recycling are indirectly carried out [62]. Otherwise, this is done by reducing greenhouse gas emissions [63] towards environmental efficiency and the improvement of human health [64]. The development of waste management patterns can be an opportunity to develop electric equipment towards renewable energy [65] which facilitates the manufacturing process. To achieve all of that, systematic efforts are needed for organizations, governments, communities, and even the media unite to carry out social acceptance.

3.2.3. Cluster 3 (Factor Affecting Circular Economy Practices and Sustainability)

In this cluster, we group the determinants of the circular economy into building sustainability. So far, the circular economy has been carried out in companies with a high level of readiness, such as the automotive industry, because they have circular supply-chain management [66,67], sustainable product development [68], and value co-creation [69]. The literature reveals that the circular economy approach is an important trigger in building environmental economics towards a green economy [70]. Assuming that the green economy can be stimulated by circular economy practices, it will have an impact on the realization of three things: first, social sustainability; second, sustainability transformation; and third, corporate sustainability [71,72].

The challenge of implementing the circular economy is that the organization is not ready to implement this due to a lack of method [19], the adoption of technology that costs a lot [73], and sustainability challenges [56]. For this reason, it is necessary to increase understanding of knowledge management and open innovation [74] to make product designs and product development in building environmental organizational legitimacy [75]. Obviously, the positive impact is that corporate leaders have profitable options to realize sustainability goals [30,71].

3.2.4. Cluster 4 (Environmental Process and Its Impacts)

The available literature has revealed that the circular economy is the process of reworking the various outcomes of a linear economy to reduce the use of resources [40,76]. Reductions in carbon emission, resource consumption, and carbon dioxide emissions are a pattern in arranging eco-efficiency, environmental protection [77], and energy conservation [78]. As is well known, energy consumption, energy efficiency, energy intensity, and energy saving involve the implementation of environmental regulations that have an impact on economic development and economic growth [17,77]. In fact, countries that are concerned about efforts to preserve the environment obtain investment faster so that they can sustainably carry out green product innovation, green technology innovation, green total factor production, and green development [79]. Assuming that all resource allocations are effective, the circular economy transition will have an effect on changes in technological innovation, technological progress, productivity [80], and industrial development [4]. Thus, the relationship between energy consumption, economic growth, and climate change depends on parameters that vary over time, which are observed and debated through political implications [23].

3.2.5. Cluster 5 (Circular Business Model and Mechanism)

In this cluster, the results of the analysis produce various keywords related to the business model and business activity associated with innovation. A circular economy business model is a business model innovation that can affect organizational growth and sustainability [81,82]. The application of the circular business model can be implemented to strengthen the circular supply chain and value proposition [21]. Furthermore, organizations need to improve information communication technology considering that the circular economy requires digitalization and the strengthening of dynamic capabilities [83]. Following the input-process-output logic, all processes from building a sustainable business model, adopting technology, forming an entrepreneurial ecosystem to innovating an ecosystem and a product service system will have implications for increasing social enterprise, social innovation (which ultimately results in profitability), sustainable growth, and sustainable competitive advantage [84].

3.2.6. Cluster 6 (Aligning the Circular Economy for Sustainable Energy Development)

The literature reveals that the circular economy is an important transition in increasing environmental awareness [46]. With various ways to apply it to all industrial sectors, circular economy practices are expected to stimulate the environmental value proposition [85] and become a new business model [82]. In cluster 6, there are links between numerous variables that can be explored more deeply in relation to the circular economy. A circular economy applied to various industrial sectors will harmonize sustainable development [86,87]. In addition, the ecosystem formed from the circular economy transition allows for an energy transition for sustainable development. A sustainable energy transition leads to regional developments that can mitigate risks, encourage green development, and minimize the effects of industrialization. On the other hand, the development of information technology allows the government to build smart cities to improve the sustainable energy transition [88], circular bioeconomy, and climate change mitigation towards sustainability [86]. Thus, the proposed operation to increase the efficient solar energy system is an alternative energy solution to meet energy needs in the context of economic and environmental growth [89].

3.2.7. Cluster 7 (Circular Economy and Behavior)

The effectiveness of implementing a circular economy lies in the ability to educate all parties to be responsible for the environment [44]. That is, the internal and external aspects of the organization are very influential on the success of circular economy practices.

From the internal aspect, organizations or managers are expected to apply the characteristics of pro-environmental behavior by implementing green human resource management [90,91], green intellectual capital [92], and environmental orientations [93]. The routine activities of an environment-oriented organization are expected to build a culture that is sensitive to environmental changes. As a result, both employees and organizational leaders will feel responsible and committed to the environment [93,94] in order to build environmental organizational legitimacy [75].

From the external aspect, the alignment of the interests of the organization and the government is a mutually beneficial collaboration mechanism. Governments can provide green economic incentives to organizations to increase their commitment to the environment [95]. Incentives can be in the form of financial or non-financial incentives. The aim is to provide a stimulus to make the circular economy transition more focused and sustainable. Furthermore, the government can carry out pro-social and pro-environmental incentives as a strategic effort to carry out conservation [44]. On the other hand, the incentives given can be a trigger for the organization to share knowledge and communicate about the environment [96,97].

In cluster 7, environmental-saving behavior can also be associated with social capital and creativity. In some of the literature, the circular economy has not been explored in the context of creativity and social capital much. In fact, these two constructs can play an important role in implementing a circular economy. The authors of [98] revealed that social capital is the basis for innovation, while building innovation requires creativity [99]. As such, the role of sustainability-oriented innovation resulting from a circular economy will encourage organizational output, such as sustainability performance, a sustainable future, sustainable manufacturing, a sustainable society, and technological change [43,100–102]. Sustainability-oriented innovation translated into various kinds of innovations, such as green innovation, green product, green technology, product innovation, technological innovation, and process innovation, will increase the chances of winning the competition in the international market and increase [98,103,104].

Upon further analysis, we identified the history on the topic of circular economy and sustainability-oriented innovation in the last three years (Figure 6).

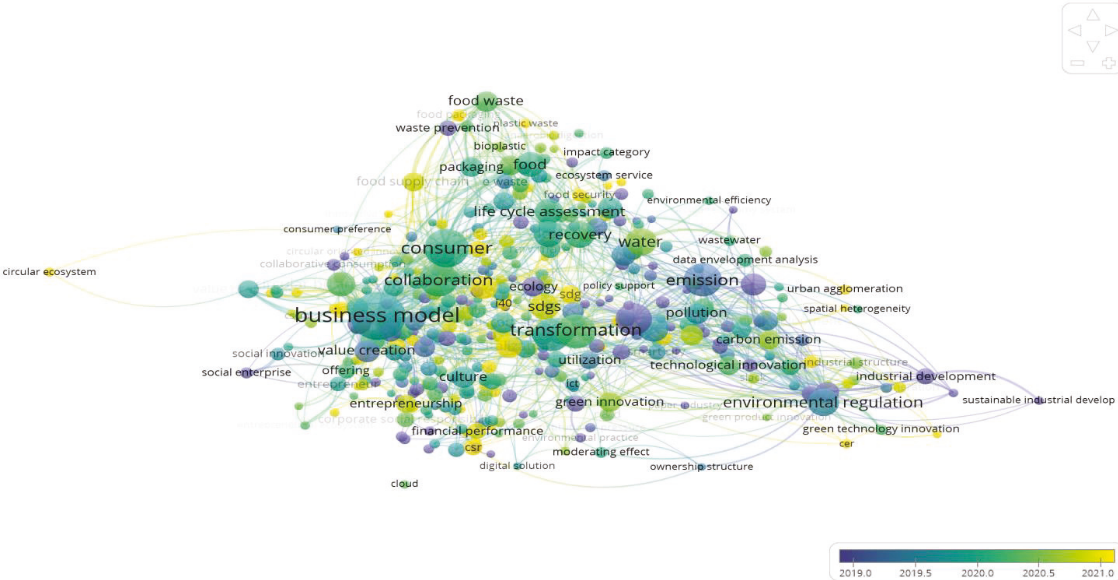

Figure 6. Overlay visualization of circular economy and sustainability-oriented innovation.

The results show that at the beginning of 2019, circular economy and sustainability-oriented innovation were mostly related to emissions, followed by value creation, ecology, industrial development, waste prevention, social enterprise, sustainable industrial development, collaboration consumption, and environmental practice. After mid-2019, the most relevant topics related were business models and environmental regulation, followed by culture, pollution, smart city, and utilization. In early 2020, the most relevant topics were consumer and transformation, followed by life cycle assessment, recovery, collaboration, packaging, food, technological innovation, spatial heterogeneity, wastewater, environmental efficiency, information communication technology, social innovation, data development analysis, green technology innovation, digital solutions, and green technology innovation. After mid-2020, the most relevant was water, followed by green innovation, carbon emission, industrial structure, green product innovation, bioplastic, entrepreneurship, corporate social responsibility, and cloud. The most relevant in 2021 was sustainable development goals, digitalization, and food supply chain, followed by circular ecosystem, entrepreneurship, financial performance, food packaging, food security, industry 4.0, urban agglomeration, and corporate social responsibility. The results of this overlay analysis show that 2022 has a high probability for research because the most recent research was detected in early 2021.

The results of density visualization (Figure 7) show research on circular economy and sustainability-oriented innovation, concentrated on three main topics, namely business model, transformation, and consumer. It then concentrates on several smaller groups, namely collaboration, food, life cycle assessment, recovery, water, emission, environmental regulation, value creation, ecology, industry 4.0, sustainable development goals, pollution, culture, and entrepreneurship.

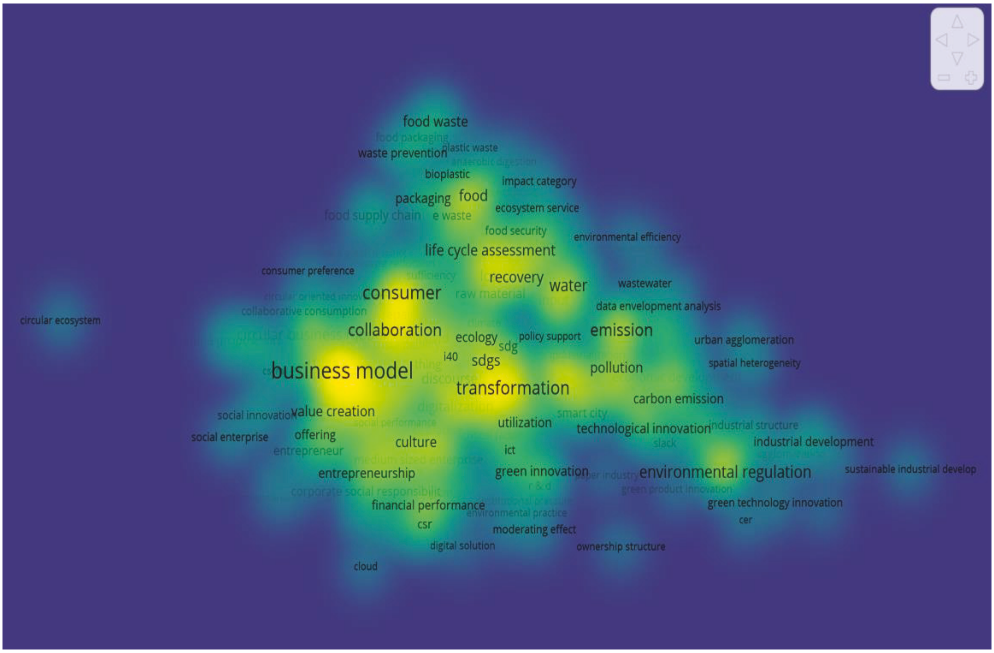

Figure 7. Density visualization of circular economy and sustainability-oriented innovation.

Other topics are still evenly distributed and there is no visible grouping which is indicated by the position of the items in the dim area. That is, it has great opportunities for research, one of which is the circular ecosystem, as well digital solution, ownership structure, sustainable industrial development, green technology innovation, urban agglomeration, environmental efficiency, social innovation, social enterprise, social innovation, corporate social responsibility, environmental practice, green product innovation, circular oriented innovation, food waste, waste prevention, food packaging, plastic waste, anaerobic digestion, and food supply chain.

4. Discussion

Based on the groups identified through a bibliography of 1842 selected articles from six fields, the proposed framework for a circular economy and sustainability-oriented innovation is presented in Figure 8. In general, circular economy and sustainability-oriented innovation relies on establishing strategic options and taking a multi-level approach that incorporates stakeholders into the practice of a circular economy [9].

This strategy enables the exchange of knowledge, provision of higher quality raw materials, and the adoption of technology and information that enables faster transitions for companies to build appropriate conditions to seize opportunities and develop a circular economy and sustainability-oriented innovation. The impact of this provides an environmentally oriented development pattern to spread the proposition of environmental values globally and to innovate, in a sustainable manner, towards the achievement of sustainable development goals (SDGs).

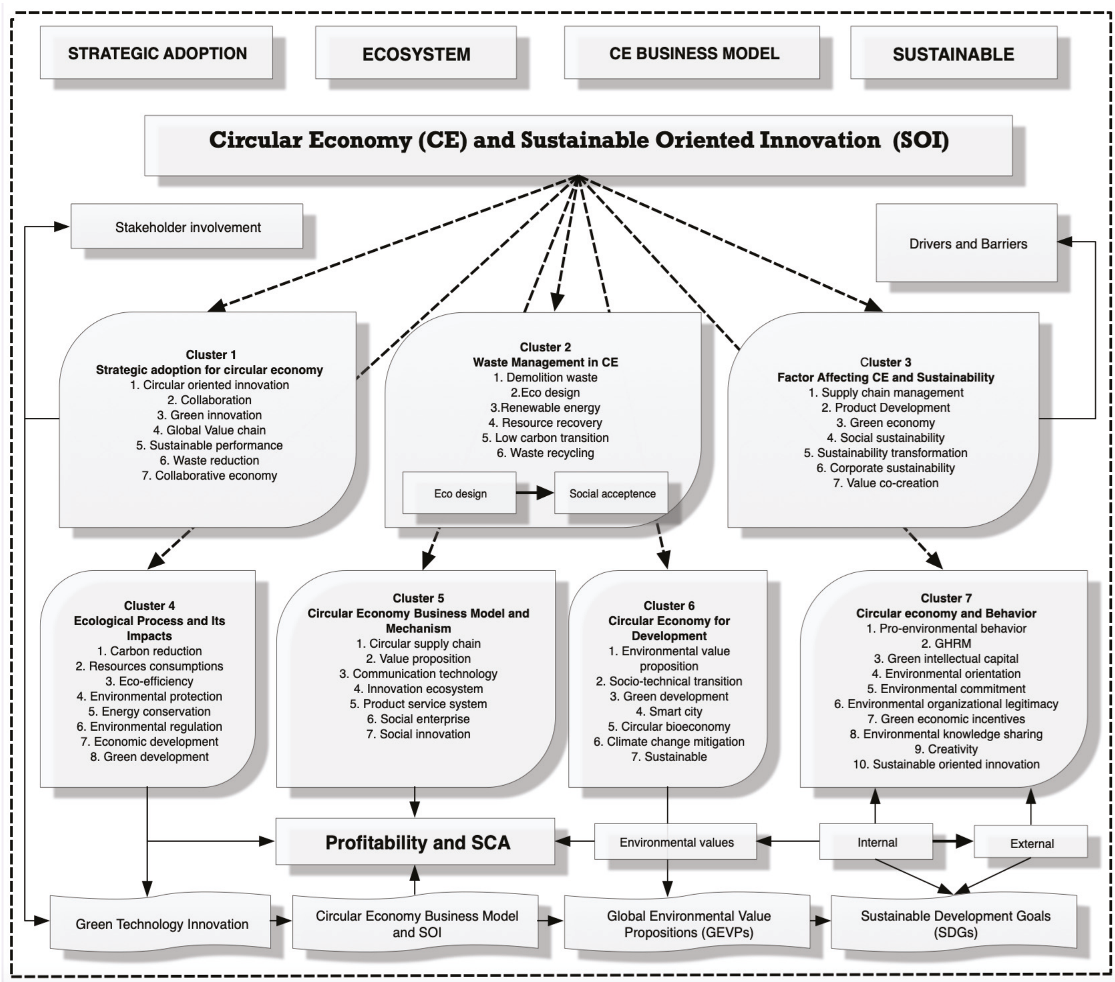

Figure 8. Framework for examining sustainability-oriented innovation in circular economy.

5. Considerations and Research's Future Line

The circular economy provides a fundamental input for creating sustainability-oriented innovation in this transitional model. Waste management, green product development, pro-environmental behavior, and green technology are the main drivers that form the basis for the transition to a sustainability-oriented innovation model. The fundamental dimensions of circular economy and sustainability-oriented innovation are behavior that manifests in the form of green human resource management, green intellectual capital, environmental orientation, and environmental commitment. Green behavior is the backbone of how the circular economy can be applied to build sustainability-oriented innovations. In addition, it is necessary to strengthen communication for knowledge transfers so as to increase creativity [105,106].

At this stage, it is necessary to pay attention to various obstacles such as a system that does not support a circular economy, has limited resources, and exhibits resistance to technology. As such, companies that are able to explore all green behaviors will have long-term environmental strategies and establish environmental organizational legitimacy. Regarding waste management, companies need to design environmentally friendly products and implement eco-designs and even waste recycling. In this stage, the process starts from the determination and selection of raw materials so as to reduce production waste [107,108].

This study seeks to identify the various conditions necessary to advance sustainability-oriented innovation through the circular economy. The number of articles in each cluster of bibliographic coupling shows that the literature recognizes the importance of the interaction between stakeholder engagement, waste management, and the identification of factors in the circular economy (clusters 1–3). However, other emerging topics, reflected in clusters 4–7, are also worth considering and developing, such as ecological processes and their impacts, circular economy business model mechanisms, and circular economy business model for development. As such, an exploration of dynamic resource capabilities and internal resources and activities is needed to take advantage of opportunities to strengthen sustainability-oriented innovation.

In addition, the literature shows the need to expand research on sustainability-oriented innovation in a circular economy to all industrial sectors given that many studies focus on specific sectors, such as manufacturing and sectors dealing with biological cycles. There is a need to research all industry sectors, as this represents a more efficient and effective way to introduce innovations and identify new market opportunities. Opportunities for the circular economy will enable a more rational use of raw materials and energy sources. Moreover, overall, the studies only focus on European countries, so there is a need to explore developing countries and capture differences due to regulations, social and cultural conditions, markets, and technology. The role of consumers in sustainability-oriented innovation also needs serious attention because they are the main contributors and users of environmentally friendly products. Finally, we suggest a longitudinal study to conduct empirical studies of organizations that are adopting circular economy and sustainability-oriented innovations around the world. The transition to clean energy through the use of sustainability-oriented innovation and the introduction of sustainable energy technology in the context of a circular economy can help reduce greenhouse gas emissions in industries.

This study also succeeded in identifying organizational internal factors, such as campaigning for pro-environmental behavior, implementing green human resource management, green intellectual capital, environmental orientation, environmental commitment, and creativity. While they are external factors, more emphasis is placed on optimizing green economic incentives and environmental knowledge sharing towards environmental organizational legitimacy. Finally, this study maps out the main topics in the literature at the intersection between sustainability-oriented innovation and themes related to the circular economy so that it is expected to serve as a starting point for conducting future research (Table 1). This study differs from previous systematic reviews, primarily in the extent and temporal range of the articles analyzed, including a large number of recent articles that convey the increasing prominence of this theme. However, utilizing only one database is a limitation that may have prevented the inclusion of relevant research studies.

Table 1. Suggestion for future research.

No	Clusters	Suggestions for Future Research
1	Strategic adoption for circular economy	Strengthening collaboration between parties Conducting empirical studies on global value chains and the drivers Examining the relationship between green innovation, waste reduction and sustainable performance
2	Waste management in circular economy	Research regarding nexus between eco-design and waste recycling for resource recovery Expanding the research sample to be able to generalize the results
3	Factors affecting CE and sustainability	Carry out research that focuses on product development and value co-creations Mapping resources and capabilities to build a green economy
4	Environmental process and its impact	Verify the impact of carbon reduction on energy conservations Examine the relationship between environmental regulation, economic development, and green development in various sectors Testing the impact of ecological processes on sustainable development
5	CEBM and mechanism	Investigation of technology adoption, circular supply chain and social innovation in building an innovation ecosystem Examining product service system and social enterprise
6	CE for development	Investigate environmental value proposition and circular bioeconomy and sustainable energy transition
7	CE and behavior	Identify key competencies, specific resources, and capacities Investigating customer perception about companies that implement sustainability-oriented innovation (SOI) Researching the role of knowledge sharing in strengthening collaboration and CE practice

6. Conclusions

This study produces three main conclusions that are useful in increasing understanding of the circular economy and sustainability-oriented innovation. First, this study succeeded in mapping 1832 articles on circular economy and sustainability-oriented innovation into seven main clusters. Cluster 1 is about strategic adoption with a total of seven keywords, which contains organizational efforts to collaborate to strengthen the mechanisms for building infrastructure to strengthen the circular economy. Collaboration will have implications for strengthening social capital and exchanging knowledge so as to produce important ideas that are useful in developing environmentally friendly programs. Cluster 2 discusses waste management with six main parameters, while cluster 3 discusses factors affecting the circular economy and sustainability with seven main indicators. Meanwhile, cluster 4 reveals the ecological process and its impact on achieving green development with eight parameters. Furthermore, cluster 5 discusses the circular economy business model and the mechanisms in it, including seven important indicators from the circular supply chain to social innovation. Cluster 6 discusses the topic of circular economy for energy development with seven main parameters. Finally, cluster 7 reveals the circular economy and behavior that supports pro-environmental behavior, environmental legitimacy, and sustainability-oriented innovation.

