

## Article

# Integrated Digital Governance and Sustainability Management in Higher Education: Evidence from a Central Asian Technical University

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## Abstract

The growing implementation of the United Nations Sustainable Development Goals (SDGs) has increased the importance of sustainable transformation in higher education institutions. Universities are increasingly expected to integrate environmental management, digital technologies, governance, education, and community engagement into unified sustainability frameworks. However, integrated sustainability management models for technical universities in emerging economies remain insufficiently explored. This study analyzes the long-term transformation of the EKTU Green Campus project at D. Serikbayev East Kazakhstan Technical University (Kazakhstan) during 2018–2025. The research is based on methodological triangulation combining institutional statistical data, official UI Green-Metric methodologies and indicators, university sustainability reports, and verified ranking results. The study examines the interaction between Smart Campus technologies, digital governance, sustainability-oriented education, environmental management, and campus infrastructure modernization. The results indicate substantial progress across multiple dimensions of institutional sustainability, including energy efficiency, digital sustainability governance, renewable energy implementation, sustainable transportation, circular economy practices, and education and research indicators. The findings suggest that Smart Campus technologies and digital monitoring systems can function as core instruments of institutional sustainability management rather than solely as technical infrastructure solutions. The EKTU Green Campus experience provides a practical reference for sustainability transformation in technical universities in Central Asia and other developing regions, while acknowledging that its applicability may depend on local institutional and socio-economic contexts. The study is limited by its single-case design and its reliance on institutional and ranking data, which may affect the generalizability of the findings.

**Keywords:** sustainable university; Green Campus; digital governance; sustainability management; higher education; SDGs; sustainability transformation



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## 1. Introduction

In the context of the implementation of the United Nations Sustainable Development Goals (SDGs) and the increasing scale of global environmental challenges, universities are becoming critically important as catalysts for positive social transformation [1–4]. Higher education institutions are expected not only to generate knowledge but also to demonstrate the practical implementation of sustainable practices, thereby establishing the foundations for long-term environmental stability and responsible resource management.

This growing role of universities in sustainability transformation is further reinforced by international policy frameworks, global academic networks, sustainability rankings, and institutional initiatives that increasingly position higher education institutions as key actors in achieving the SDGs and implementing integrated Green and Smart Campus strategies worldwide.

As early as 2008, the United States Congress adopted the Higher Education Sustainability Act, which provided for the organization of a national sustainability summit for universities and established a federal grant program to support sustainable practices in higher education institutions [5]. In China, the transition toward “green” universities began with the Agenda 21 initiative in 1993, which emphasized the importance of sustainability-oriented education. Subsequently, the government introduced the “Green School” and “Green University” programs and, in 2008–2009, published national guidelines on campus energy efficiency and environmentally sustainable infrastructure development [6].

The growing importance of sustainability in higher education has also been reinforced through international initiatives and policy frameworks. The 2022 UNESCO World Higher Education Conference in Barcelona gathered more than 14,000 participants and resulted in the adoption of the “Beyond Limits: New Ways to Reinvent Higher Education” roadmap aimed at transforming universities in support of the Sustainable Development Goals (SDGs) [7]. In parallel, the Higher Education Sustainability Initiative (HESI), launched under the auspices of the United Nations in 2012, has brought together hundreds of universities and academic networks worldwide to strengthen the role of higher education institutions in achieving the SDGs through annual forums, partnerships, and sustainability-oriented activities [8].

At the European level, the Council of the European Union adopted a recommendation in June 2022 encouraging member states to integrate the “green transition” across all levels of education. The document emphasizes the need for an institutional approach that incorporates sustainability principles into curricula, governance systems, and campus infrastructure in order to support the implementation of the SDGs [9]. Complementing this agenda, the European University Association (EUA) published the “Green Deal Roadmap for Universities” in 2023, outlining mechanisms through which universities can contribute to climate neutrality and social equity by integrating the European Green Deal into research, education, and institutional governance practices [10].