Second, research on the circular economy and sustainability-oriented innovation concentrates on three main topics, namely business model, transformation, and behavior. These three topics provide opportunities for understanding how the circular economy business model provides insight into all the industrial sectors make efforts to preserve the environment by changing strategies, mechanisms, and routine activities that are environmentally friendly.

This transformation requires the contribution of all elements of the organization, an innovative approach and the achievement of the vision, mission, and objectives of the organization. Finally, the transformation from a linear economy to a circular economy requires a behaviorally relevant approach. Recognizing that environmental conservation is a complex construct, the smallest changes start from the individual aspects of the organization. If each individual has the characteristic of pro-environmental behavior in routine activities, it will form an environmentally friendly organizational culture, environmentally oriented environmental strategies, and strategic planning.

Third, we recommend a total of 16 future agendas from seven clusters resulting from this systematic literature review. Thus, this study is expected to be a starting point and a reference for empirical research conducted in the future. All the ideas expressed based on the seven clusters are strategic efforts to improve the quality and quantity of research on the topic of the circular economy and sustainability-oriented innovation. By identifying various research agendas and opportunities for collaboration, citation and expanding expertise will be achieved towards sustainable development goals.

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An Integrated Methodology for Scenarios Analysis of Low Carbon Technologies Uptake towards a Circular Economy: The Case of Orkney

Selman Sevindik * and Catalina Spataru

Energy Institute, Bartlett School Environment, Energy and Resources, University College London, London WC1E 6BT, UK
* Correspondence: s.sevindik@ucl.ac.uk

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Abstract: This study aims to create a comprehensive, holistic approach to evaluate the environmental, energy, and economic impacts of air source heat pump deployment scenarios through: (i) a life cycle assessment of air source heat pumps in Orkney houses, (ii) energy systems optimisation modelling to optimise the performance of an air source heat pump coupled with thermal energy storage tank to reduce use phase related impacts in Orkney, (iii) modelling of Orkney's domestic building stock to understand the housing condition, and (iv) economic modelling to analyse the life cycle cost of an air source heat pump and potential savings when replacing conventional heating systems. The results show that an 82% reduction in energy supply could be achieved when ambitious energy efficiency improvement measures are adopted in the circular economy scenario. The use phase related emissions could be reduced by 98% when the air source heat pump becomes the only heating technology in Orkney. However, the life cycle-wide approach suggests that strong commitments are required in the manufacturing stage of these technologies through implementing circular principles, such as including the use of secondary materials, eco-design, and reusability of all components. Moreover, total heating costs paid by consumers in Orkney could be reduced by 84% in the circular economy scenario when air source heat pump uptake is coupled with energy efficiency improvement measures, but it requires a £130 million investment to insulate the whole housing stock of Orkney. Future scenarios indicate that decision-making has significant importance on overall results. Therefore, circular economy standards for air source heat pump manufacturing and deployment are crucial to reduce the negative impacts of fuel poverty and reach the net zero target.

Keywords: circular economy; energy systems modelling; islands; life cycle assessment; low-carbon heating

1. Introduction

The Intergovernmental Panel on Climate Change [1] declared that achieving the Paris Climate Agreement target of limiting temperature increases to 1.5 °C requires exceptional actions. As countries face increasing challenges due to the scarcity of resources and dependence on raw materials, while carbon emissions reduction targets need to be met, CE could help move from a traditional linear take, make, and waste economy to a circular model.

The UK is the first country to set legislation to achieve 'Net Zero' greenhouse gas (GHG) emissions by 2050 [2]. This requires strong commitments to avoid further delays in reducing emissions. The built environment in the UK represents 30% of the total emissions [3].

The heat pump market has been growing gradually and reached 10% of the global building heating demand in 2021 [4]. Heat pump sales in Europe reached 7 million units in 2021 led by France with 537,000 units per year [5]. In the UK, yearly heat pump uptake is lower when compared with European countries (43,000 in 2021). The UK government aims to reach 600,000 heat pump installations per year by 2028 [6]. The Climate Change Committee suggest that this number should reach 1 million installations per year by 2030 to track UK's Net Zero pathway. The UK government introduced the Boiler Upgrade Scheme

(BUS) in 2020 to accelerate this transition by providing a grant of £5000 for heat pump installations [7]. The Scottish Government granted a slightly higher subsidy named the Home Energy Scotland (HES) loan providing a cashback of up to £7500 and an interest-free loan for the rest of the costs of up to £2500 for heat pumps [8].

The Paris Agreement declared that the reliance on fossil fuels and energy imports makes islands vulnerable to climate change. The price cap for heating homes in Shetland and Orkney islands is the highest two figures with 107% and 96% more than the average price cap in 2021 with the highest annual energy bills among UK local authorities [9]. Orkney is an archipelago in the Northern part of Scotland. Even though Orkney generates its electricity from local renewable sources, electricity prices are assumed to be 2.5 pence higher than southern Scotland values [10]. Orkney's Fuel Poverty Strategy report indicates that 63% of households are living in fuel poverty in Orkney due to higher heating costs, older housing stock conditions, lower average income, and a long winter season with strong wind speeds [10].

Buildings are responsible for 35% of the energy use after transport (45%) in Orkney [11]. The majority of building-related energy consumption occurs in the domestic sector. The main fuel types used for heating are electricity and oil with 52% and 43%, respectively. The amount of electricity generated from renewables was more than the island's need in 2016 [12]. Therefore, there is a transition for electrification in heating. The number of all heat pump types deployed in 2021 was more than 1000 which accounts for 117 heat pumps per 1000 households [13]. This is the second-largest heat pump uptake among the Scottish local authorities. Therefore, this study aims to take an integrated approach to investigate the environmental impacts of replacing conventional heating systems with heat pumps by combining life cycle assessment with energy systems optimisation modelling (ESOM). A multi-level assessment framework helps to identify energy, environmental, and economic savings of individual heating technologies by house archetypes and cumulative savings for the island level in line with the UK's net zero target. Orkney was selected as a case study to analyse the existing electrification of heating trend and potential future decarbonisation scenarios towards a CE.

2. Literature Review

Life cycle assessment (LCA) and energy systems optimization modelling (ESOM) methodologies are widely used individually. Studies about ESOM and LCA suggest different frameworks, however, they share a common interest in CE principles. The integrated application of these methods has also been investigated in the literature previously to provide a comprehensive approach [14]. A very recent case study by Quest et al. [15] examined integrating life cycle assessment with energy system modelling. The operation of different heating and power systems is optimized with the energy model and their environmental impacts are evaluated with LCA. The optimization scenario offered a shift from the gas boiler to CHPs, heat pumps and PV systems. The results show that a nearly 40% reduction in GHG emissions is expected in the cost-optimized scenario and a more than 50% reduction in the CO2-optimised scenario. Ecotoxicity results expect a 22% increase due to oversized battery storage. Hybrid applications of solar technologies with heating and cooling systems are investigated in a recent study [16]. A multi-objective optimization model is coupled with the life cycle assessment methodology to assess the solar-assisted natural gas combined cooling, heating, and power (CCHP) system. The results show that solar collectors help to reduce acidification impact by 6.7% and respiratory effect by 28.4%. The environmental impacts of electricity production technologies in Spain are investigated by Garcia-Gusano et al. [17]. The TIMES model is used to create future scenarios and LCA provided environmental impacts based on these scenarios. The results show that the 80% reduction scenario has higher environmental impacts than the BaU scenario due to the higher deployment of renewables. Metal requirements for solar PV and wind turbines create ozone depletion and acidification problems. However, damage to human health and ecosystems is reduced by phasing out fossil fuels. Pietrapertosa et al. [18] created a framework for the integration of LCA, ExternE (Externalities of Energy), and comprehensive analysis (a bottom-up model) to investigate energy systems. This approach has been applied to a case study in Italy where authors investigate the environmental impacts of sustainable strategies adopted in energy systems. The results show that renewable technologies are crucial for future energy supply systems. However, more focus should be given to the manufacturing and disposal phases of these technologies.

The circular economy (CE) definition has been widely used in the literature. Several studies have systematically reviewed the literature to identify CE features and perspectives [19–23]. Implemented studies and concepts on different levels (macro, meso and micro levels) are analyzed based on the CE framework. According to a review study conducted by Kirchherr et al. [24], the CE system aims to replace end-of-life operations with reducing, reusing, recycling, and recovering material usage in the production and consumption stages. The perception of CE also differs among people. Some authors in the literature equate the CE concept with 'recycling' and some of them neglect 'reduce' in their definitions. The waste hierarchy is not clarified in one-third of the definitions, and more than half of the definitions are lacking systems perspective. On the other hand, economic prosperity is seen as the dominant perspective among previous studies, whereas more focus should be given to the environmental implications and social aspects. Only one out of five definitions include the consumer as an enabler of CE so more emphasis should also be given to the end-user side of the system. Karali and Shah [25] investigated the collection and recycling strategies for critical raw materials for low-carbon technologies from a circular economy perspective. The results show that end-of-life recovery will still be limited in 2050 when the current practices continue. However, enhanced collection and recycling could provide 37–91% of critical material demand through secondary materials. Moreover, recycling low-carbon technologies could also provide potential economic value and employment opportunities. EU's 'Circular Economy Action Plan' has been utilized to create a circular ecosystem for Scotland in a previous study [26]. Implementing this action plan at a national or regional level could help to accelerate the transition into a circular economy. The study has defined twelve actions under four thematic areas: business, support, and finance; skills and education; promotion and awareness; and policy and regulation.

Integration of LCA and ESOM methods was investigated in the literature [14–18]. Most of the studies focused on the environmental impacts (mainly GHG emissions) of energy production technologies on a larger scale at the supply side of the system [17,18]. Some studies focus on individual low-carbon heating technologies [15,16] without assessing overall impacts. The lack of a methodological approach which does not accommodate system thinking creates difficulties between actors and the consistent development of circular practices. On the other hand, national targets on decarbonizing heating require strong commitments in terms of electrification of heating by heat pumps and energy efficiency improvements of houses. However, a holistic approach considering the end-user side by investigating archetype-level savings and system thinking with achieving macro-level targets is needed. This research advances the current literature of specialty by combining LCA with ESOM, considering a number of archetypes for the building stock and assessing the impact of ASHP at the macro level (in this case Orkney).

3. Methods

This study aims to create a comprehensive integrated methodological approach to support the UK's net zero target, which sets ambitious requirements in terms of decarbonising space heating. The method consists of the integration of four different models that inform each other (Figure 1):

(i) a building stock model (BSM) of Orkney's domestic sector to understand the housing stock condition and evaluate the energy efficiency improvement (EEI) requirements,
(ii) a life cycle assessment (LCA) of low-carbon heating technologies (in this case ASHP) utilised in the Orkney houses for decarbonisation,

(iii) an energy systems optimisation modelling (ESOM) to optimise the performance of an ASHP coupled with a thermal energy storage (TES) tank for Orkney houses and
(iv) a life cycle cost (LCC) of technologies to create a holistic approach for Orkney as described in Sections 3.1–3.4. The connections between the methods is depicted in Figure 1.

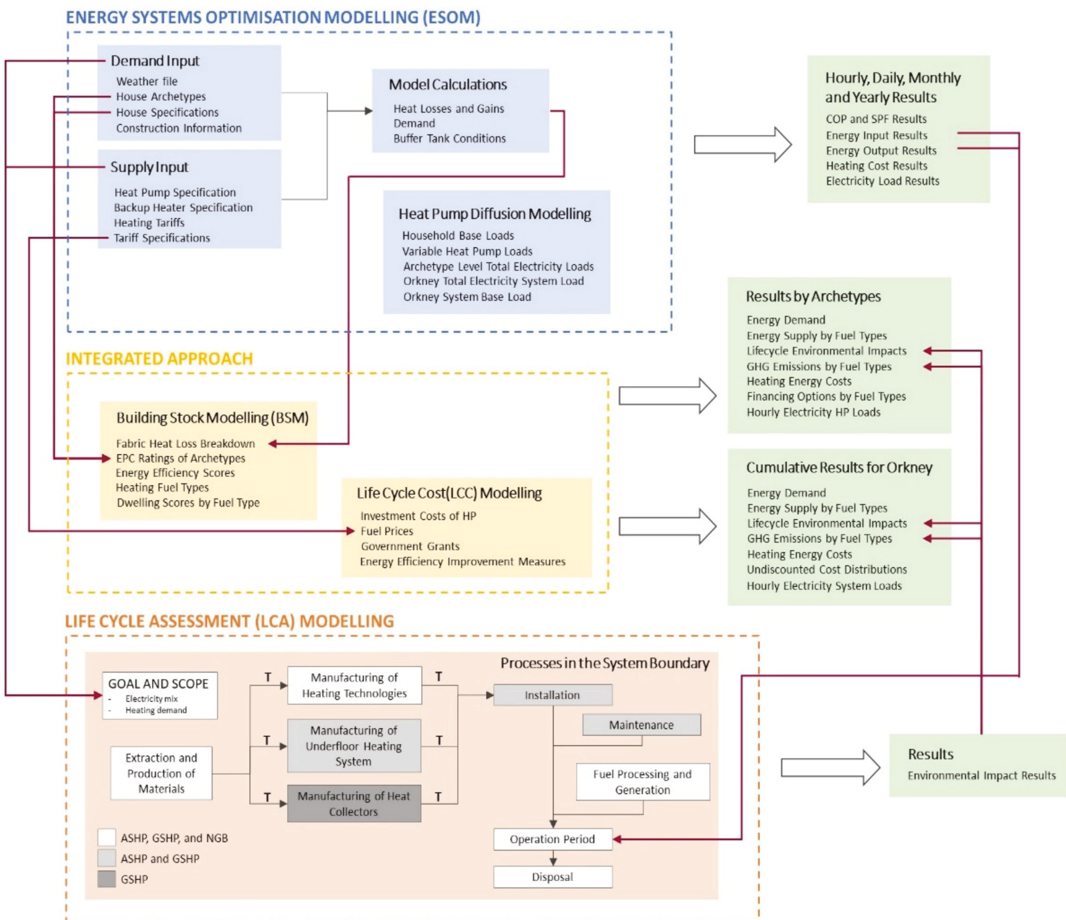

Figure 1. A schematic diagram of the proposed integrated approach.

First, individual energy, environmental, and economic results of different archetypes are calculated. Then, cumulative results for Orkney are calculated by multiplying the individual results by the number of archetypes and heating types for the baseline model based on BSM results. Finally, a scenario analysis is conducted to compare overall results for the current situation with future scenarios to analyse energy, environmental, and financial savings. In this study, only an ASHP is considered for the analysis for simplicity. However, the study can be extended to other heat pump typologies and heating technologies. Two scenarios have been developed for the year 2050 (Section 3.5).

3.1. Building Stock Modelling (BSM)

Energy Performance Certificates (EPC) assess the energy efficiency of a building and include information about recommended improvements [27] showing the current and potential energy rating of a property named as Standard Assessment Procedure (SAP). The overall EPC rating is comprised of walls, roof, floor, windows, hot water, lighting and heating efficiencies, and has 7 bands ranging from A to G with a certain amount of SAP points out of 100 points as a maximum [27].

EPCs provided by Scottish Government Statistics [28] have been used to explore Orkney housing stock in terms of archetype, age and efficiency. Orkney has 11,228 dwellings and the majority of them are detached houses with 59.8% of the total followed by semi-detached, terraced, and flats with 22.1%, 11.1%, and 6.9%. The EPC dataset has 1740 dwellings representing 15% of the total housing stock but the share of detached houses in this dataset is around 75% which is greater than real data. The EPC dataset has been used for archetype characteristics and specifications.

Some elements of the EPC calculated by SAP are directly linked to the heating demand such as walls, roof, floor, and windows efficiencies. Therefore, these categories are investigated to understand the heat loss condition in the housing stock. The dataset has five efficiency categories as 'very poor', 'poor', 'average', 'good', and 'very good'. These categories are represented with numeric values (1, 2, 3, 4, and 5 respectively) to calculate the average efficiency score of the construction element and the overall efficiency score of the housing stock.

The average efficiencies of individual construction elements (walls, roof, floor, and windows) are calculated and illustrated in three categories based on their scores (1.0–3.5, 3.5–4.5, 4.5–5.0) to represent 'unrefurbished', 'refurbished', and 'new building' categories used in energy modelling. However, the impact of individual construction elements varies in different archetypes and building specifications. Therefore, while calculating the overall efficiency score of the house, the weight of the construction element has been altered as in the following equation:

$$E_{overall} = (E_{wall} \times W_{wall}) + (E_{window} \times W_{window}) + (E_{roof} \times W_{roof}) + (E_{floor} \times W_{floor}) \quad (1)$$

where E refers to efficiency and W is the weight of the construction element in different house archetypes which is calculated in the energy model and illustrated in Section 4.1.

3.2. Energy Systems Optimisation Modelling (ESOM)

A heat pump diffusion model has been developed to explore the potential uptake of heat pumps and quantify the impact on the electrical load at the dwelling and island level for Orkney to help assess the transition from fossil fuels to electricity. The model considers different building archetypes (detached, semi-detached, end-terraced and mid-terraced), building specifications (unrefurbished, refurbished, new building), heat pump sizes (8.5 kW, 11.2 kW, 14.0 kW), TES tank sizes (250 L, 500 L, 750 L, 1000 L), flow temperatures (35 °C, 45 °C, 55 °C), backup heater settings (gas boiler as a backup heater, no backup heater), and electricity tariffs (Standard, Economy7, Comfy Heat, Economy12, Economy20), each of them being modelled as in [29]. We assume the heat pumps have a variable operation pattern, where variable load curves are used for the analysis. The model calculates hourly heat pump electricity loads, so an electricity load profile study is conducted to investigate the Orkney grid level.

The time resolution of weather data (outside temperature and solar radiation) has been scaled to hourly for a high temporal resolution. Thermal bridging, internal gains, thermal mass, and standing loss for TES tank calculations are included in the model. Heat pump specifications for different sizes and flow temperatures are taken from the manufacturer's website. Hourly heat pump maximum, medium, and minimum capacities and COP curves are calculated based on outside temperature and flow temperature.

Hourly outdoor temperature and solar irradiation data have been collected from Renewables.ninja to calculate heat gains and losses [30]. The internal thermostat set point temperature is specified as 21 °C based on recommendations from the World Health Organization [31] and Public Health England [32]. A number of archetypes have been identified to represent the housing stock ('detached', 'semi-detached', 'end-terrace' and 'mid-terrace') based on BSM results. These archetypes are used to analyse the variation of heating technologies' performance with different physical properties.

EPC data [28] were used for information about the gross floor area of the houses, the number of storeys, room height and occupancy. Glazing ratio information and building thermal properties data were taken from The Building Regulations Approved Document Part L1A [33]. The houses are named into three categories 'refurbished', 'unrefurbished' and 'new building'. Data on domestic hot water (DHW) consumption, distribution of DHW throughout the day, and heating patterns were taken from Energy Saving Trust's report [34]. The Government's SAP for Energy Rating of Dwellings [35] was used for generic values (plan aspect ratio, floor thickness, etc.).

Electricity and gas tariff data were collected for 6 different tariffs. Standard and Economy7 tariff was gathered from ScottishPower [36] to analyse Orkney electricity prices. Moreover, tariffs which are not yet available on Orkney such as Economy12 [37], Economy20 and Comfy Heat [38] also analysed to investigate different options. The peak time prices for Economy7, Comfy Heat, Economy12, and Economy20 tariffs are identified as 20.8 p, 15.7 p, 20.7 p, and 16.3 p. Off-peak tariffs are identified as 9.0 p, 8.6 p, 8.6 p, and 11.4 p, respectively. Standing charges are also identified as 23.9 p, 20.3 p, 18.0 p, and 46.9 p, respectively. Standard electricity tariff and gas prices are identified as 16.5 p and 3.2 p for unit prices and 23.8 p and 23.3 p for standing charges (Appendix B, Table A1).

The distribution of off-peak and peak hours during the day was identified according to tariff options. Standard tariff assumes that there is no peak time pricing so standard pricing is assumed as an off-peak tariff. Economy7 tariff assumes 7 h of off-peak time during the night. The number of off-peak hours is very similar in the Comfy Heat tariff with 8 h, but they are distributed throughout the day with 4 h during the night and 4 h during the day. Economy12 and Economy20 tariffs have 12- and 20-h off-peak time with 2 h during the day and the remaining during the night (Appendix B, Table A1).

TES tanks store energy in required times and help to avoid overpricing in peak times. Therefore, four different sizes of TES tanks (250 L, 500 L, 750 L, and 1000 L) are tested in the model to explore lower peak time heating costs. Standing losses are calculated based on SAP document [35] and Hot Water Association [39] methodologies. In terms of the backup heater, both electricity and natural gas-fired heaters are tested. It has been assumed that a condensing gas boiler has a 15 kW size capacity with 90% efficiency, and the electric heater has an 8.5 kW size capacity. In scenario analysis, the performance of the heat pump is tested with and without these backup heaters in operation.

There are various heat pump types. ASHP has been selected in the modelling for its wide range of use and less space requirement during installation. Mitsubishi Ecodan PUZ series are selected because of using R32 (low GWP and Ozon Depletion potential) to explore various heating performances [40]. However, the PUHZ series is also investigated to test the impact of using a different refrigerant (R410) on energy performance. To select the correct size of the heat pump, three different sizes are explored, namely 8.5 kW (PUZ85), 11.2 kW (PUZ112), and 14.0 kW (PUZ140). COP and capacity data under different outdoor temperature conditions and water outlet temperatures (35 °C, 45 °C, and 55 °C) are calculated hourly in the model. These figures illustrate that the PUZ series provide higher capacities and COP values under the same flow temperatures. Moreover, the PUZ series has an R32 type of refrigerant, which has a lower environmental impact. Therefore, the PUZ series are selected for scenario analysis.

A heat pump diffusion model [41] quantifying the impact of installing ASHPs on the electrical load curves at the dwelling and UK levels was integrated into this research. Data for Orkney electricity system load were taken from Scottish and Southern Electricity Networks [42]. Average household level hourly electricity load structures were taken from a study conducted by Intertek [43] for various types of household settings including with/without electricity heating. Heating-related loads were taken from the total values so the impact on dwelling and grid level load curves are calculated. The loads are calculated for the coldest winter workday and holiday to investigate.

The model calculates heat gains and losses to analyze the performance of the dwelling. Fabric heat loss, ventilation heat loss, thermal bridging, solar gains, internal gains, and thermal mass properties are calculated based on SAP methodology (Appendix A—Equations (A1)–(A16)). TES tank temperature is calculated as in the following equations:

$$\sum DDHW = V_W \times 4.18 \times T \tag{2}$$

$$H_R = \sum Ltotal - \sum Gtotal + \sum DDHW \tag{3}$$

$$\begin{array}{ll} \text{if } T_{TS} > 5 + T_e & T_{TE} = T_{TS} - \frac{\sum H_R}{V_T \times 4.18} - \frac{\sum H_P}{V_T \times 4.18} - L_S \\ \text{if } T_{TS} \leq 5 + T_e & T_{Ts} = T_e \end{array} \tag{4}$$

where D_{DHW} is DHW demand, V_W is the volume of the water (litre), T is required water outlet temperature (°C), H_R is required heat, L_{total} is total losses (W), G_{total} is total gains (W), T_{TE} is tank end temperature, T_{TS} is tank starting temperature, T_e is external temperature, H_P is provided heat with heat pump and backup heater, V_T is tank size (litre), and L_S is standing loss (°C) of the tank. Standing loss is calculated as in the following equations:

$$L_S = f_V \times f_T \times f_C \times V_C \tag{5}$$

$$f_V = (120/V_C)^{\frac{1}{3}} \tag{6}$$

$$f_C = (0.005 + 0.55/(t+4) \tag{7}$$

where L_S is the standing loss of the cylinder tank, f_V is the volume factor, f_T is the temperature factor, f_C is the cylinder loss factor, V_C is cylinder tank volume (litre), and t is insulation thickness (mm). The heating schedule is decided as maximizing heat pump operation during off-peak times and avoiding gas boiler usage, and then minimizing heat pump operation during peak times and covering the remaining demand with a backup heater. The model calculated heat pump and backup heater capacities as in the following equations:

In peak times;

$$\begin{array}{ll} \text{if } C_{MIN} \geq H_R & E_P = C_{MIN} \\ \text{if } C_{MIN} < H_R & E_P = C_{MID} \end{array} \tag{8}$$

$$\text{if } T_E < T_L \qquad \text{HP} \geq \text{ON} \tag{9}$$

In off-peak times;

$$E_P = C_{MAX} \tag{10}$$

$$\text{if } T_E > T_H \qquad \text{HP} \geq \text{OFF} \tag{11}$$

At all times;

$$\text{if } T_E < T_B \qquad \text{Backup} \geq \text{ON} \tag{12}$$

where C_{MIN}, C_{MID}, and C_{MAX} are minimum, medium, and maximum heat pump capacities, H_R is required heat demand, E_P is provided energy, T_E is the end temperature of the tank, T_L is the lower threshold temperature, T_H is the higher threshold temperature, and T_B is the backup temperature.

3.3. Life Cycle Assessment (LCA) Modelling

A previously modelled LCA study [44] was adapted to evaluate the environmental impact associated with heat pumps in house archetypes in Orkney. The functional unit of the study is decided as generating the required thermal energy for house archetypes in Orkney during the lifetime of an ASHP which is assumed as 20 years. The amount of energy required for different house archetypes is calculated in the energy model. The LCA software SimaPro 8.0.3 [45] was used to model the products and the ReCiPe Midpoint (H) method [46] was used to calculate environmental loads. The model assumes that ASHPs are manufactured in Europe and transported to Orkney. Currently, Orkney produces a surplus of renewable electricity from wind and tidal sources, and the electricity mix in

Orkney comprises 100% renewable energy sources. Therefore, this electricity mix is used in LCA [12]. Electricity demand varies based on archetypes and their specifications. Therefore, environmental results for these individual archetypes are calculated.

3.4. Life Cycle Cost (LCC) Modelling

Existing heating fuel types (oil, coal, LPG, wood, electricity), fuel prices, investments costs, discount rate, and lending rate information are included in the model to calculate savings coming from the transition to heat pumps. Different financing alternatives, including support from the government (BUS/HES), are also investigated at both the archetype level and the island level. In this section LCC analysis of a heat pump is calculated based on baseline model results. Then, results for CE and resource efficiency (RE) scenarios are analysed for future results.

The cost of installing heating measures is analysed by Delta-EE [47] for different heating types including heat pumps. An existing report from the Carbon Trust [48] investigates the overview of heat pump retrofit in London through 15 case studies and CO_2 savings and cost analysis. Nesta and BIT have several economic and social studies on heat pumps about reducing the cost of heat pumps, increasing end-user awareness and policy review [49–51]. In line with these studies and market research, the upfront cost of an ASHP is assumed as £9250, £10,250, and £12,000 for 8.5 kW, 11 kW, and 14 kW sizes of heat pumps (Table 1) (these costs include buffer tank costs as it was investigated in energy model). The upfront cost is assumed as £9250 for houses in the new building category, and £10,250 for the remaining house specifications except for unrefurbished, detached houses. As detached houses have higher demands than remaining archetypes £12,000 upfront cost is assumed for a larger size of a heat pump. Future cost reductions for heat pumps are expected by DECC [52] for a mass market scenario. Therefore, 10% and 20% cost reductions are assumed for RE and CE scenarios. Average lending rates and discount rates for a 15-year period are decided from market research and quotes from providers.

The Boiler Upgrade Scheme (BUS) replaces the Renewable Heat Incentive (RHI) and provides a grant of £5000 for the upfront cost of an ASHP [53]. Similar to this support, the Scottish Government provides a loan for EEI measures and renewable heating systems, including cashback payments [8]. The government can provide a £2500 interest-free loan and £7500 cashback (£10,000 in total) for an ASHP installation. The unrefurbished, detached house is the only category which has more than £10,000 upfront cost so the interest-free loan is not limited to £2500 in this study for simplicity. These support measures are also included in LCC calculations. The results are expressed in discounted costs at an annual rate of 3.5% [54].

Data for fuel prices of energy sources used in Orkney were collected from previous studies and quotes from suppliers. BEIS [55] provides historical data for fuel prices and future trends. National Infrastructure Commission [56] researched the current fuel prices for the year 2050. With the help of these reports and market research from suppliers, the fuel prices for the baseline scenario, RE scenario, and CE scenario are identified [55–58]. LPG, oil, coal and wood prices are identified as 6.3 p, 5.2 p, 4.7 p, and 5.3 p, respectively. Standard electricity tariff price is identified as 16.5 p, and Comfy Heat tariff is identified as 8.6 p, 15.7 p, and 20.3 p for off-peak, peak, and standing charge prices (Appendix B, Figure A1). Fossil fuel prices are expected to increase in the future with carbon taxes, and electricity prices to decrease [57].

Specification and EEI conditions of construction elements in house archetypes are analysed in Orkney (Appendix C, Figure A2). Many of the houses require external wall insulation when needed which is around 45% of the total housing stock. Cavity wall insulation accounts for 30% and internal insulation for 3%, respectively. Moreover, 22% of the housing stock does not have any specified construction type, whereas they are classified under the new building category, so they do not require any wall insulation. The dominant potential insulation type in refurbished detached houses is cavity insulation. Further, 54% of the total housing stock has double-glazed windows. High-performance windows only exist in the new building category, so they do not require any efficiency improvements. In terms of roof insulation, loft insulation is the dominant potential insulation type. However, 11% of houses require flat roof insulation. Underfloor insulation is the only option for the floor category and the majority of refurbished houses and all unrefurbished ones require floor insulation.

Table 1. Summary of assumptions for life cycle cost analysis and future scenarios.

	Baseline	RE	CE	References
Upfront Cost (8.5 kW)	£9250	£8325	£7400	
Upfront Cost (11 kW)	£10,250	£9225	£8200	[47–49,51,52,59,60]
Upfront Cost (14 kW)	£12,000	£10,800	£9600	
Upfront Cost Change	0%	−10%	−20%	[52]
Lending Rate	3.0%	2.8%	2.5%	
Discount Rate		3.5%		[54]
Period		15 years		
BUS		£5000		[53]
HES		£7500		[8]

The cost of efficiency improvement steps for each construction element is identified by house archetypes. While deciding on the insulation type, the dominant construction element is selected. The highest installation cost occurs in unrefurbished detached houses with £22,100 followed by semi-detached and end-terraced houses with £16,325 and £15,525 respectively. Mid-terraced houses require less wall insulation area. Therefore, the total cost is relatively low (£9425) when compared with other archetypes. External wall insulation is the major contributor to the costs in all archetypes except mid-terraced houses. Replacing windows dominates the wall insulation in mid-terraced houses as they have less wall area exposed to outside conditions. Refurbished houses also require some improvements to reach the new building category which includes secondary glazing to have higher insulation on windows, drought proofing, and further insulation on roofs and floors. The installations costs for detached, semi-detached, mid-terraced, and end-terraced houses are £9000, £7075, £6675, and £4975, respectively (Appendix C, Figure A3). The efficiency improvement costs are included in the LCC analysis for a broader perspective on the housing stock condition.

3.5. Proposed Scenarios

Two scenarios have been developed for the year 2050. Only the case of ASHP is considered for the analysis for simplicity. However, the study can be extended to other heat pump typologies and heating technologies.

Baseline Scenario: It represents the current situation at Orkney. The number of heat pumps deployed on the island is around 1050 (representing one-tenth of total dwellings). The number of dwellings and fuel types of house archetypes and specifications for the scenarios are provided in Figure 2.

Resource Efficiency (RE) Scenario: A reduction in energy demand is expected but this decrease is lower than the CE scenario. EEI applications are limited. RE scenario assumes that 75% of fossil fuel heating technologies will be replaced with heat pumps. EEI measures are taken for 75% of unrefurbished and 25% of refurbished houses. Half of the new dwellings constructed before 2050 are assumed to be in the new building category and those remaining are in the refurbished category, all of which use heat pumps for space heating.

Circular Economy (CE) Scenario: High technology development and high consumer engagement are supported by policies. Therefore, more efficient houses and low-carbon technologies portend a reduction in energy demand. The uptake of heat pumps reaches 100% to achieve UK's Net Zero target. CE scenario assumes more ambitious numbers to achieve UK's Net Zero target. All of the heating technologies will be replaced by heat pumps in this scenario. The majority of the new dwellings (75%) constructed before 2050 will be in the new building category and the remaining will be in the refurbished category. CE scenario assumes higher EEI measures taken with 100% heat pump uptake

Note: RE and CE scenarios expect an increase of around 2000 in the total number of dwellings (from 11,227 in the baseline model to 13,313 in the year 2050) in line with the historical trend.

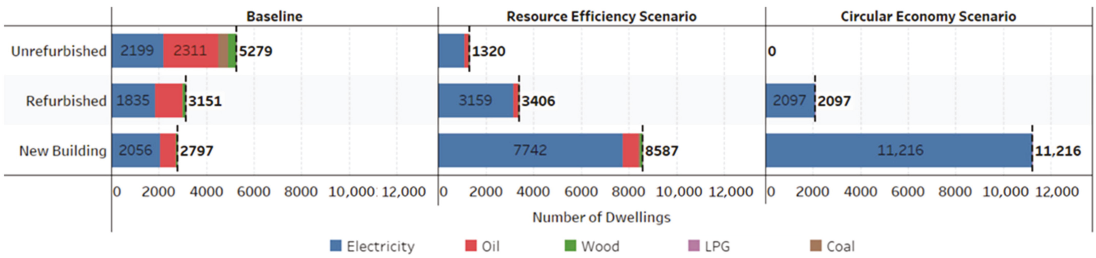

Figure 2. Number of dwellings and fuel types by house archetypes and specifications for baseline and future scenarios.

4. Results

4.1. Building Stock Modelling (BSM) Results

BSM results illustrate that most of the houses in Orkney are detached houses with a mean gross floor area of 118 m^2 (Appendix D—Figure A4). Only 7.4% of this archetype has an EPC rating of A or B. However, C–F bands are distributed evenly between 23–18%. Semi-detached houses have higher B–D band ratings and account for 85% of the total. The mean gross floor area is 80.5 m^2 for this archetype stock. Terraced houses have mainly B–D rating bands with a 73 m^2 mean floor area. Flats are not considered in this study as it is the smallest category among the number of houses, and the EPC dataset does not have enough sample to analyse this archetype. EPC rating results show that half of the building stock is built before 1975 and only 6% has an EPC rating of A or B or C. However, this reaches 37% with the houses built after 1975. One-fifth of the housing stock does not have age information in the dataset. However, 82% of this category has a rating of A or B or C. So, it can be assumed that many of these categories comprise either new buildings built with higher energy efficiency standards or well-refurbished houses in the existing housing stock.

Heat losses occurring in the building fabric are calculated by the energy model described in Section 3.2 for different construction types (walls, windows, floor, and roof) to explore the impacts of individual construction elements on fabric heat losses (FHL). Results for four different archetypes (detached, semi-detached, end-terraced, mid-terraced) with three different specifications (unrefurbished, refurbished, new building) are investigated. The results illustrate that walls are the main contributors to FHL overall with 51.9% followed by windows, floor, and roof with 26.9%, 13.3%, and 7.9 respectively (Figure 3). However, windows contribute more to a mid-terraced new building because the area of the exposed wall is smaller, and the wall is highly insulated. The contributions are varies depending on the house specification. The impact of walls and floor reduces when the house becomes more insulated, i.e., the impact of windows increases.

Considering these calculations, Figure 4 shows the energy efficiency categories based on their scores of individual construction components and overall results by different archetypes. The impact of individual construction elements varies in different archetypes and building specifications. Therefore, while calculating the overall efficiency score of the house, the weight of the construction element has been altered based on the results illustrated in Figure 3.

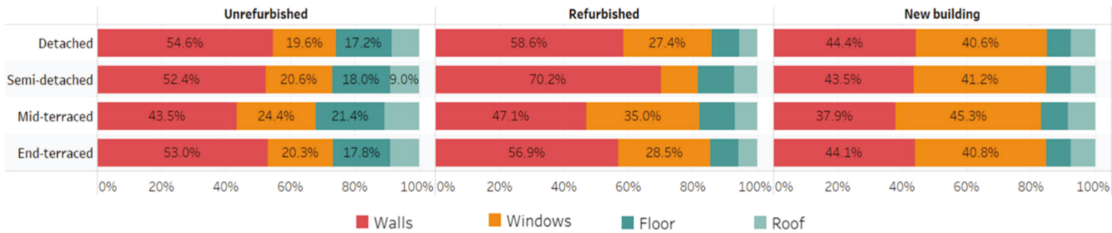

Figure 3. Contribution of construction components to fabric heat loss.

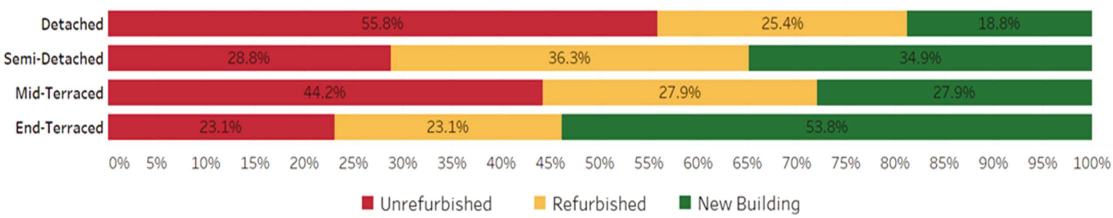

Figure 4. Energy efficiency scores for wall, roof, floor, windows and overall, by house archetypes.

The results illustrate that a majority of the houses in Orkney are categorised as refurbished with 49.7% of the total housing stock, followed by unrefurbished and new building categories with 27.6% and 22.7%, respectively. The most unrefurbished housing stock exists in detached and mid-terraced houses with 55.8% and 44.2%. The most efficient construction parts are the roof and walls with 69.1% and 60.8% respectively. The floor is the least efficient category in all archetypes and the highest contribution occurs in detached and mid-terraced archetypes with 66.2% and 51.4%.

After identifying the housing stock condition, the current heating situation of Orkney is explored. The main heating type in Orkney is electric heaters with 45.2% of the total housing stock (Figure 5). It is followed by oil boilers and heat pumps with 36.7% and 9.0%. The remainder is provided by wood, coal, and LPG boilers. The majority of heat pumps are used in the new building category with 7.7%.

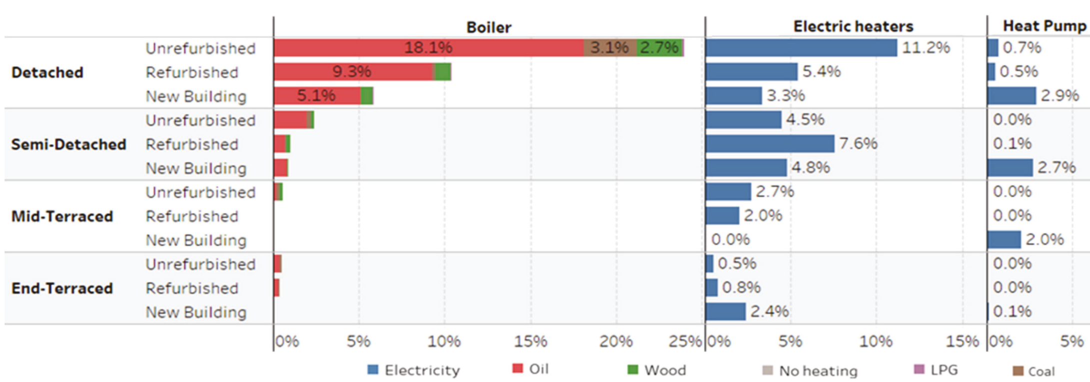

Figure 5. Proportion of main heating fuel type and the total number of heaters.

4.2. Energy Systems Optimisation Modelling (ESOM) Results

A refurbished detached house with a mediumweight thermal mass construction material and PUZ112 heat pump type with 35 °C flow temperature is selected as the baseline scenario. As the water flow runs in low temperatures, the stored water will be heated to 60 °C one hour once a week to avoid legionnaires' disease based on HSE [61] guidance. Five types of tariffs (Standard, E7, Comfy Heat, E12, and E20) and four tank sizes (250 L, 500 L, 750 L, and 1000 L) are compared with two different settings (Gas boiler as a backup heater and no backup heater) for the optimisation.