International collaboration has become another important mechanism for accelerating sustainability transformation in higher education. For example, the International Sustainable Campus Network (ISCN), which includes more than 100 universities worldwide, serves as a platform for exchanging best practices and developing collaborative strategies for sustainable campus development [11]. Annual ISCN conferences bring together institutional leaders, researchers, and students to discuss innovative approaches to sustainability governance and “green” university transformation. Similarly, the United Nations Sustainable Development Solutions Network (SDSN) connects more than 2100 universities and research institutions through regional and national networks focused on advancing the SDGs and the Paris Climate Agreement. The network actively promotes the integration of sustainability principles into higher education research and teaching activities [12].

In Kazakhstan, the SDGs have been formally incorporated into national strategic development priorities. The country adopted the “Concept of Transition to Sustainable Development” for 2007–2024, followed by the “Concept for the Development of Education for 2022–2026”, both of which emphasize the integration of sustainability principles and Education for Sustainable Development (ESD) into educational programs and institutional policies [13,14].

Consequently, over the last decade, the concepts of “green” and “smart” campuses have become important research directions in higher education studies. Nevertheless, limited attention has been paid to integrated sustainability management models in universities that combine governance, digitalization, Smart Campus technologies, environmental performance, education, and stakeholder engagement within a unified institutional framework, particularly in the context of technical universities in emerging economies and Central Asia.

A growing body of literature emphasizes the necessity of integrated approaches combining infrastructure transformation, digitalization, and community participation. For example, Sun et al. [15] conducted a comprehensive assessment of nine Chinese university campuses, analyzing user satisfaction with green infrastructure and demonstrating a multi-dimensional approach to campus quality evaluation, including land use, transportation systems, and green buildings. Similar ideas are reflected in research on Smart Campus development for emerging regions. Using the case of Papua New Guinea, Polin et al. [16] argued that Smart Campus models developed in high-income countries require adaptation to local infrastructural and socio-economic conditions. Their findings highlight how digital and educational initiatives may be modified to regional realities, which is particularly relevant for the replication of Green Campus practices in developing regions. In another study, Polin et al. [17] identified the key social, economic, environmental, and governance dimensions of Smart Campus systems and proposed a conceptual framework for their integration into higher education environments.

However, these studies mainly focus on individual dimensions of sustainable campus development, such as infrastructure quality, smart technologies, or user perception, while integrated governance models combining digitalization, sustainability management, educational transformation, and institutional decision-making within a unified long-term framework remain insufficiently explored.

The integration of digital technologies into campus sustainability management has become another important research direction. Manokeaw et al. [18] developed a modular digital twin system for campus infrastructure management at Chiang Mai University, integrating 3D building models, IoT sensor networks, and analytical dashboards for real-time energy monitoring and optimization. Likewise, Zaballos et al. [19] proposed a Smart Campus concept combining BIM technologies and IoT sensors to monitor microclimate conditions and user comfort. Their study demonstrated how sensor networks can function as digital twins of university campuses, collecting environmental data to improve building energy efficiency and campus sustainability performance. In addition, Rey-Hernández et al. [20] introduced an AI-based framework for predicting and optimizing energy consumption and CO<sub>2</sub> emissions across university buildings. Their results confirmed that machine learning models can effectively support energy demand forecasting and contribute to campus decarbonization strategies.

In addition to the integrated sustainability governance perspective, this study is informed by the Socio-Technical Systems (STS) Theory [21], which emphasizes that organizational performance emerges from the interaction between technological systems, institutional processes, and human actors rather than from technological innovation alone. From this perspective, digital tools such as Smart Campus platforms and E-monitoring systems

contribute to sustainability transformation only when they are embedded within organizational governance, management practices, and stakeholder engagement. The STS perspective therefore provides a suitable theoretical lens for interpreting the long-term integration of digital governance and sustainability management in higher education institutions.

Despite the growing interest in Smart Campus technologies, most of these studies primarily focus on technological architectures and operational efficiency, while insufficient attention is given to the institutional integration of digital platforms with sustainability governance, educational transformation, and long-term strategic management.