The amount of energy produced by the heat pump and backup heater varies between 16,500 and 17,500 kWh based on TES tank sizes. Figure 6 illustrates the energy input for optimisation scenarios for the heat pump and boiler. When the gas boiler is used as a backup heater, Standard tariff results show the lowest energy consumption values because the heat pump is running at full capacity assuming that there is no peak or off-peak time tariff, so the gas boiler usage is minimised. The boiler is only running when the tank size is 250 L. Even though the consumption figure is 6015 kWh with a 250 L tank size, energy input values occur as 3794 kWh, 3879 kWh, and 3973 kWh for larger tank sizes respectively. The 250 L tank size is not enough to replace the gas boiler in the Standard tariff. E20 tariff results show similar but slightly higher results than the Standard tariff. The consumption increases to 6553 kWh with 250 L tank size. However, when the tank sizes increased, the consumption figures decreased in the E20 tariff. So, increasing the tank size has a positive impact on this tariff.

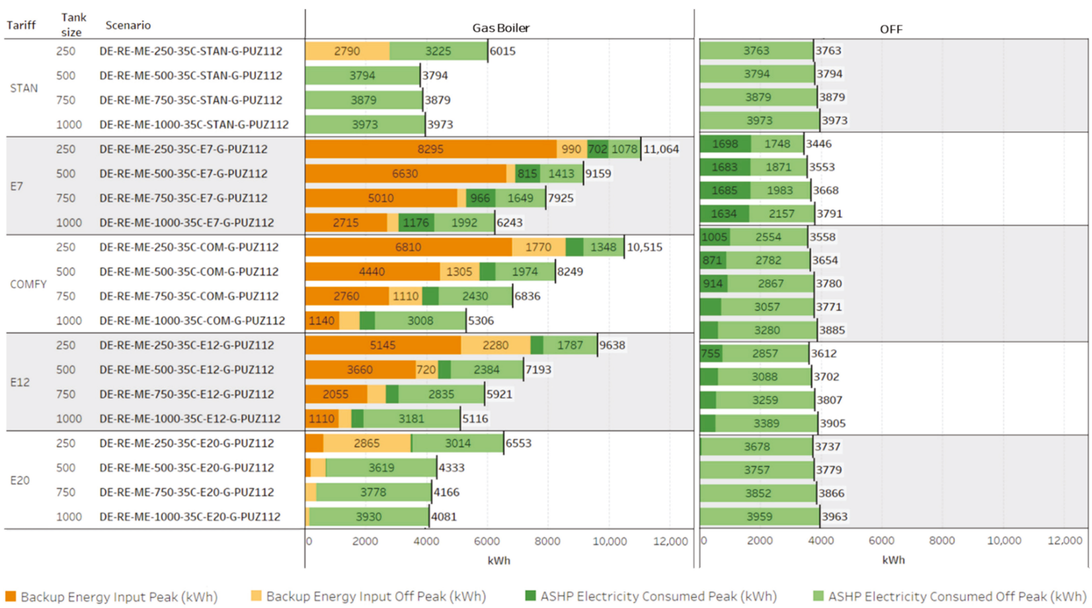

Figure 6. Energy input of backup scenario analysis for heat pump and backup heater during off-peak and peak times.

The highest consumption occurs in the E7 tariff with 250 L tan size (11,064 kWh). This is mainly because the low number of off-peak hours leads to natural gas usage during peak time and decreases electricity usage to 16% of total energy consumption. Higher tank sizes help to decrease energy consumption to 9159 kWh, 7925 kWh, and 6243 kWh with 500 L, 750 L, and 1000 L tank sizes, respectively. Higher tank sizes offer higher electricity usage in off-peak times and help to reduce natural gas usage. Even though the share of electricity in total energy consumption is 16% in 250 L tank size, this could be increased to 24%, 33%, and 51% with higher tank sizes, respectively.

Comfy Heat and E12 tariffs have 12% and 25% lower results than E7 tariff on average. When the number of off-peak hours increases energy consumption reduces because of a higher heat pump fraction in energy generation. This reduction is greater in higher tank sizes. However, the trend in natural gas usage is similar. When tank sizes are increased, energy consumption reduces. E12 tariff with a 1000 L tank size can reduce the consumption to 5116 kWh, which is 25% higher than the lowest energy consumption in all scenarios. This is relatively small when compared with the 9638 kWh consumption of a 250 L tank size.

When the backup heater is not in operation, all energy demand is provided by the heat pump. Energy consumption figures are very similar in all scenarios ranging between 3446 kWh and 3763 kWh with a 250 L tank size. When the tank size increases, energy consumption could reach 3791–3973 kWh, but the difference is still small when compared with the backup heater operation. Even though the total energy consumption values are similar, the fraction of peak and off-peak times changes for E7, Comfy Heat, and E12 tariffs. The peak time usages in E7 tariff are 49%, 47%, 46%, and 43% for 205 L, 500 L, 750 L, and 1000 L tank sizes. However, these numbers reduce to 28%, 24%, 19%, and 16% for Comfy Heat tariff and 21%, 17%, 14%, and 13% for E12 tariff. These differences could result in higher heating costs because of higher peak time tariffs, but this will be covered in the heating cost discussion.

Figure 7 illustrates the total heating cost results for both heating technologies during peak and off-peak times. Even though there is no differentiation between off-peak and peak time costs for natural gas, the results are presented in the same format as electricity. This approach helps to understand the optimisation of the scenario by reducing gas usage and maximising electricity in off-peak time.

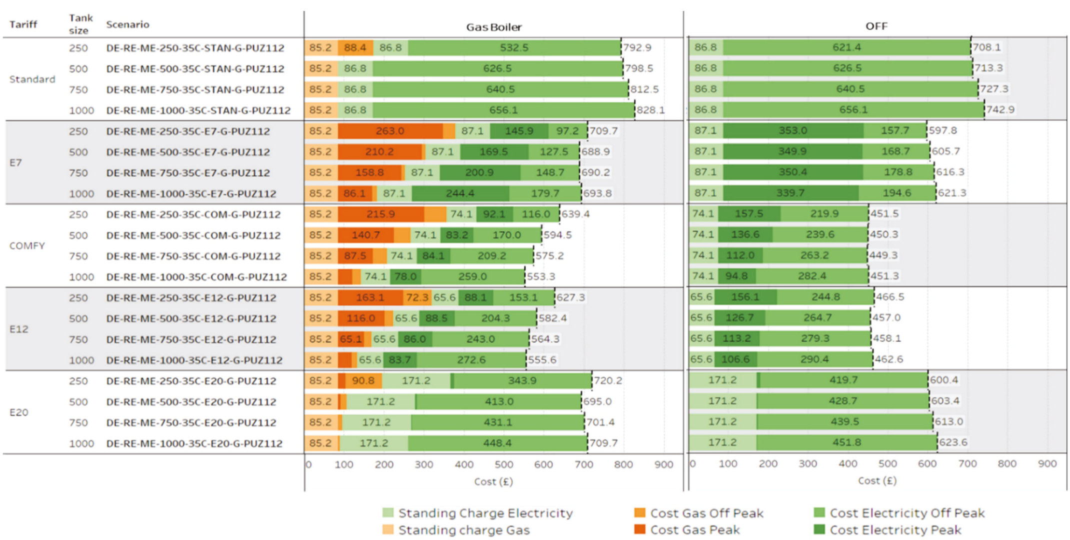

Figure 7. Heating cost of backup scenario analysis for heat pump and backup heater during off-peak and peak times.

When the backup heater is in operation, the Standard tariff has the highest cost with £792.9, £798.5, £812.5, and £828.1 with 250 L, 500 L, 750 L, and 1000 L tank sizes respectively. Increasing the tank size creates higher heating costs as there is no off-peak time strategy in this tariff. E20 tariff expects an average 14% reduction in total heating cost. However, the highest standing charge occurs in this tariff with £171.2 followed by £87.1, £86.8, £74.1, and £65.6 in E7, Standard, Comfy Heat, and E12 tariffs, respectively. Therefore, the reduction in the total cost is limited in the E20 tariff. Another reason for the high heating cost is that even though the 20 h of off-peak rate is very competitive, the highest electricity off-peak rate among other tariffs also exists in this tariff.

E7 tariff shows around 15% lower results than the Standard tariff. The cost of the scenario with a 250 L tank size reduces to £709.7. Electricity peak time cost dominates off-peak time results with £145.9 and £97.2 respectively. A similar trend occurs for larger tank sizes. However, the electricity share increases from 53% with 250 L tank size to 44%, 37%, and 26% with larger tank sizes. Even though the reduction of total heating cost is not significant when the tank size increases, the contribution of the heat pump increases from 47% to 74%.

Comfy Heat tariff has an average of 37% lower results than the Standard tariff, but the lowest reduction occurs in the E12 tariff with around 39% in all scenarios. Off-peak time electricity cost dominates peak time results, and the difference is greater with larger tank sizes. Peak time electricity share in total electricity cost is 23% in both tariffs with 1000 L tank size. Although half of the cost in scenarios with 250 L tank size comes from natural gas, this contribution reduces to 25% with 1000 L tank size.

When the backup heater is not in operation, heating costs in all scenarios reduce. The main reason for that is there is no standing charge for the gas boiler in this setting, so it creates a benefit. The high efficiency of the heat pump could eliminate increases coming from electricity costs depending on different electricity rates in different tariffs. The lowest reductions occur in Standard, E7, and E20 tariffs with an average of 12%, 14%, and 16% decreases. The highest reduction can be achieved with the Comfy Heat tariff with a 31% reduction followed by the E12 tariff with 26%. The total cost of a heating bill can be achieved as £450 with the Comfy Heat tariff. The weather conditions and having no extreme conditions provide higher COP values which could compete with gas prices and make standalone operations financially feasible.

4.3. Integrated Modelling Approach Results

4.3.1. Energy Savings

Current energy results (supply and demand) and proposed scenarios are calculated at individual archetype and Orkney levels. The unrefurbished houses have the highest demand as expected, where detached houses have the highest demand among archetypes with an average of 16,591 kWh because of the larger gross floor area and exposed walls to outside conditions (Figure 8). However, it also varies depending on the building specifications. The highest demand occurs in an unrefurbished detached house with 21,774 kWh. This could be reduced to 16,525 kWh if the building is refurbished or to 11,473 kWh if the house has stricter EEI measures.

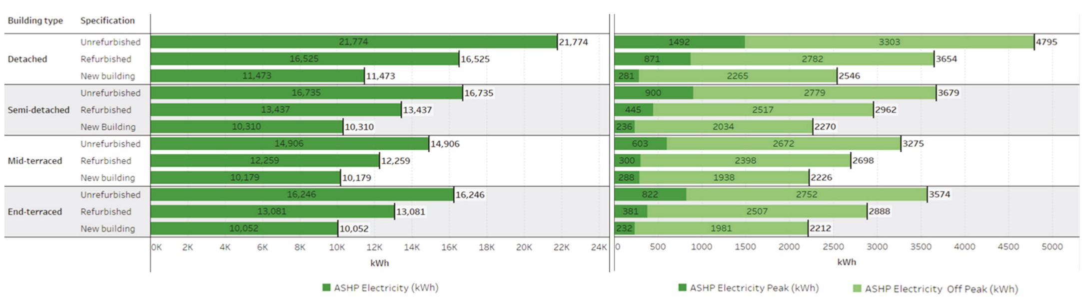

Figure 8. Energy demand results (**left**) and proposed energy supply (**right**) by house archetypes for heat pump uptake scenarios.

The demand figures and main heating fuel type results in the EPC dataset are integrated with BSM to illustrate overall results for Orkney (Figure 9). Overall domestic demand occurs at 186.4 GWh whereas supply stands at 192.0 GWh. While calculating the supply, 2.65 is used as an average seasonal performance factor (SPF) value for the current heat pumps as the field trial shows [62]. The majority of supply is currently provided by electricity and oil with 84.2 GWh and 83.3 GWh respectively. However, heat pump model scenario results show that supply could be reduced to 67.0 GWh with the RE scenario by replacing 75% of the electric heaters and boilers with ASHPs. The supply could even be reduced to 34.4 GWh if all heating types are changed to ASHPs with the CE scenario. It is also important to recall that the energy efficiency of housing stock also plays an important role because unrefurbished houses require higher supply values. Therefore, RE and CE scenarios consider EEI measures taken at different rates explained in the methodology section.

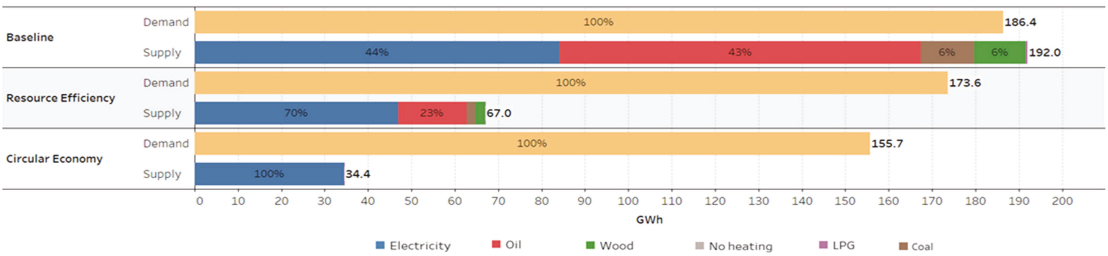

Figure 9. Comparison of energy demand and supply for house archetypes with heat pump uptake scenarios by fuel type.

RE results show that if EEI measures are taken, energy demand will decrease to 173.6 GWh and supply will be reduced to 67.0 GWh. This accounts for a 7% decrease in demand and a 65% decrease in supply respectively. The demand figures also include the new housing stock by 2050, which is around 19% of the existing houses. However, energy efficiency improvements help to decrease the total demand.

CE scenario results show that more strict efficiency standards could provide a 16% reduction in demand even though the total number of dwellings is increased. Higher EEI measures create less energy demand for the entire housing stock. Energy supply is expected to decrease by 82% (to 34.4 GWh) by replacing all heating technologies with ASHPs. The main reason for a higher reduction in energy supply is that heat pumps are significantly more efficient than other heating technologies. Therefore, the reduction in supply is significantly higher than demand in the CE scenario.

4.3.2. Environmental Savings

Comparative LCA results of heat pumps and gas boilers are calculated for the UK in a previous study [44]. In this study, Orkney results show that there is a significant reduction in most categories when it is compared with the results for the UK (Figure 10). The main reason for that is the change in the use phase. In UK results, the use phase was dominating the remaining categories. However, the amount of electricity used for the heat pump throughout the lifetime (20 years) is reduced because of higher efficiencies (2.8 SPF used for the UK study and the average optimized SPF modelled for archetypes in Orkney is 4.5). Moreover, electricity is produced mainly from wind energy. Therefore, the negative consequences are decreased.

The highest reduction occurs in the Ionising Radiation (IR) category with a nearly 99% decrease. The main contributor to this category is electricity from nuclear. Therefore, renewable electricity helps to reduce this impact. Other high reductions occur in agricultural land occupation (ALO), terrestrial ecotoxicity (TE) and national land transformation (NLT) categories, with 98%, 98%, and 96%, respectively. The reduction in ALO and TE categories is relevant to electricity produced from biomass which exists in the UK electricity mix but not in Orkney. NLT category is relevant to the fossil fuels that exist in the UK electricity mix.

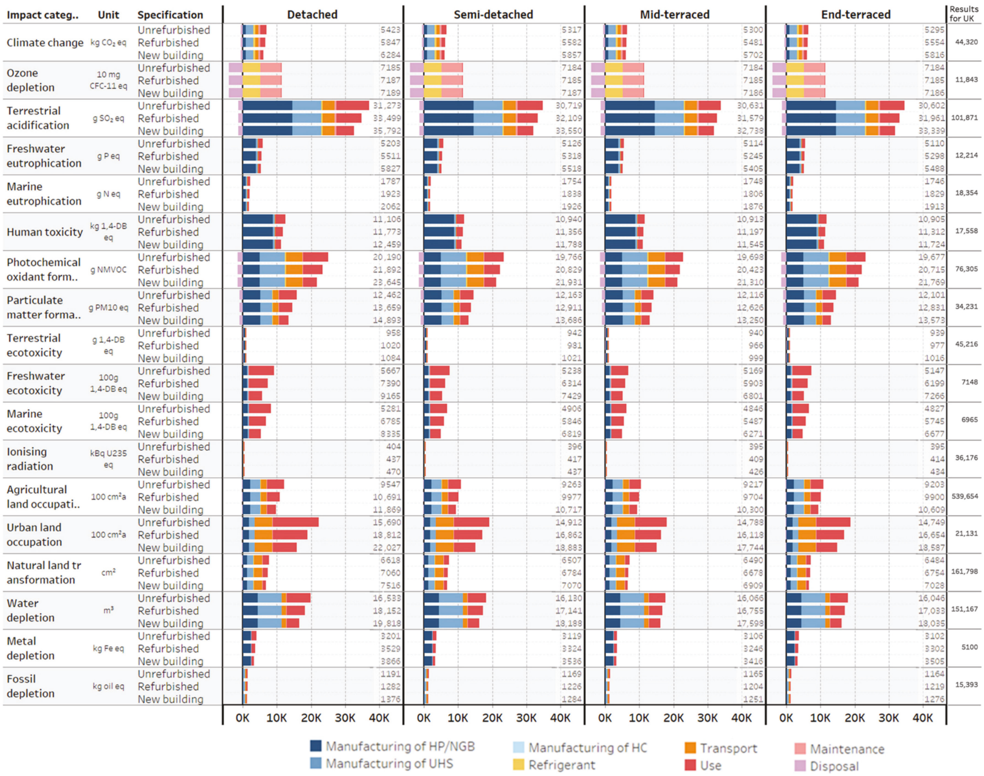

Figure 10. Lifecycle environmental impacts of heat pump uptake scenarios by house archetypes.

The lowest changes occur in freshwater ecotoxicity (FE) and marine ecotoxicity (ME) categories with a 9% and 14% reduction. The main processes that contribute to these categories are the manufacturing and disposal of scrap metals so as there are no changes in these phases the results remain similar and only the use phase creates these differences. urban land occupation (ULO) and metal depletion (MD) categories also have 19% and 34% lower results mainly because of the differences in the electricity mix.

The climate change (CC) category results decreased from 44,320 $kgCO_2e$ to 5621 $kgCO_2e$ on average. Even though the average value is very low when compared with the UK figure, results vary based on the archetype and building specification. It can reach 6284 $kgCO_2e$ if the building is an unrefurbished detached house or decrease to 5295 $kgCO_2e$ if it is a new semi-detached house. The new buildings category shows 14%, 5%, 7%, and 9% lower results for detached, semi-detached, end-terraced, and mid-terraced archetypes, respectively.

The highest changes in one impact category exist in FE, ME, and ULO categories. The differences between an unrefurbished detached house and a new building end-terrace house could be as high as 78% in FE, 73% in ME, and 49% in ULO category. These results emphasize that not only the environmental impacts of different space heating technologies are important, but also the house archetypes and specifications. A refurbished house and a new building category have 5% and 10% lower results than an unrefurbished one in the CC category. The highest change occurs in the FE category with a 16% and 30% reduction in refurbished and new building categories. ME category shows similar reductions with 15% and 29% for the same building specifications. ULO category also shows reductions of around 11% and 22% with EEI.

Figure 11 illustrates the breakdown of GHG emissions for the baseline scenario and total emissions for future scenarios. Oil is responsible for 77% of total emissions (20,552 tCO_2e), followed by coal with 16% (4248 tCO_2e) and electricity with 6% (1612 tCO_2e) in the baseline scenario. Wood and LPG account for only 1% (269 tCO_2e) of total emissions. RE and CE scenarios reduce total emissions by 79% and 98% respectively. RE scenario expects an 81% reduction in fossil fuel emissions and a 44% reduction in electricity emissions. CE scenario replaces all heating technologies with heat pumps, so the emissions are 659 tCO_2e coming from electricity, which is very low when compared with the RE scenario. Even though the demand is higher in the future with around 2000 more new dwellings, ambitious EEI targets also help to reduce both demand and emissions. The UK's net zero target is an ambitious target and requires ambitious steps, including not only a shift in the heating system, but also a shift in EEI.

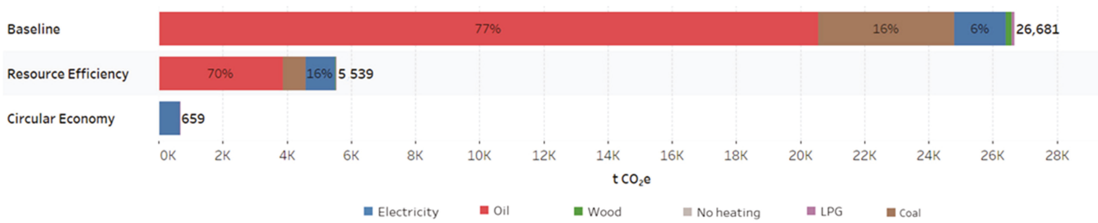

Figure 11. Comparison of current and heat pump uptake scenario GHG for house archetypes contributed by fuel type.

4.3.3. Heating Cost Savings

Energy modelling results illustrated that Comfy Heat and E12 tariffs have the optimum heating cost results. Therefore, the heating cost of house archetypes and specifications for Comfy Heat tariff are presented in Figure 12. E12 results are very similar to Comfy Heat tariffs and consequently omitted for simplicity. Detached houses have the highest heating cost with an average of £452 heating cost. Mid-terraced houses have 25% less heating cost on average, followed by end-terraced and semi-detached houses with 21% and 19% respectively. The main reason for this difference is that the demand varies based on gross floor areas and house archetypes.

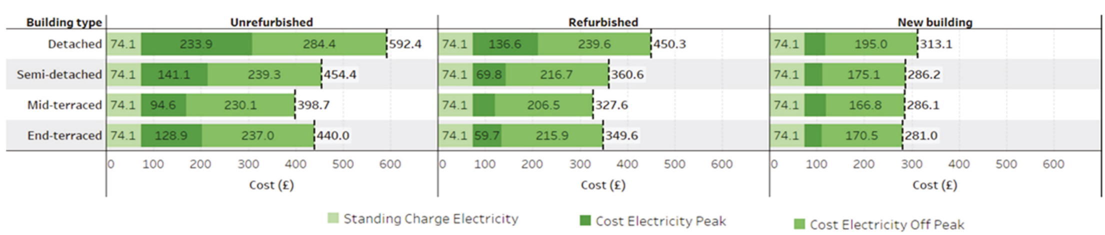

Figure 12. Heating energy cost for heat pump uptake scenarios by house archetypes from Comfy Heat tariff.

House specification is also a significant factor to reduce heating costs. An unrefurbished detached house's energy cost could be as high as £592.4 for the entire year. Moreover, 48% of this cost comes from off-peak time electricity usage and 39% comes from peak time usage. Further, 13% is the standing charge which is the same for all house archetypes. When the energy efficiency of the house is improved to the refurbished category the total heating cost could be reduced to £450.3, and £313.1 with the new building category. The major reason for this reduction is that not only does the heating demand decrease with the help of EEI measures, but it also can help to shift much of the energy usage to off-peak time. Therefore, the share of peak time usage decreases to 30% and 14% in refurbished and new building categories. Similar trends occur for the remaining house archetypes and the lowest heating cost occurs in a new building category end-terraced house with £281.

The total heating cost on the island is around £23.0 million and the majority of it comes from detached houses (Figure 13). Electricity is responsible for 76% of the total heating cost followed by oil, coal, and wood with 19%, 3%, and 3% respectively. RE scenario could help to reduce heating cost results to £8.4 million via replacing 75% of the heating technologies with heat pumps and EEI measures. The share of fossil fuels is reduced to 12% of the total heating cost in this scenario. CE scenario offers more reduction with more ambitious heat pump uptake and EEI targets in line with UK's net zero target. Even though only 25% of the heating technologies are not replaced in the RE scenario, replacing this stock could help to reduce the heating cost to £3.7 million which is less than half of the RE scenario. The main reason for this reduction is that the CE scenario not only offers to replace fossil fuels, but also an ambitious EEI scenario, so there will be no unrefurbished houses left and the majority of the houses are in the new building category with high-efficiency standards.

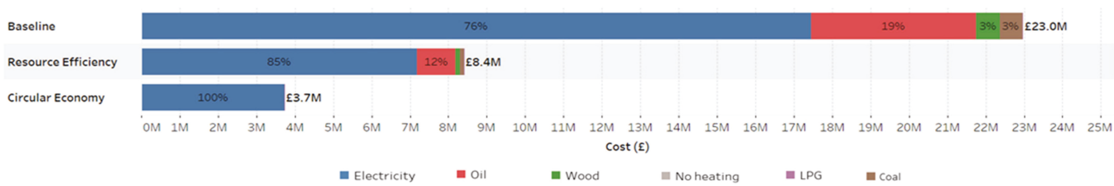

Figure 13. Heating energy cost of baseline model by archetypes and specifications and future scenarios.

4.3.4. Financial Options

The previous section shows the heating cost of heat pumps and the cost saving of replacing existing heating technologies with heat pumps. This section focuses on the LCC of heat pumps and financial alternatives. Figure 14 shows different financial options for a refurbished detached house; self-financed, financed, financed with Boiler Upgrade Scheme (BUS) grant, interest-free financed with Home Energy Scotland (HES) cashback and interest-free financed with HES cashback including EEI costs. The results are illustrated in discounted costs of 3.5% for a 15-year period. Figure 14 only shows the results for a refurbished detached house for simplicity.

Self-financed and financed options are not economically viable in the baseline scenario for end-users for all fuel types except electric heaters. Replacing oil boilers with heat pumps shows savings of £4525 and £4164 for self-financed and financed scenarios respectively. Coal and wood have similar results, while LPG still performs negatively with –£2094 and −£1732 for self-financed and financed options, respectively.

Grants and cashback provided by governments help to reduce upfront costs so heat pumps become an economic option for end-users. BUS grant offers a £5000 grant for homes in UK and Wales, and HES provides £7500 cashback and an interest-free loan for the remaining costs for Scottish homes. In these scenarios, the highest outcome occurs in LPG boilers with £6045 and £3091 from HES and BUS grants, respectively. Coal and Wood have lower results with around £4500 for HES and £1500 for BUS grant. The oil boiler has £3613 for HES and only £659 for BUS grants.

EEI measures are beneficial for reducing energy demand so reducing heating costs increase savings. However, installation costs of energy efficiency measures are significant, especially for unrefurbished houses (illustrated in Appendix C, Figure A3). A refurbished detached house requires £9000 for more ambitious EEI measures. Therefore, EEI measures become economically viable for only LPG with £1480 in LCC. The remaining fuel types, (oil, coal, and wood) show negative results with −£951, −£12, and −£86 respectively.

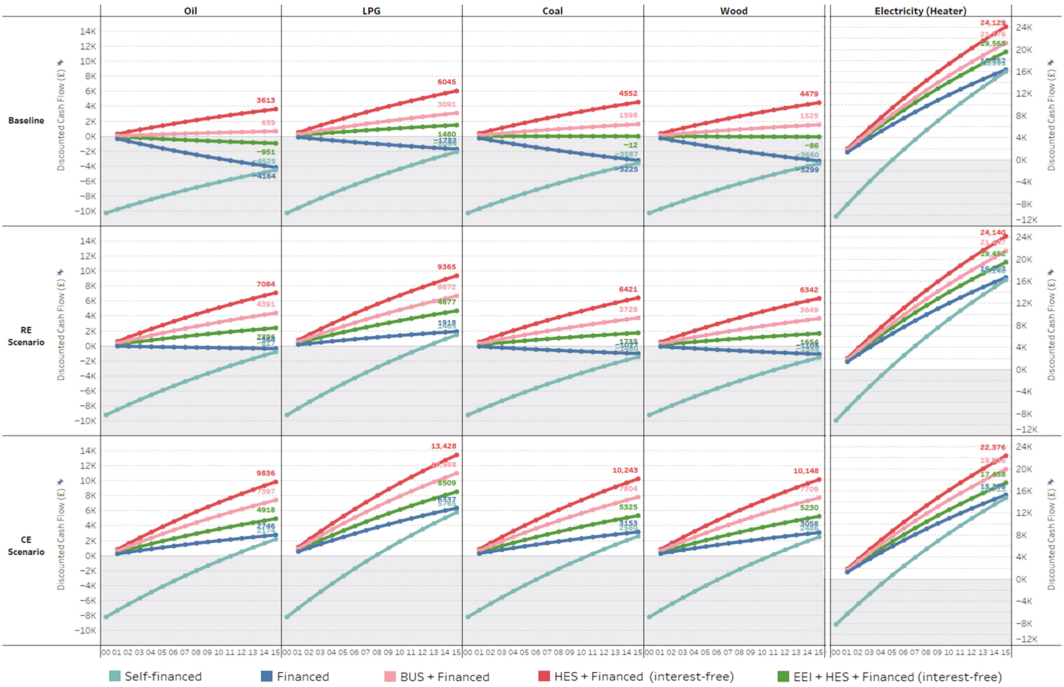

Figure 14. Cumulative lifetime costs of replacing heating technologies with heat pumps and different financial options for future scenarios (BUS: Boiler Upgrade Scheme Grant, HES: Home Energy Scotland Cashback, EEI: Energy Efficiency Improvement Cost).

Replacing electric heaters with heat pumps always shows positive results for all financial options as electricity prices are higher than fossil fuels, creating higher potential fuel cost savings. The results could be as high as £24,129 with the HES grant whereas self-financing is also significantly high (£15,991) when compared with other fuel types.

Future scenario results show that changes in fuel prices increase the financial benefits. HES grant savings could reach £7084 in the RE scenario and £9836 in the CE scenario for oil. Coal and wood also show similar trends to oil, but the highest benefits occur with LPG among fossil fuels. Savings from LPG could reach £13,428 in the CE scenario. Self-financed and financed options are still negative for oil, coal, and wood fuel types in the RE scenario. However, they also become positive in the CE scenario. Only a reduction occurs in electric heaters because electricity prices are expected to decrease in the future. Therefore, consumers using electric heaters should replace their heating system in the baseline scenario to achieve the highest potential savings.

Figure 15 shows total undiscounted savings for Orkney when heat pump uptake is followed by future scenarios and the breakdown of total undiscounted costs by fuel and payment type. CE scenario results show that all financial options offer potential positive savings. The highest savings occur in HES + Financed (interest-free) scenario with £161.0 million, followed by BUS + Financed (interest-free) and BUS + Financed scenarios with £141.5 million and £135.5 million. The lowest savings occur in the self-financed with £81.9 million and EEI + HES + Financed (interest-free) scenario with £77.5 million. CE scenario helps to increase savings from EEI measures and become more viable than the self-financed scenario. The total EEI measure cost is £129.9 million in the CE scenario. This investment in EEI measures helps to reduce the total project cost from £87.8 million to £79.8 million with smaller size heat pumps. As the energy demand is reduced, electricity cost is also reduced from £62.3 million to £49.0 million.

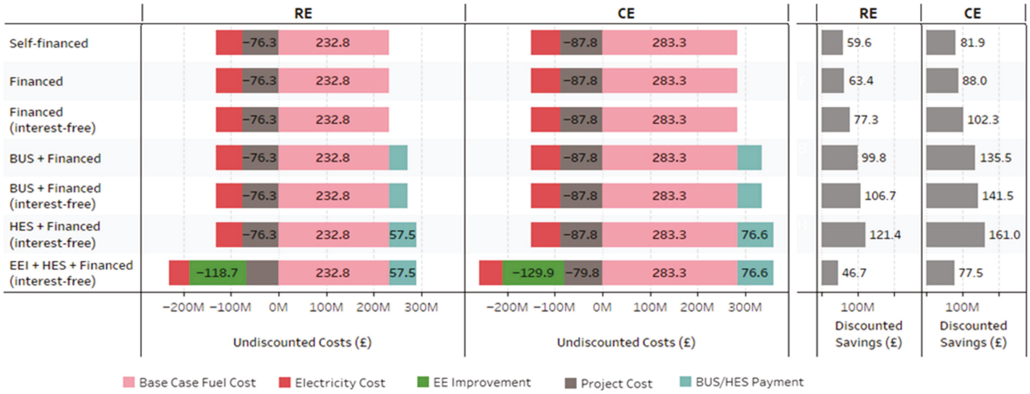

Figure 15. Cumulative undiscounted cost distribution of replacing heating technologies with heat pumps in Orkney for different financial alternatives and future scenarios by fuel types.

Even though the EEI scenario does not provide positive savings in the baseline scenario, future scenarios could help to create savings for refurbished archetypes. However, unrefurbished houses require more support to make EEI measures financially viable. The total EEI measures require an investment of around £130 million in the CE scenario. Further, £21.3 million savings could be achieved as a result of EEI (£8.0 million reduction from up-front project cost and £13.3 million reduction from electricity costs). However, £108.5 million support is still required to achieve the same total savings with HES + Financed (interest-free) scenario. Therefore, more grants are needed. The number of unrefurbished and refurbished houses eligible for EEI coupled with heat pump uptake is around 5300 and 3150, respectively. Hence, £14,000 support for unrefurbished houses and £7500 for refurbished ones could provide the required financial support to the consumers.

4.3.5. Hourly Electricity Load Savings

Figure 16 shows load profiles of house archetypes and specifications for Comfy Heat and E12 tariffs for the coldest winter workday and holiday. Maximum peak loads occur as 4.05 kW in Comfy Heat tariff and 3.94 kW in E12 tariff for all archetypes in the coldest winter workday. Detached houses have the highest energy demand. Therefore, the total variable load is 27.7 kW and 28.8 kW in comfy Heat and E12 tariffs in the unrefurbished category. Semi-detached and end-terraced houses have similar total loads, approximately 19.0 kW in Comfy Heat tariff and 21.0 kW in E12 tariffs. Mid-terraced houses have the lowest total load with 16.8 kW and 18.3 kW in Comfy Heat and E12 tariffs, respectively. When houses become more energy efficient, their energy demand reduces, so lower loads are seen in efficient houses. Total heat pump loads in detached houses could be reduced to 20.4 kW in a refurbished house or 13.7 kW with a Comfy Heat tariff in a new building category. Moreover, fewer peaks occur throughout the day. A similar trend occurs in other house archetypes and total heat pump loads could be reduced to 12.7 kW, 11.3 kW, and 12.7 kW for semi-detached, mid-terraced, and end-terraced new building categories, respectively. The coldest winter holiday results also show similar trends but slightly lower load profile results.

This study tries to break down the load results into different house archetypes and specifications so cumulative electricity system load profiles would be more accurate. Each archetype profile is multiplied by the number of houses using heat pumps for all scenarios. Figure 17 shows Orkney electricity system load for baseline, RE, and CE scenarios for the coldest winter workday and holiday. The results are presented for Comfy Heat and E12 tariffs separately and their equally mixed usage scenario. Existing electric loads coming from room heaters are also presented in the figures with yellow bars. The baseline scenario has a limited number of heat pumps deployed. Therefore, the total daily variable heat pump load is 14.4 MW and 15.4 MW for Comfy Heat and E12 tariffs with 27.9 MW and 26.3 MW peak loads in the coldest winter workday.

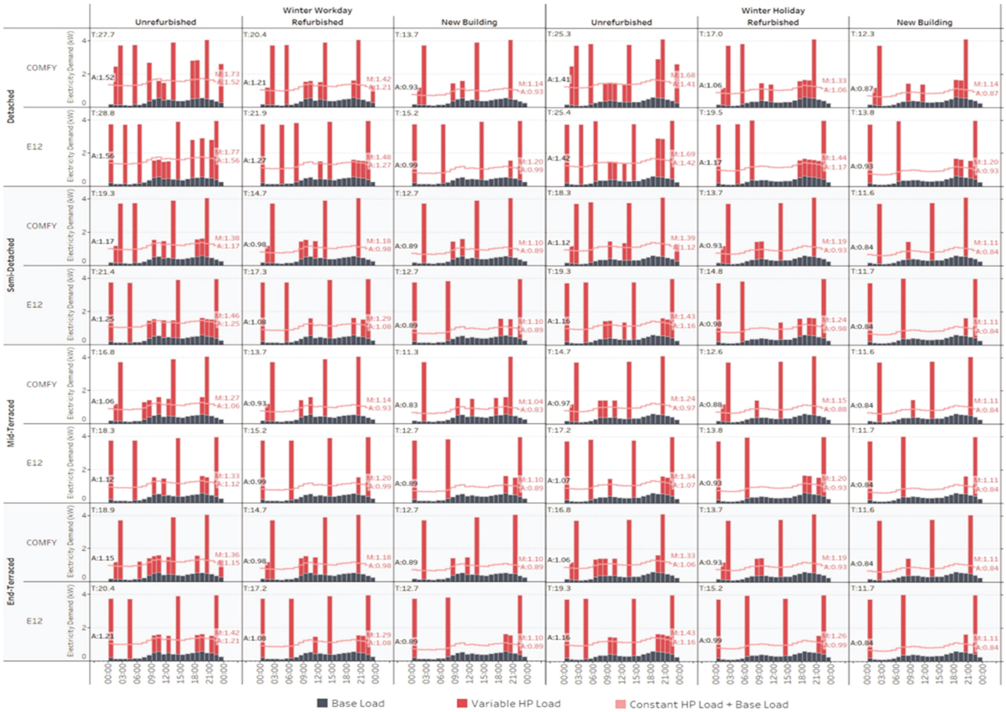

Figure 16. Average hourly electricity demand load curve of a representative heat pump profile by different archetypes and electricity tariffs for the coldest winter workday and holiday (T: Total, M: Maximum, A: Average).

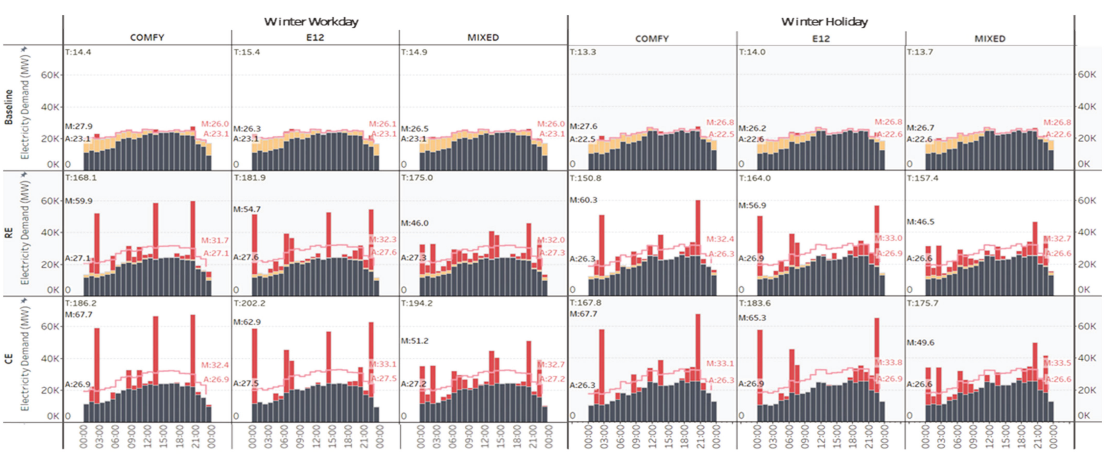

Figure 17. Average hourly electricity demand load curve of heat pump scenarios for Orkney for the coldest winter workday and holiday (T: Total, M: Maximum, A: Average).

RE scenario has high deployment rates of heat pumps (around 80% of total dwellings) so daily total variable heat pump loads reach 168.1 MW and 181.9 MW in Comfy Heat and E12 tariffs with 59.9 MW and 54.7 MW peak loads respectively. Combining both tariffs reduces the peak load to 46.0 MW. When CE scenario has total daily variable heat pump loads with 186.2 MW in Comfy Heat tariff and 202.2 MW in E12 tariff, the peak loads reach 67.7 MW and 62.9 MW in the tariffs, respectively. Comfy Heat tariff has a smaller number of peaks but E12 tariffs have more spread around the day, so the mixed deployment of tariffs helps to reduce peaks to 51.2 MW. When variable heat pump load is compared with constant heat pump load (light red line), the majority of the variable loads stay below constant load, and heat pumps do not operate in the evening, which is when the highest baseload occurs. Peaks are happening in three periods: during the night, before evening and before midnight with two peaks in each. When the coldest holiday results are analyzed, these peaks are even less in the CE scenario with a mixed tariff setting. Only the peak happening before midnight needs to be handled.

Different tariffs create load peaks in different time periods which could be beneficial to combine electricity tariffs to have a more evenly electricity load spread throughout the day. EEI measures help to reduce the total daily variable heat pump load which is crucial to decrease energy demand. However, peak loads remain the same. Therefore, combining more than one electricity tariff in the market could help to reduce peak loads.

5. Discussions

Integrating energy modelling, LCA, and financial modelling helps us to understand various aspects of heat pump uptake scenarios. Energy savings results emphasize that EEI could help to reduce energy demand by 16% in the CE scenario even though the housing stock is increased by 19% by 2050. The uptake of heat pumps could reduce the energy supply by 82% when coupled with ambitious EEI in the CE scenario.

The main heating types in Orkney are electric heaters and oil boilers, so heat pump uptake could help to reduce use-phase-related GHG emissions by 98% in the CE scenario (from 26,681 tCO2e to 659 tCO2e), but this requires strong commitments in terms of EEI and heat pump deployment. Even though the electricity mix is 100% renewable, GHG emissions coming from the production of materials used for electricity supply technologies make it difficult to reach the net zero target. CE principles could help to reduce the impact of the manufacturing phase with greener production lines and eco-design principles.