Research on sustainable digital transformation in higher education further confirms the growing convergence between digitalization and sustainability. Abad-Segura et al. [22] demonstrated an exponential increase in publications related to sustainability, technologies, and sustainable management in higher education during the last decade. Their findings indicate that digital transformation is becoming increasingly interconnected with environmental agendas in universities. Nevertheless, these studies mainly analyze publication trends and conceptual interrelations, while providing limited empirical evidence on how integrated sustainability management systems are implemented at the institutional campus level.

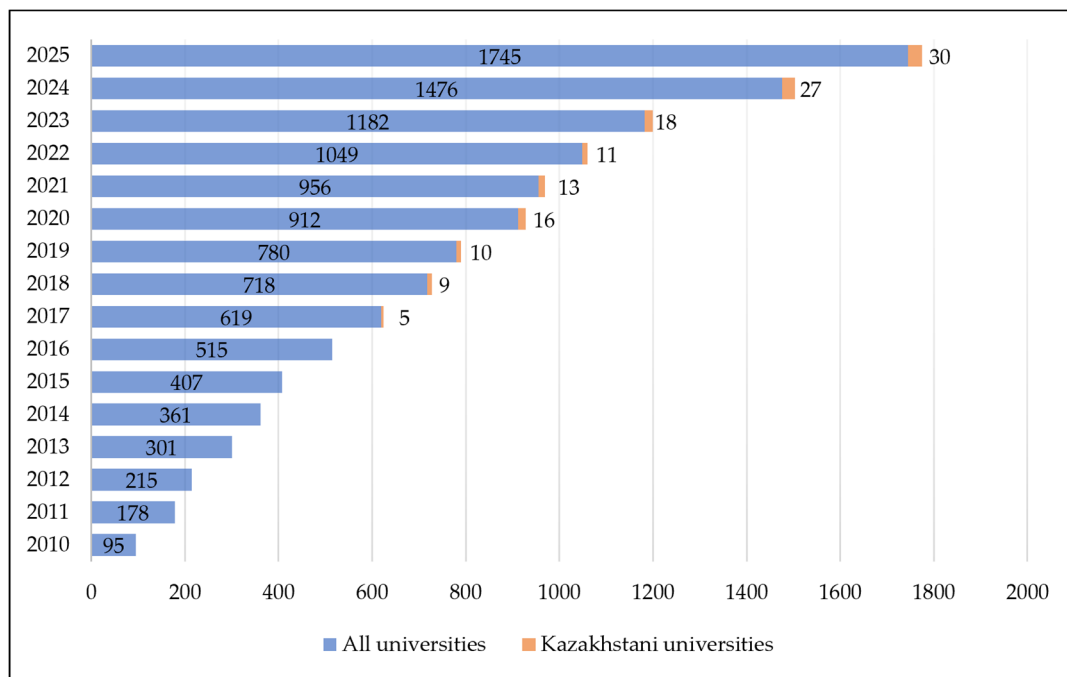
The operational dimension of sustainable campuses has also received considerable attention in recent years. Araújo et al. [23] emphasized that university campuses can be viewed as small cities due to their scale and resource consumption patterns. Their study analyzed renewable energy implementation, energy-efficiency measures, water conservation, and sustainable transportation practices, demonstrating the importance of integrated sustainability actions combined with environmental education for students and staff. Waste management and circular economy practices have similarly become important topics within campus sustainability research. A case study by Savi-Bortolotto et al. [24] described the implementation of a selective waste collection system at a Brazilian federal university, where community engagement and systematic waste management significantly increased recycling rates and reduced municipal solid waste generation. Rodríguez-Guerreiro et al. [25], in a global review of waste management practices in higher education institutions, highlighted the importance of stakeholder participation, circular economy principles, and multidisciplinary approaches for achieving zero-waste campus models.