ASHP perform better than other heating technologies (oil, LPG, coal and wood boilers, and electric heaters) in terms of heating costs with the optimized operation. Total cumulative heating costs paid by end-users in Orkney could be reduced by 84% in the CE scenario (from £23.0 million to £3.7 million). This could be achieved by the 100% uptake of heat pumps coupled with more efficient houses and changes in energy prices in the future. Increased levies on fossil fuels and reduced levies on electricity could make the electricity market more competitive in the future to accelerate the transition.

Financial analysis results show that self-financing or financing options without any support are not a desirable path for fossil fuel consumers in the baseline scenario. High installation costs of heat pumps still stand as a barrier. The highest benefits are achieved with Boiler Upgrade Scheme (BUS) grant and Home Energy Scotland (HES) loan and cashback scheme with £659 and £3613 for consumers using oil boilers, respectively.

Total discounted savings in the baseline model could be tripled with the CE scenario with the help of reductions in electricity prices and increases in fossil prices with a carbon tax in the future. Moreover, self-financing and financing without support options also create positive savings for all fuel types in the CE scenario due to more efficient houses with lower electricity prices.

EEI maximize fuel savings whereas high upfront cost is significantly high, especially in unrefurbished houses. Energy modelling results show that the heating demand of an unrefurbished house could be reduced by 40% if the house is insulated, so the new building category is the best option for the optimum heat pump operation. The CE scenario could help to avoid negative savings resulting from EEI measures and creates a financially viable solution for end-users. Therefore, the CE scenario offers significant potential benefits.

EEI measures are consequential for the optimum performance of heat pumps; however, it requires a £130 million investment for the entire island. Therefore, these measures also require support to become more engaging to consumers. This support could be around up to £14,000 grant for unrefurbished houses (around 5300 houses in total) and up to £7500 grant for refurbished ones (Around 3150 houses in total). These grants could also be flexible for different archetypes based on their initial project cost, and these figures could provide around £108.5 million to support the entire island. The remaining savings (£21.3 million) could be achieved by reductions in electricity costs and project costs with the help of EEI measures. New grants and incentives could also be introduced, such as vouchers similar to BUS/HES grants for some part of the total cost, interest-free loans for the remaining part of the cost, and removing VAT on equipment and labor costs.

Electricity load results emphasize that detached houses have the highest peaks due to their higher energy consumption, but the new building category has the lowest load results. Therefore, EEI could help to reduce peak loads. At the Orkney level, a combination of Comfy Heat and E12 tariffs provides a more even spread of hourly load profiles. The maximum peak load is 26.5 MW in the baseline scenario whereas it reaches 51.2 MW in the CE scenario. When the increase in the heat pump capacity is considered (1203% increase in total daily system loads from 14.9 MW in the baseline to 194.2 MW in CE), a 93% increase in maximum peak loads is seen. In order to achieve this, a competitive electricity market with a high number of off-peak hours, such as the E12 tariff, or more equally spread off-peak hours throughout the day, such as the Comfy Heat tariff, is required.

Orkney is facing a high level of fuel poverty due to lower average income and higher energy prices than the mainland. Moreover, the housing stock is older than the national average. Accelerating the heat pump uptake could help to reduce the negative impacts of volatility in oil prices and energy security problems with the help of a high level of renewable electricity generation. However, high installation costs of heat pumps and EEI require financial support, such as grants, incentives, and interest-free loans. The highest potential savings at the individual household level and island level could be achieved with these subsidies.

Data Quality and Limitations

LCA methodology requires a thorough analysis for all phases and conducting an LCA for existing heating technologies (oil, coal, wood, LPG boiler, and electric heater) requires significant time and data. Moreover, the use phase dominates most of the categories, so the importance of the manufacturing phase remains limited. Only use phase related GHG emissions are compared in the cumulative savings.

House archetypes and their specifications create different electricity demands and heat pump size requirements. This study compares the life cycle impacts of different archetypes by differentiating the electricity use. However, one size heat pump is considered in the LCA study. This is mainly because the data are limited in terms of amount of materials used for different sizes of heat pumps.

Replacing existing heating technologies with low-temperature heat pumps requires upgrading the heat distribution system, which could mean increasing the size of radiators or installing underfloor heating systems. Environmental impacts of underfloor heating systems are calculated in the LCA chapter to investigate the overall impact. However, financial analysis in the integrated approach only considered minor upgrades, such as increasing the size of several heat pumps to avoid high installation costs.

6. Conclusions

This study has investigated the impacts of large-scale heat pump uptake in Orkney with circular economy (CE) principles to support the UK's 2050 net zero target. An integrated approach of different methods (LCA, ESOM, BSM) was taken. Firstly, EPC data were used to analyze the housing stock in terms of the conditions of construction elements (wall, window, roof, floor) by different house archetypes. The requirement of energy efficiency improvement (EEI) for these archetypes was decided. Existing heating technologies and fuel types were investigated to analyze the current situation in Orkney. Then, potential energy, environmental and economic savings under heat pump uptake scenarios were calculated based on the BSM and existing heating types. Financing options for heat pump uptake scenarios were also investigated for consumer engagement. The results are illustrated at both the house archetype level for end-users to provide individual savings and the island level to emphasize cumulative savings.

By taking an integrated approach, results show that the heat pump uptake scenarios could help to reduce energy supply by 82% with ambitious energy efficiency improvements in the CE scenario despite a 19% increase in the number of houses by 2050.

The use-phase-related GHG emissions could be reduced by 98% in the CE scenario with EEI measures taken and 100% heat pump uptake. The life cycle-wide approach includes the emissions coming from the production of energy supply technologies (manufacturing wind turbines, etc.), so reaching the net zero target requires strong commitments in all industries covering the manufacturing of the products, energy production, and consumption.

Total heating costs paid by consumers in Orkney could be reduced by 84% from £23.0 million to £3.7 million in the CE scenario. However, it could only be achieved with 100% heat pump uptake and implementation of EEI measures, which requires a £130 million investment for the entire island to insulate unrefurbished housing stock. New grants and incentives, such as vouchers similar to BUS/HES grants, interest-free loans, and reductions in VAT on equipment and labor costs, should be introduced to cover the cost of energy efficiency improvement measures. Increased levies on fossil fuels and reduced levies on electricity could make the electricity market more competitive against fossil fuels.

CE scenario results show benefits in all energy, environmental, and financial results. Therefore, developing CE standards for the production of heat pumps, including the use of secondary materials, circular material banks, eco-design, and re-usability of all components is crucial. Developing a stock and flows for materials could help to improve material efficiencies and reliance on raw materials. Different heating technologies require similar material demands and waste streams despite technological differences. The boiler industry represents the second largest UK heat pump market after air conditioning manufacturers, so reshaping these production lines could benefit the market knowledge used by the companies. Moreover, a market introduction program should be provided before shifting from one technology to another, so greener production lines achieved through adapting CE principles could help to reduce the negative impacts on the manufacturing phase.

The integrated approach provided flexibility to work on scenario analysis to assess both the demand and supply side of the system with life-cycle-wide thinking. This comprehensive manner is novel and fundamental to creating a holistic approach to reducing GHG emissions to reach the net zero targets while observing other negative consequences and implications, so all aspects of energy, environmental, and financial benefits can finally be achieved. Focusing on the island level, specifically in Orkney, could help to provide sustainable solutions to the economic pressure that islands are facing and to the high level of fuel poverty.

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Abbreviations

IPCC	Intergovernmental Panel on Climate Change
IR	Ionising Radiation
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LPG	Liquid Petroleum Gas
ME	Marine Ecotoxicity
MEU	Marine Eutrophication
MD	Metal Depletion
NIC	National Infrastructure Commission
NLT	National Land Transformation
OD	Ozone Depletion
PMF	Particulate Matter Formation
POF	Photochemical Oxidant Formation
RHI	Renewable Heat Incentive
RE	Resource Efficiency
SPF	Seasonal Performance Factor
SAP	Standard Assessment Procedure
TA	Terrestrial Acidification
ULO	Urban Land Occupation
WD	Water Depletion
ALO	Agricultural Land Occupation
ASHP	Air Source Heat Pump
BUS	Boiler Upgrade Scheme
BSM	Building Stock Model
CE	Circular Economy
CC	Climate Change
COP	Coefficient of Performance
BEIS	Department for Business, Energy & Industrial Strategy
DHW	Domestic Hot Water
EE	Energy Efficiency Improvement
EPC	Energy Performance Certificate
ESOM	Energy Systems Optimisation Modelling
FD	Fossil Depletion
FE	Freshwater Ecotoxicity
FEU	Freshwater Eutrophication
GHG	Green House Gas
HES	Home Energy Scotland
HT	Human Toxicity
TE	Terrestrial Ecotoxicity
TES	Thermal Energy Storage

Appendix A. Energy System Optimisation Model (ESOM) Calculations

Fabric heat loss is calculated as in the following equation:

$$L_F = \sum(A \times U) \tag{A1}$$

where L_F is fabric heat loss (W/K), A is the area of component (m^2) and U is the thermal transmittance of the component (W/m^2K). Thermal bridges are calculated as in the following equation:

$$L_{TB} = y \times A_{exp} \tag{A2}$$

where L_{TB} is losses from thermal bridging (W/K), A_{exp} is the total area of exposed surfaces to the external environment and y is the thermal bridging factor (W/m^2K). Ventilation heat loss is calculated as in the following equation:

$$L_V = 0.33 \times n \times V \tag{A3}$$

where L_V is ventilation heat loss (W/K), n is air change rate (ach) and V is the volume of heated space (m^3). Total heat loss is calculated as in the following equation:

$$\sum \mathrm{L_{Total}} = (L_F + L_{TB} + L_V) \times T_h - T_e \tag{A4}$$

where L_{Total} is total heat loss (W), T_h is heating setpoint temperature, T_e is external temperature. Solar gains are calculated as in the following equation:

$$\mathrm{G_S} = 0.9 \times Aw \times S \times g \times FF \times Z \tag{A5}$$

where 0.9 represents typical average transmittance, A_w is the window area (m^2), S is the solar flux (W/m^2), g is the transmittance factor of the glazing at normal incidence, FF is the frame factor (fraction of the glazed area) and Z is the solar access factor. Internal gains are calculated as in the following equation:

$$\mathrm{G_I} = A \times f \tag{A6}$$

where A is the gross floor area (m^2) and f is the internal gain factor (W/m^2). Total gains are calculated as in the following equation:

$$\sum G_{Total} = G_S + G_I \tag{A7}$$

The temperature reduction from setpoint temperature depends on the thermal properties of building materials used in the dwelling calculated as in the following equations:

$$HLP = \frac{\sum L_{Total}}{AGF} \tag{A8}$$

$$TMP = \frac{\sum C \times A}{AGF} \tag{A9}$$

$$Tau = TMP \ / \ (3.6 \times HLP) \tag{A10}$$

$$a = 1 + Tau/15 \tag{A11}$$

$$Tc = 4 + 0.25 \times Tau \tag{A12}$$

$$\gamma = \sum G_{Total} / \left(\sum L_{Total} \times (T_h - T_e) \right) \tag{A13}$$

$$\begin{aligned} \text{if } \gamma > 0 \text{ and } \gamma \neq 1: \quad & \eta = \tfrac{1-\gamma^a}{1-\gamma^{a+1}} \\ \text{if } \gamma = 1: \quad & \eta = \tfrac{a}{a+1} \\ \text{if } \gamma \leq 0: \quad & \eta = 1 \end{aligned} \tag{A14}$$

$$Tsc = (1 - R) \times (Th - 2) + R \times (Te + \eta \times G_{Total}/L_{Total}) \tag{A15}$$

$$u = 0.5 \times (T_h - T_{sc})/T_c \tag{A16}$$

where *HLP* is the heat loss parameter (W/m^2K), L_{Total} is total heat losses (W/m^2K), A_{GF} is the gross floor area of the building (m^2), *TMP* is the thermal mass parameter (kJ/m^2K), C is the specific heat capacity of building materials, A is the area of building materials, T_{au} is a time constant, α is a constant, T_c is a time constant, γis a constant, G_{Total} is total gains, L_{Total} is total losses, T_h is heating setpoint temperature, T_e is external temperature, η is utilisation factor, T_{sc} is internal temperature without heating, R is the responsiveness of the heating system, u is temperature reduction.

Appendix B. Fuel Prices and Tariff Specifications

Table A1. Electricity and gas tariffs, and distribution of peak hours during the day [36–38].

Tariff	Peak Time Price (p)	Off-Peak Time Price (p)	Standing Charge (p)	Peak Hours
Standard		16.5	23.8	
Economy 7	20.8	9.0	23.9	00:00–07:00
Comfy Heat	15.7	8.6	20.3	02:00–06:00, 13:00–15:00, 20:00–22:00
Economy 12	20.7	8.6	18.0	00:00–08:00, 14:00–16:00, 22:00–00:00
Economy 20	16.3	11.4	46.9	00:00–13:00, 15:00–17:00, 19:00–00:00
Gas		3.2	23.0	

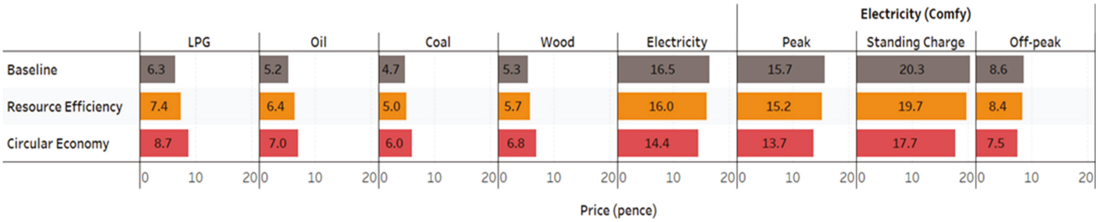

Figure A1. Fuel prices for baseline and future scenarios [55–58].

Appendix C. Construction Elements of the Building Stock and Efficiency Improvement Costs by House Archetype

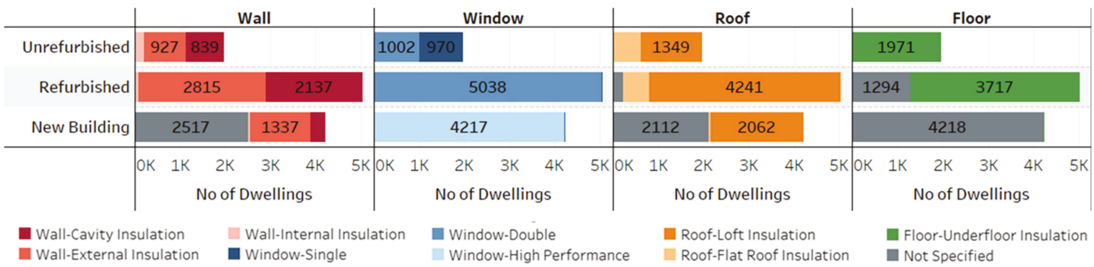

Figure A2. Types and specifications of construction elements (wall, window, roof, floor) in house archetypes and number of houses required energy efficiency requirement.

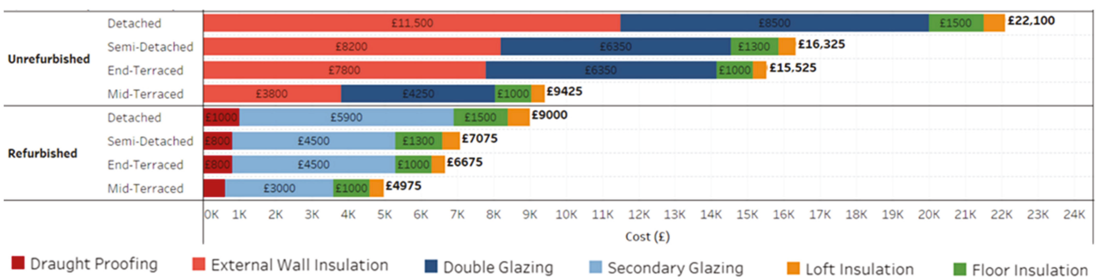

Figure A3. Breakdown of EEI costs by house archetypes and specifications.

Appendix D. EPC Ratings and Floor Area of House Archetypes

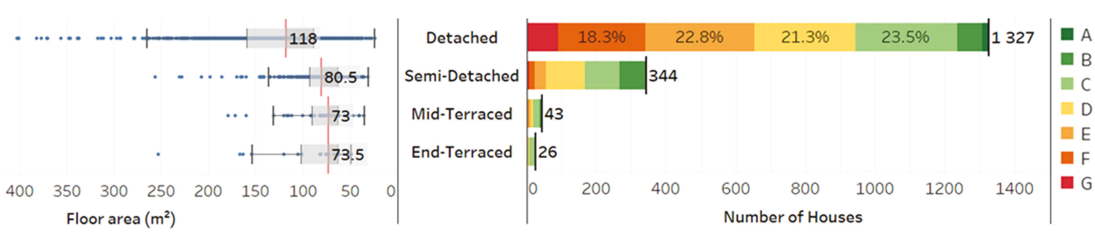

Figure A4. EPC ratings (**right**) and gross floor area (**left**) of house archetypes.

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Review

Green Marketing and Customers' Purchasing Behavior: A Systematic Literature Review for Future Research Agenda

Ilona Skackauskiene * and Neringa Vilkaite-Vaitone

Department of Management, Faculty of Business Management, Vilnius Gediminas Technical University (VILNIUS TECH), Sauletekio av. 11, LT-10223 Vilnius, Lithuania
* Correspondence: ilona.skackauskiene@vilniustech.lt

Abstract: With the rising concern for environmental issues, there is an ever-increasing demand for sustainable actions to minimize the damage to ecosystems. Seeking to meet such a demand, energy companies worldwide embrace green marketing solutions. This article aims to provide a comprehensive and systematic overview of green marketing and its impact on customers' purchasing behavior to develop a research agenda that helps to identify promising areas for future research. We conducted a systematic literature review to fill in the lack of conceptual clarity on the relationship between green marketing solutions and customers' purchasing behavior. After compiling a candidate pool of 2604 papers and applying a set of inclusion and exclusion criteria, the final sample comprised 166 articles published between 1995 and 2022. The results demonstrate that scholars frequently chose the energy sector to research green marketing's impact on purchasing behavior. The review indicates that the theory of planned behavior with its progenitor theory of reasoned action seems to be highly featured. The literature emphasizes green marketing at the tactical level as impacting customer behavior measures at the purchase and post-purchase stages. Our study helps marketers to identify the best practices in the area to influence customers' behavior effectively.

Keywords: responsible consumption; sustainability; green purchase; purchase intention; strategy; tactics; operations; clean technology

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1. Introduction

The increase in world population and lack of environmental consciousness has determined unsustainable consumption patterns. Unsustainable consumption has caused severe environmental problems such as increased greenhouse gas emissions, pollution, global warming, and natural resource depletion [1,2]. The rapid intensification of these problems raises the need for sustainability measures at every level of production, consumption, and general livelihood [2]. Therefore, "sustainability has become the mantra for companies seeking to create a competitive advantage in the global marketplace" [3] (p. 118).

Due to Russia's invasion of Ukraine, energy prices have hit all-time highs. The impact of the war and sanctions on Russia as a primary supplier of gas to Europe has determined a 3–4-fold increase in energy prices [4]. Under such circumstances, societies face the need for alternative and more ecological energy resources. The development and diversification of renewable energy sources have become fundamental issues of Europe's future attempts at sustainability and overcoming adverse climate changes.

Green marketing solutions have created a platform for sustainable consumption globally [1]. Even though the concept of green marketing has been circulating for quite some time, it currently enjoys a revival in popularity in the business world [5]. At the stage when customers' knowledge of renewable energy-related terms (such as renewable power, carbon footprint, and carbon offset) is increasing in scope and depth, businesses gain more pressure and opportunities to employ green marketing strategies [6]. Organizations embrace green marketing challenges to meet their customers' ever-growing demand for sustainable consumption. Green marketing has gained considerable importance in the contemporary marketplace [1]. This type of marketing provides a competitive advantage, improves organizational performance, and increases customer satisfaction [7,8]. Green marketing solutions enhance customer behavior indicators, i.e., purchase intention and energy consumption [2,9–11].

Even though research on green marketing and its impact on customer behavior has experienced vast growth in the number of publications in recent years, there exists a lack of conceptual clarity on the relationship between these two concepts. The absence of a detailed clarification of the impact of green marketing solutions on specific customers' purchasing indicators obstructs the exchange and development of scientific knowledge. It prevents marketers from finding out which green marketing solutions are the most promising in terms of customer purchasing behavior. Therefore, in this study, we raise the following research question: which green marketing solutions affect customers' purchasing behavior? To answer this question, there is a need for a review that analyses and synthesizes an existing array of studies in the field. In this respect, this research aims to provide a comprehensive and systematic overview of green marketing and its impact on customers' purchasing behavior to develop a research agenda that helps to identify promising areas for future research. The review utilized the PRISMA approach and covered 166 articles. These articles present the results of the studies that tend to remain largely isolated from the others. Considering the contextual differences between the studies, integrating their perspectives into a common framework can help to provide a holistic lens upon the green marketing phenomenon and its impact on customers' purchasing behavior.

In the background of systematic reviews on green marketing and its impact on customers' purchasing behavior, no research has categorized green marketing solutions based on the marketing planning horizon. The classification of green marketing practices as strategic, tactical, and operational green marketing solutions makes the study relevant, since the authors, based on this classification, were able to identify the impacted measures of customers' purchasing behavior on each level.

The theoretical and practical contribution of the current research can be summarized as follows:

1. This paper presents a structured and comprehensive overview of research on green marketing and its impact on customer purchasing behavior.
2. This paper synthesizes and categorizes the existing approaches to green marketing and its impact on customer purchasing behavior, which may help researchers to position their studies in the literature, and practitioners to find necessary topics.
3. The paper predicts promising research gaps and develops an agenda for future research paths.

The remainder of the paper is structured as follows: Section 1 discusses the structure of green marketing solutions that may affect customer behavior. Aiming for a methodologically rigorous literature analysis, this section presents a conceptual framework. This framework will later be applied for the classification of the literature sample. The following section describes the methodology for the systematic literature review. A systematic literature review focusing on customers' purchasing behavior is conducted in Section 3. Based on the systematic literature review results, we have prepared a discussion, conclusions, and suggestions for future research in Section 4.

2. Conceptual Framework

Aiming to substantiate the chosen research approach, we present the conceptual background corresponding to the research question. In this regard, we discuss the development and scope of the green marketing concept; later, we move on to the potential of green marketing solutions impacting customer purchasing behavior.

The history of green marketing dates back to the 1960s when the wave of environmental concern led to ecological marketing. This wave was linked to the industries with the most damaging impacts. Since then, the general concept has been represented by such terms as eco-marketing, ecological marketing, sustainable marketing, and environmental marketing [5].

The scope and meaning of green marketing tend to be misinterpreted [5]. Usually, it is limited to promoting green products [5,12]; however, green marketing involves many more components and activities to meet customers' green demands [13]. Considering the previous research on green marketing [14,15], the definition that closely reveals the spirit of the concept explains green marketing as an "organization's participation in strategic, tactical, and operational marketing activities and processes that have a holistic objective of creating, communicating, and delivering products with minimal environmental impact" [15] (p. 2). In this way, green marketing is concerned with a wide range of strategic, tactical, and operational activities.

At the strategic level, green marketing involves developing strategies to target and selectively appeal to environmentally conscious customers. Defensive or assertive strategies are available based on the prospected size of the green market and marketers' abilities to differentiate green products [16].

The tactical level of green marketing contains solutions related to the marketing mix that drives the organization towards sustainable marketing outcomes, creating value. It is a controllable marketing variable; therefore, the organization can consciously control its influence on customers [2]. It means that product, pricing, distribution, and promotion must clearly emphasize environmental ideas. These marketing mix components become part of green marketing strategies to meet customer demands [7].

Green products may be slight modifications of existing products or truly new green products. The latter may become a source for the company's differentiation; however, at the same time, they are riskier [3]. Green price demonstrated that environmentally sound products are more cost-intensive [5]. The green place's credential resides in renewable energy usage in supply chains [6]. According to Bañares et al. [12], green marketing strongly manifests its significance in advertising. Through advertising, business organizations communicate the environmentally friendly characteristics of their products [17].

At the operational level, green marketing focuses on attracting targeted environmentally conscious customers and efficiently completing the selling process [18]. We suggest marketers concentrate not only on the efficient completion of the selling process, but also on delivering environmental and social values.

Usually, green marketing applies to business-to-customer (B2C) markets; however, Gelderman & Vijgen [19] have proven that this concept is appropriate in business-to-business (B2B) or business-to-government (B2G) settings as well. Within the strategic, tactical, and operational contexts, the green customer with his specific behavior in B2C, B2B, or B2G market appears. Green purchasing behavior in any of these markets is generally associated with purchasing in a sustainable, responsible, ethical, and environmentally friendly way. Adopting green behavior is a central facet of achieving sustainability [17].

Seeking to understand green customer behavior, the concept of purchase intention has been featured in a number of studies [2,9,20]. Purchase intention is a crucial factor in predicting customer behavior [2]. Green purchase intention is defined as customers' tendency to pay a price premium for a green product or brand [20]. The increase in purchase intention shows that the possibility of purchasing a particular product by the customer increases correspondingly [2]. It means that marketers must develop marketing solutions that are green in nature to encourage the increase in purchase intention to grow into a purchase decision. However, it is essential to mention that the intention does not always translate into actual purchasing behavior [10,17]. If it translates, there is an opportunity to segment the customers based on their actual behavior. For example, Paço & Varejão [10] suggest segmenting customers who use electrical household appliances and other electrical equipment, air conditioning, and lighting based on their energy-saving behavior into savers and non-carers.

As the research object, green marketing follows two approaches in terms of impact. The first approach focuses on the green marketing influence on customer purchasing behavior, while the other systematizes the possible effect on the organization (with or without customer purchasing intention as a moderating/mediating variable). This research considers both approaches, with a relevant condition for the second approach. The studies representing the latter approach shall be included in the systematic literature review only if they involve any variable of customer purchasing behavior (as a dependent, moderating, or mediating variable).

3. Materials and Methods

Having analyzed the conceptual approaches to seeking desirable customers' purchasing behavior with green marketing, we now focus on the articles in the field to examine the links between green marketing and customers' purchasing behavior. For this reason, we have chosen to conduct a systematic literature review in the paper at hand. A systematic literature review is a robust, rigorous, and transparent method that allows one to examine a corpus of scholarly literature and develop critical reflections, insights, future research questions, and paths [21].

The research aims to provide a comprehensive and systematic overview of green marketing and its impact on customers' purchasing behavior to develop an agenda that helps to identify promising areas for future research. This study includes existing papers that met the selection criteria defined in this paper without any limitations on the year of publication. The paper employs a conceptual framework that covers all the relevant stages of the literature-selection process (Figure 1). The research used the PRISMA approach which presents clear step-by-step instructions for a systematic way of reviewing literature.

Following the methodology of a systematic literature review described in Patticrew and Roberts [22], and applied, for example, by Kostagiolas and Katsani [23], Khan, and Qureshi [24], we systematically searched the literature to identify the articles that cover the problems of green marketing and its impact on customer purchasing behavior. Three databases, namely Scopus, Web of Science, and EBSCOhost, were searched using the following keywords: "green marketing", "customer behavior", "consumer behavior", "purchasing behavior", "purchasing intention", "consumption", "buying", "purchasing", "green purchase", and "green consumerism". The combination of three databases prevents possible shortcomings of one database. The search in the databases was addressed to papers containing at least one combination of "green marketing" and any other keyword from the list in their title, abstract, or keywords. Only papers in English that appeared in peer-reviewed academic journals were considered relevant. We refrained from analyzing other publication outlets such as monographs, books, book chapters, commentary essays, conference proceedings, and letters to the editor. Searches were performed on May 2022.

Papers with a different content focus (e.g., demarketing, conventional marketing) or works that did not present empirical evidence were excluded from the analysis. An initial search resulted in many papers not specifying the possible relationship between green marketing and customer purchasing behavior in the title, abstract, or keywords. We manually screened the titles, abstracts, and keywords to determine whether the identified papers addressed our research problem. In particular, we eliminated duplicate articles. We also have decided to exclude literature reviews from the analysis.

The first evaluation condensed the literature sample to 254 papers. After reading the contents, we reduced the working sample to 166 relevant research articles. We have created an Excel workbook for records of primary data of the 166 articles that formed the evidence base of the review.

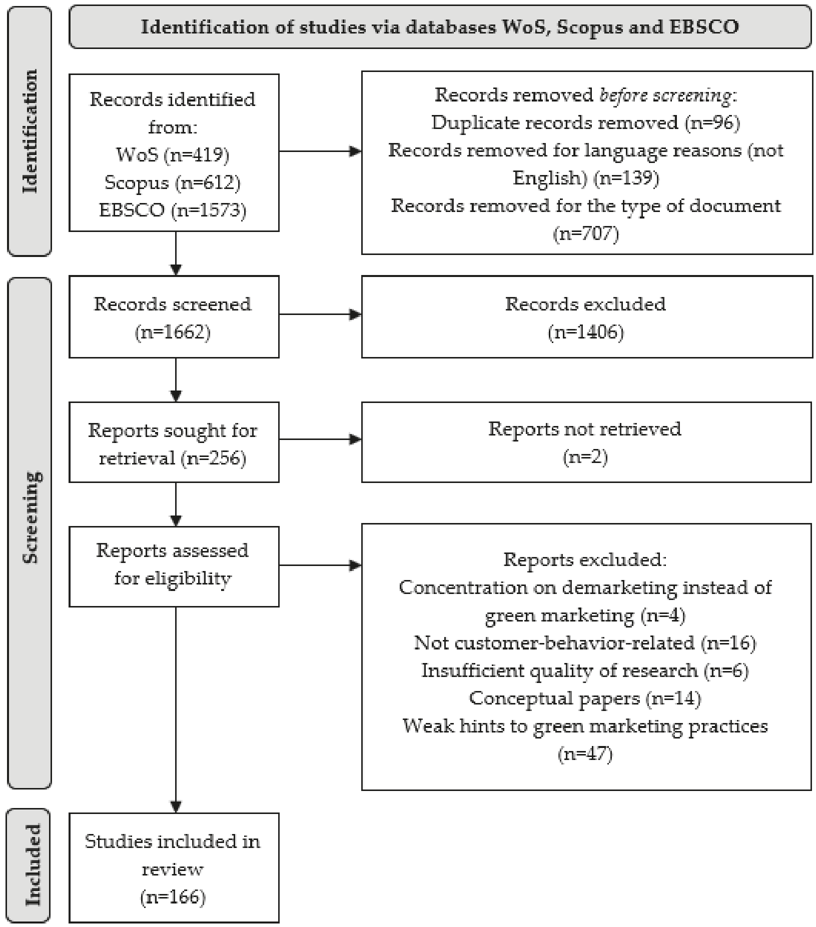

Figure 1. Flowchart of the literature-selection process based on the PRISMA approach.

4. Results

4.1. Characteristics of the Body of the Literature

The database search led to 612 initial hits in Scopus, 419 in WoS, and 1573 in Business Source Premier. After the first screening procedure for relevance in light of the chosen selection criteria and the elimination of duplicate papers, 254 papers remained in the initial sample. All the documents of the working pool were utterly read. Examining their contents led to a further exclusion of 87 articles and a final sample of 166 studies.

Figure 2 presents the number of sampled papers published every year. The first studies on green marketing and its relationship to customer behavior were published in 1995 (the work of Shrum et al. [25]). The trendline highlights the increasing research output in this field. On average, six articles per year were published during 1995–2022, with the years 2019–2021 being the ones with the highest productivity.

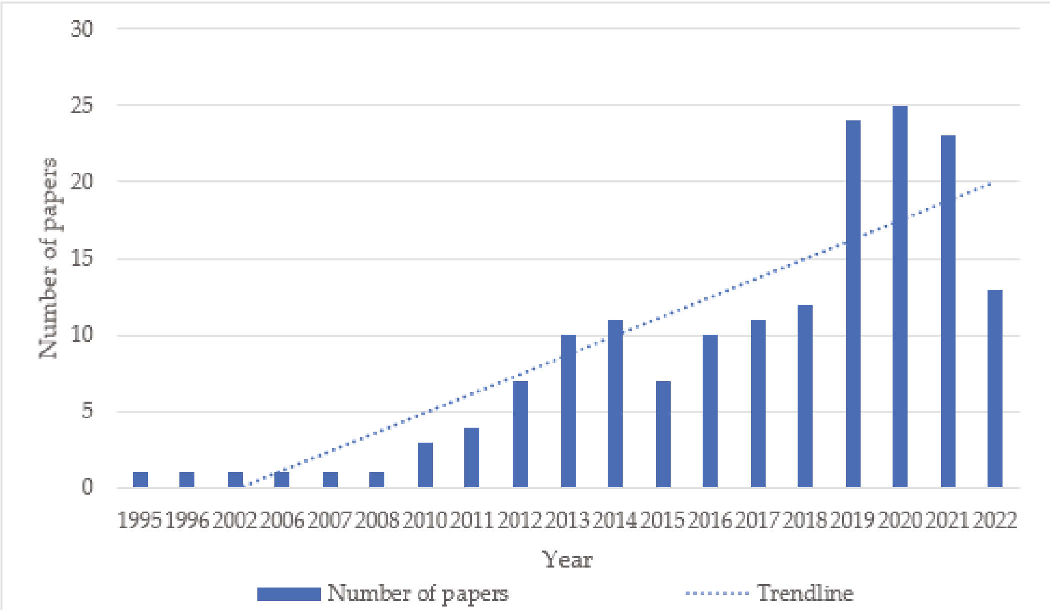

Figure 2. The number of papers published per year.

The articles were published in 120 different journals. Table 1 offers an overview of the academic journals that published papers containing the final sample. Sustainability published the most significant number of relevant studies. Marketing Intelligence & Planning, British Food Journal, Business Strategy and Environment, Electronic Green Journal, International Journal of Environmental Research and Public Health, Journal of Advertising, Journal of Cleaner Production, Journal of Retailing and Consumer Services, and Journal of Strategic Marketing are the other popular outlets for the research in green marketing. Such diversity in journal coverage reflects the interdisciplinary nature of green marketing and customer behavior. The broad nature of sources taken into consideration and not relying exclusively on marketing sources increases the credibility of a systematic literature review.

A. Paco and N.M. Suki were the authors who published the highest number of studies in the area of green marketing and customer behavior, with three records each. Fourteen other authors (A.A. Bailey, V. Bathmanathan, AB.C. Castro, Y.S. Chen, Y.R. Chen, D. Jaiswal, L.W. Johnson, A.S. Mishra, T.T. Pham, J. Rajadurai, V. Sethi, K.T. Smithy, M.F. Tiamiyu, and L. Varejeo) published two studies each.

Table 1. The number of papers published per journal.

Journal	Frequency	
	n	**%**
Sustainability	16	9.64
Marketing Intelligence & Planning	4	2.41
British Food Journal	3	1.81
Business Strategy and the Environment	3	1.81
Electronic Green Journal	3	1.81
International Journal of Environmental Research and Public Health	3	1.81
Journal of Advertising	3	1.81
Journal of Cleaner Production	3	1.81
Journal of Retailing and Consumer Services	3	1.81
Journal of Strategic Marketing	3	1.81
Innovative Marketing	2	1.20
International Journal of Advanced and Applied Sciences	2	1.20
International Journal of Consumer Studies	2	1.20
Journal of Business Ethics	2	1.20
Journal of Asian Finance, Economics and Business	2	1.20
Journal of Business Research	2	1.20
Journal of Food Products Marketing	2	1.20
Journal of Hospitality Marketing & Management	2	1.20
Journal of International Consumer Marketing	2	1.20
Journal of Islamic Marketing	2	1.20
Journal of Services Research	2	1.20
Marketing and Management of Innovations	2	1.20
World Journal of Entrepreneurship, Management and Sustainable Development	2	1.20
Other	97	58.43

4.2. Researched Settings

The selected papers are not evenly distributed across the continents in terms of researched settings. Most of them cover Asia (62.57%), with some participation from the remaining continents. The dominant position of Asia is undoubtedly related to the rapid growth of overall research activity in this continent since 2000 [26]. The papers' distribution across the continents has shown that 19% of studies were conducted in Europe and 8% in North America.

The research was carried out in 45 countries (Figure 3), distributed as follows: India with 21 studies; Malaysia with 14 studies; the United States of America with 12 studies; Pakistan and Taiwan with 11 studies each; China with ten studies; Indonesia with nine studies; Iran with eight studies; South Korea with seven studies; Vietnam with six studies; Portugal with five studies; Australia, Spain, Sweden, and the United Kingdom with four studies each; Ghana, New Zealand, and Romania with three studies each; Brazil, Canada, Netherlands, Slovakia, South Africa, Bangladesh, and Thailand with two studies each; and Algeria, Bangladesh, Brazil, Cambodia, Croatia, Egypt, France, Germany, Greece, Hong Kong, Italy, Kingdom of Bahrain, Malaysia, Mauritius, Poland, Saudi Arabia, Switzerland, United Arab Emirates, and Austria with one study in each country. Some studies (3.01%) were conducted in more than one country.

Studies on green marketing have been conducted in different sectors and industries (Table 2). Scholars conducted the most research (97.59%) in B2C markets; only four studies (2.41%) were devoted to analyzing green marketing's impact on purchasing behavior in B2B markets.

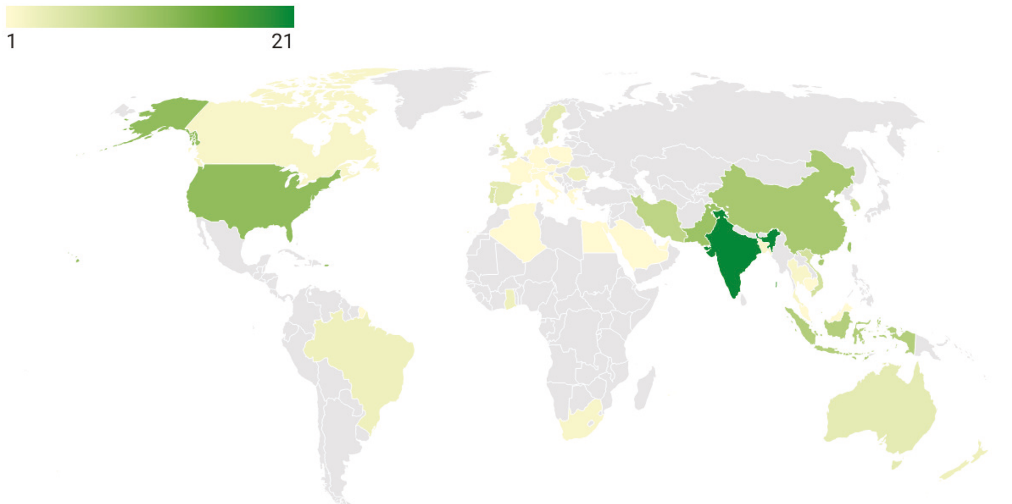

Figure 3. Countries of research locations (the colors indicate the intensity of studies).

Table 2. The researched products (classification based on The Global Industry Classification Standard).

Sector	Industry	Products
Energy	Energy equipment & services	Electronic products, batteries, renewable energy
	Oil, gas & consumable fuels	Gasoline, petrol
Materials	Paper & forest products	Paper
	Construction materials	Floor tiles
Consumer discretionary	Textiles, apparel & luxury goods	Apparel, fashion products, general handicraft & leather clothing, shoes, T-shirts
	Hotels, restaurants & leisure	Green hotels, rural tourism, restaurants services
	Automobiles & components	Alternative fuel vehicles, hybrid cars, automobile technology, motorcycles
	Household durables	Remanufactured robotic lawnmowers, reusable vacuum flasks, washing machines, furniture, kitchen cabinets
Consumer staples	Personal products	Organic cosmetics, personal care products, soap, napkins
	Food products	Bottled water, black tea, chocolate, coffee, dairy food, fruits and vegetables, meat, palm oil products, wines
	Household products	Fabric softeners, cold-water laundry detergents, dishwashing liquids, green detergents, laundry powder, single-use plastic and nylon bags
Information technology	Electronic equipment, instruments, and components	Camera, high-technology products, information and electronics products, laptops, cell phones, laser printers, smart table lamps, notebook
Communication services	Media & Entertainment	E-books
Cross-sectoral	FMCG, conventional products, environmentally friendly household products	

Approximately one-third of the studies (52 or 31.33%) were not devoted to one particular industry. Some studies focused exclusively on the energy sector and aimed to explore various facets of energy consumption (Table 3). For example, Sammer, Wüstenhagen [27], and Mydock [6] confined the analysis to the products subjected to an energy-labeling scheme. The list of such products consists of energy-efficient appliances such as washing machines. Some studies [10,11] were devoted to evaluating green marketing on energy consumption behavior, particularly energy saving. Other researchers [28,29] envisaged the risks of greenwashing in energy companies and the possible negative impact of greenwashing on customer behavior. Considering the array of green marketing studies in the energy sector, we state that this marketing is relevant and influential when the problem of depletion of finite energy resources is so essential.

Table 3. Theories/models explaining the impact of green marketing on customer behavior.

Theory/Model	Basic Ideology	Green Marketing Rationale	Representative Research
Theory of planned behavior (TPB)	Attitudes, subjective norms, and perceived control of individuals are the predictors of behavior.	The theory is capable of investigating internal factors that influence green purchasing behavior.	[8,30–46]
Theory of reasoned action (TRA)	The intention is a fundamental predictor of customer behavior, which is a function of attitudes and subjective norms.	The theory is capable of investigating internal factors that influence green purchasing behavior.	[32,45,47–54]
Attitude-behavior-context (ABC) theory	Attitude is the central predictor of behavior. Attitude may not translate into actual behavior as behavior depends on a series of contextual factors.	Favorable conditions stimulate green customers' behavior. Unfavorable conditions affect it adversely.	[28,55–57]
Stimulus-organism-response (SOR) model	The framework consists of three elements: stimulus, organism, and responses. Stimulus is associated with any environmental factor eliciting internal relations between an individual and the environment. Organism describes the structures and internal processes that intervene between individuals' final actions, responses, reactions, and external stimuli. The response is the customers' approach or avoidance.	Stimulus elements are eco-labeling and green advertising. They may have an impact on green customer-based brand equity. Organism elements may be green perceived quality, green image, and green trust. Purchasing intention falls into the response element.	[39,58–60]
Environmentally conscious consumer behavior (ECCB) model	The theory examines the reasons for behavior. Under this approach, cognition determines the act, which in turn has an impact on behavior.	The predictors of green purchase intention may be an acceleration of greenwashing, green skepticism, and customers' knowledge.	[61–63]
Cognition-affect-behavior (CAB) model	The paradigm suggests that cognition determines act, which has an impact on behavior.	Green perception and marketing strategy may change customers' perception of cognition-affect-behavior models over time.	[31,52]
Attribution theory	The theory explains causal relationships in human activities. The theory expounds on the objective of the organization and discusses how organizational behavior impacts customers' attitudes and behaviors.	Green marketing objectives in corporate settings have an influence on customer attitudes and behaviors based on customers' perceptions.	[64,65]
Four forces model	It is a structured approach that explains the cause, need, and process of sustainable development. The four main forces are customers, legislation, economic benefit, and community.	The model is the basis for engaging in the process of greening. To achieve sustainable development, the organization has to pass green marketing. The theory provides sufficient background to expect that customers will evaluate the accuracy of the promotional message and the credibility of its source.	[10,11]

Table 3. *Cont.*

Theory/Model	Basic Ideology	Green Marketing Rationale	Representative Research
Regulatory focus theory	Different motivation systems govern individuals' drive to reach the desired outcomes. Promotion-focused people concentrate on aspirations and achievements, and desired goals and life events fall into a set of gains and non-gains. Prevention-focused people tend to be vigilant and safe. For them, goals and life events fall into losses and non-losses.	Behavioral intentions regarding green marketing messages may differ among customers having different regulatory focus.	[66,67]
Signaling theory	The theory concerns how the information is represented in signals and transmitted from the sender to the receiver.	Green marketing communication is a signal that reduces customers' apathy toward product information. Eco-labeling increases the confidence and credibility of green marketing claims, and improves trust.	[56,59]
Value-belief-norm theory	The theory explains individuals' responses to environmentalism and concerns about how individuals' values lead to beliefs, subsequent norms, and purchase intentions.	The relative effect of altruistic behavioral orientation and economic orientation have an impact on customers' green purchase intention.	[68]

From the 166 articles analyzed, 154 (92.77%) applied a quantitative approach to research the chosen settings, four (2.41%) a qualitative one, and eight (4.82%) combined both approaches. Although data collection in most empirical research was quantitative-led, usually applying surveys, we have also found focus groups, interviews, and discourse observations among the pool of methods. The chosen participants in many cases of researched settings were customers, while others used students, family members, and friends. Participants' numbers ranged from 10 to 3264 (254 on average). Quantitative and qualitative or mixed studies contained specific theoretical approaches.

4.3. Theoretical Approaches Explaining the Impact of Green Marketing on Customer Behavior

This section summarizes different theoretical approaches toward desirable customer behavior with green marketing. We investigate theoretical reasoning in customer behavior theories concerning approaches to green marketing, enabling us to determine the biases and possible development directions of green marketing research.

Of the 166 documents, 66 (39.76%) provided a theory or model explaining customer behavior and green marketing as its antecedent. The remainder of the articles discussed green marketing's impact on customer behavior without explicitly choosing the theory or model (Table 3).

The theory of planned behavior is the most famous theoretical perspective on customer behavior in green marketing. This perspective considers attitudes, subjective norms, and perceived behavioral control as predictors of customer behavior. Although the recent marketing literature [69,70] criticizes the theory of planned behavior, this framework has profoundly influenced the evolution of customer behavior literature. Green marketing tools through the lens of the theory of planned behavior were introduced in the study by Testa et al. [45]. The authors focused on the effectiveness of one particular green marketing tool, eco-labeling. Since then, the popularity of the theory of planned behavior has been gradually increasing. For example, in a recent research, Ch et al. [8] emphasized that the theory of planned behavior strongly supports green purchasing behavior.

The other theoretical perspective, the theory of reasoned action, was also widely employed for research into adjusting customer behavior through the tools of green marketing. We have accumulated evidence of the use of this theoretical foundation in the studies of the impact of eco-labeling [45], green appeal [47], perception of green products [49], etc. The repeated applications of the theory of reasoned action are related to the aforementioned theory of planned behavior, as the theory of reasoned action originated as an improved version of the theory of planned behavior.

The other scholars have chosen stimulus-organism-response, cognition-affect-behavior, environmentally conscious customer behavior, four forces models, attitude-behavior-context, attribution, regulatory focus, or value-belief-norm theories as conceptual frameworks. Most research was based on one theory, but some scholars combined two or more theoretical perspectives. For example, Liao [56] confirmed that the combination of signaling and attitude-behavior-context theories could explain the moderation of green marketing on customers' purchase intention. However, some authors [2,68,69] did not exploit any theories.

4.4. Green Marketing Impact on Customers' Purchasing Behavior

The researched factors of green marketing compound three main categories based on the levels of green marketing. The first level describes the actions of green marketing exclusively from a strategic perspective. The second level focuses on tactical solutions commonly related to the marketing mix. The third level demonstrates the orientation toward operational actions in green marketing. Scholars chose these levels to research as a solitary focus or combined with the other levels (Table 4).

Table 4. The distribution of research across green marketing levels.

Green Marketing Levels	Frequency	
	n	%
Strategic	21	12.65
Tactical	105	63.25
Operational	0	0.00
Combination of strategic and tactical	23	13.86
Combination of tactical and operational	1	0.60
Combination of strategic, tactical, and operational	3	1.81
None or level is not explicitly stated	13	7.83
Totally	166	100.00

Many of the included documents focus on tactical green marketing's impact on customer behavior. The most common standard approach is to reveal tactical green marketing through the product (for example, energy labeling and cleaner production) or promotion (for example, green campaign and media exposure) (Table 5).

Table 5. The green marketing factors that have an impact on customer behavior.

Level	Researched Factors Having an Impact on Customer Behavior		Representative Research
Strategic	Brand (branding, image, brand relationships, brand equity, brand affect, brand associations), reputation, green marketing awareness, green design, green positioning, waste marketing, green integration, green management, greenwashing, image, perception, policy, strategic green marketing orientation, strategies		[7,28,29,71–76]
Tactical	Product	Packaging (claims, recyclability), eco-labels (trust, involvement), awareness about green products, cleaner production	[9,30,77–82]
	Price	Green pricing, price consciousness, price premium, price tags, price fairness, price advantages, awareness of price, price barriers	[8,33,36,68,83–85]
	Place	Green availability, green shops, point of purchase	[60,83,86,87]

Table 5. *Cont.*

Level	Researched Factors Having an Impact on Customer Behavior		Representative Research
	Promotion	Green advertising (design, advertisement credibility, appeals, skepticism), message (type, the use of sentiments, credibility), sources of marketing communication, media formats, green viral communication, green campaign, communication involvement, receptivity to green communication, media exposure	[17,20,46,58,62,67,78,88–90]
	Processes	Care in shopping, green procurement	[3,25]
Operational	Salesperson's green expertise, eco-servicescape, point of purchase information		[19,85]

Twenty-one of the reviewed papers (12.65%) used an entirely strategic approach to green marketing. It means that the development of branding, reputation, green marketing awareness, green design, green positioning, waste marketing, green integration, green management, greenwashing, image, perception, policy, strategic green marketing orientation, and strategies is a common practice to achieve the desired customer purchasing behavior.

By implementing strategic, tactical, and operational green marketing solutions, companies contribute to the desired customer behavior. The studies reviewed presented the relationships between green marketing solutions and key variables of customer behavior. Considering the wide variety of the variables, we have chosen to classify them based on the customer decision process and the theory of planned behavior (Figure 4). Traditionally, the customer decision process starts with need recognition, then passes to the stages of information search and evaluation, and ends in the stages of purchase and post-purchase [91]. Customer behavior metrics employed in the studies fall into the last two phases of the customer decision process. The purchase stage covers behavioral intention and actual behavior.

The studies reviewed confirm the relationships between green marketing and intentions measured as an intention to behave in an environmentally friendly manner, intentions to support a brand or organization, purchasing interest, product preference, green purchase intentions, and intentions to pay a price premium. The studies also register positive impacts of green marketing solutions on customer behavior towards the environment, energy-saving behavior, purchase behavior, and consumption level. Regarding the relationship between green marketing solutions and key variables of post-purchasing behavior, the studies analyzed show the increase in customer loyalty towards the brand, green product, green-oriented store, or green organization.

Based on green marketing research, we could find out the specific impact green marketing factors at different levels have on customer behavior measures (Table 6). It was found that promotion as an element of tactical green marketing has an immense potential to impact customer behavior measures.

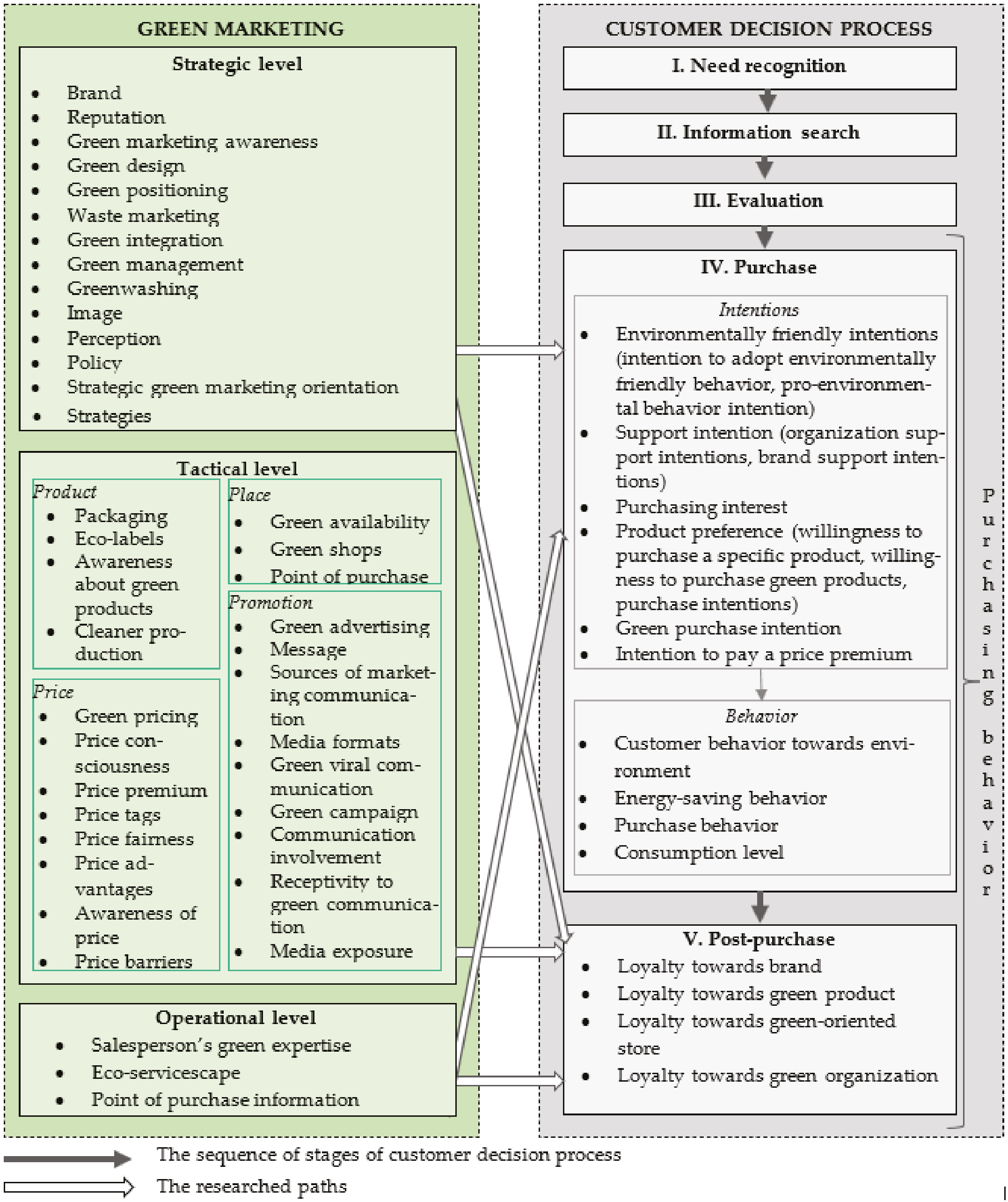

Figure 4. The researched paths between green marketing and customers' purchasing behavior.

Table 6. The researched paths between green marketing at different levels and specific customer-behavior measures.

The Stages of the Customer Decision Process		Customer-Behavior Measures	Green Marketing Levels								
			Strategic	Tactical: Product	Tactical: Price	Tactical: Place	Tactical: Promotion	Tactical: Processes	Combination of Strategic and Tactical	Combination of Tactical and Operational	Combination of Strategic, Tactical, and Operational
Purchase	Intentions	Environmentally friendly intentions					•				
		Support intention					•				
		Purchasing interest	•	•	•						
		Product preference	•	•	•	•	•				
		Green purchase intention	•	•	•	•	•		•		•
		Intention to pay a price premium		•					•	•	
	Behavior	Customer behavior toward the environment							•		
		Energy-saving behavior		•			•				
		Purchase behavior	•	•	•	•	•	•	•		
		Consumption level	•								
Post-purchase		Loyalty towards brand		•	•	•	•		•		
		Loyalty towards green product	•								•
		Loyalty towards the green-oriented store	•								
		Loyalty toward a green organization		•	•	•	•				•

5. Discussion

Green marketing solutions enhance various indicators of customer behavior; however, to date, there has been a lack of a detailed specification of how strategic, tactical, and operational green marketing practices affect customer behavior at different stages of the customer decision process. To unlock this puzzle, we aimed to provide a comprehensive and systematic overview of green marketing and its impact on customers' purchasing behavior to develop a research agenda that helps to identify promising areas for future research. We reviewed a large body of literature with the chosen systematic literature review methodology. We explored the past 28 years of research concerning the impact of green marketing on customer behavior. Even though we have reviewed a large number of existing literature on the effect of green marketing on customer behavior, there may still be papers that were not examined in this study. Since the last time we conducted a search was May 2022, it is likely that some 2022 papers on this topic were not included.

After the comprehensive review of articles included in the analysis, we categorized green marketing factors into three categories based on the levels of green marketing. The most common viewpoint to green marketing initiatives is bounded by the tactical level of green marketing, particularly promotion. However, green marketing is not only about the promotion of green products; it is a strategy, as well—a strategy that implies a radical change in the vision to lead organizations and not only to generate profits through desirable consumption behavior [92].

In the literature, there are definitions of purchasing behavior that explain the concept as the customer's search, purchase, usage, appraisal, and disposal of products, services, or ideas in order to satisfy their needs [93] (p. 1682). With regard to measuring customers' green purchasing behavior, we have identified the metrics that fall into two categories based on the stages of the traditional customer decision process, i.e., purchase and post-purchase. Green marketing at the strategic level increases purchase interest, product preference, purchase intention, purchase behavior, consumption level, loyalty towards green products, and green-oriented store. Regarding the green marketing solutions at the tactical level, we have noticed that green product and green promotion impact the widest variety of customer-purchasing measures, while the impact of green processes manifests in purchasing behavior. In the studies reviewed, any combination of green marketing solutions at different levels did not seem as powerful as initiatives implemented on one specific level. Therefore, we assume that the synergy of green marketing solutions representing more than one level may not strongly impact customers' purchasing behavior. However, a short list of measures may not mean a slighter impact; the impact may be strong but not diverse in terms of measures. Additional empirical evidence is required to determine how different combinations of green marketing solutions representing strategic, tactical, and operational levels affect customers' behavior at the purchase and post-purchase stages. Therefore, the authors of this paper commit to carrying out an empirical study in European countries to test the possible relationships between green marketing solutions and customers' purchasing behavior.

At the purchase stage, green marketing solutions influence intentions and actual behavior. However, we have to note that "the intention to purchase does not always translate into actual purchase behavior when consumers are confronted with a purchase situation" [91] (p. 423). This means that there may exist a gap between planned and actual customer behavior. In such a way, the possible impact of green marketing may end at the intentions without proceeding to the actual and post-purchase behavior. Despite this limitation, most reviewed studies confirm that green marketing is a reliable and essential tool that significantly impacts customers' purchasing behavior in the challenging business environment.

The other limitation of this systematic literature review is related to the choice to concentrate exclusively on behavioral indicators. According to the theory of planned behavior, an important antecedent of behavioral intention is attitude. In the researched sample, there were studies [62,89,94–96] that involved attitudinal indicators (attitude towards the green purchase, attitude towards the advertisement, brand attitude, etc.) next to the behavioral ones. However, this systematic literature review did not cover them as they fall out of the scope of behavioral indicators. However, the authors of this paper endorse the impact of attitudinal measures in aiming for desirable customer behavior.

The systematic literature review is limited in the choice of databases (WoS, Scopus, and EBSCO). Including other databases, for example, ProQuest, Springer, ScienceDirect and others, could contribute to the search for studies on green marketing and its impact on customers' purchasing behavior. However, the chosen three databases assured the research area's reliability. With this limitation in mind, we recommend that future studies in the analyzed field include more databases (for example, ProQuest, Springer, and ScienceDirect) and search engines (for example, Google Scholar and Microsoft Academic).

One more limitation of the systematic literature review on green marketing and its impact on customers' purchasing behavior is that this review does not present the quantitative results of a meta-analysis. However, the collected amount of data regarding the effect of green marketing solutions on customers' purchasing behavior is vast, and the authors of this paper consider the possibility of using this data in the future for a thorough meta-analytic structural equation modeling study of green marketing factors affecting customers' purchasing behavior.

The results of our literature review suggest the following research recommendations:

1. Much of the existing research supports green marketing only at the strategic or tactical level. We assume that more studies should adopt green marketing at more than one particular level. A demand exists for an integrated view of green marketing to maximize the impact on customer purchasing behavior.

2. In light of an increasing number of works on green marketing and its impact on customer behavior, the topic seems to be under-researched in terms of the following sectors: industrials, health care, financials, utilities, and real estate.

6. Conclusions

This review extends the existing literature on green marketing and its impact on purchasing behavior by providing an exhaustive overview of studies that developed the clarification of paths between strategic, tactical, and operational marketing, and customer behavior measures at different stages of the customer decision process, and it may support scholars in finding promising angles for future research.

Aiming to provide a comprehensive and systematic overview of green marketing and its impact on customers' purchasing behavior to develop a research agenda that helps to identify promising areas for future research, we suggested a framework of green marketing based on the strategical, tactical, and operational levels, and then categorized customer behavior measures depending on green marketing levels. Subsequently, papers that were found in databases were assigned to the identified categories. The analysis of 166 articles has shown that green marketing in terms of purchasing behavior has attracted vast attention during the last decades, with publication numbers increasing enormously after 2010 (over 96% of the sampled articles were published after 2010). Our review has indicated that the energy sector was frequently chosen for the research in green marketing's impact on purchasing behavior. Most sampled papers featured a theoretical approach based on the theory of planned behavior or its progenitor theory of reasoned action.

Our review shows that green marketing at the tactical level was often addressed as impacting customer behavior measures at the purchase and post-purchase stages. The most frequently affected customer behavior measures are green purchase intention and purchase behavior.

Even though the paper at hand has used a scientifically rigorous research methodology, our study has some limitations. First, the literature review sample was limited to articles published only in peer-reviewed academic journals. Including book chapters or conference proceedings may have resulted in additional important studies and insights. Similarly, the chosen keywords may have led to the exclusion of possibly relevant studies.

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