At the same time, most of these studies investigate individual operational components of sustainable campuses—such as energy systems, waste management, transportation, or circular economy practices—without sufficiently examining how these elements can be integrated through digital governance, Smart Campus infrastructure, and institution-wide sustainability management systems.

A broader systematic perspective is presented in the work of Oliveira and Proença [26], who reviewed sustainable campus operations literature and identified strong interconnections among energy management, infrastructure, transportation, waste management, governance, and innovation. Their findings emphasize the importance of leadership, institutional coordination, and integrated management approaches in achieving campus sustainability. In this context, international sustainability rankings have become important instruments for benchmarking and stimulating sustainability transformation in higher education institutions.

One of the most influential frameworks is the UI GreenMetric Sustainable University Rankings (Figure 1) developed by Universitas Indonesia [27]. The ranking system currently includes 60 indicators across seven categories: Setting and Infrastructure, Energy and Climate Change, Waste, Water, Transportation, Education and Research, and Governance and Digitalization. Annual ranking statistics demonstrate the growing global involvement of universities in implementing SDG-oriented sustainability initiatives on campuses and

within surrounding communities. Furthermore, official reports from the Ministry of Science and Higher Education of Kazakhstan indicate the increasing participation of Kazakhstani universities in the global sustainability agenda [28].



**Figure 1.** Number of participating universities in UI GreenMetric.

Thus, contemporary university campuses are increasingly viewed as integrated environments that combine the functions of small cities with experimental platforms for sustainable and Smart development. Existing studies have extensively examined individual dimensions of campus sustainability, including energy efficiency, carbon reduction, waste management, renewable energy, digital twins, AI- and IoT-based Smart Campus technologies, and sustainability assessment through frameworks such as UI GreenMetric. Collectively, these studies demonstrate the value of digital technologies and sustainability initiatives for improving campus performance. However, they tend to address these dimensions separately, with relatively limited attention to the institutional mechanisms that integrate digital governance, environmental management, education, campus infrastructure, and stakeholder engagement into a coherent long-term sustainability strategy. From this perspective, Smart Campus technologies can be understood not only as technical solutions but also as governance instruments that support data-driven decision-making, coordination, and continuous sustainability management.

This limitation is particularly evident in studies of technical universities in emerging economies, where sustainability transformation is shaped by financial, infrastructural, and regional constraints. Consequently, there remains limited empirical evidence on how integrated sustainability governance evolves over time within a single institutional framework and how digital governance supports this process. To address this gap, the present study analyzes the long-term transformation of the EKTU Green Campus project during 2018–2025, examining the interaction between digital governance, Smart Campus technologies, environmental management, education, and stakeholder engagement within an integrated sustainability management framework.

This study addresses the following research questions:

1. How has the EKTU Green Campus project evolved from isolated environmental initiatives into an integrated sustainability management system?

2. What role do digital governance and Smart Campus technologies play in supporting sustainability governance and campus operational performance?
3. How do infrastructure modernization, sustainability-oriented education, and stakeholder engagement contribute to institutional sustainability transformation?
4. To what extent can the EKTU Green Campus experience inform sustainability practices at technical universities in Central Asia and other developing regions?

The contributions of this study are threefold. First, it contributes to the theoretical discussion by conceptualizing digital governance and Smart Campus technologies as enabling mechanisms for integrated sustainability transformation in higher education. Second, it provides empirical evidence from a longitudinal case study of a technical university in an emerging economy, illustrating how digitalization, governance, environmental management, and education interact over time within a unified institutional framework. Third, it offers practical insights for higher education institutions seeking to strengthen sustainability governance through the integration of digital monitoring systems, Smart Campus technologies, and SDG-oriented management practices.

This study is guided by the proposition that digital governance and Smart Campus technologies facilitate the integration of sustainability management processes within technical universities.

This study does not seek to develop a new general theory of sustainable universities; rather, it contributes to the understanding of how digital governance mechanisms can facilitate the institutional integration of sustainability processes in the context of a resource-constrained technical university.

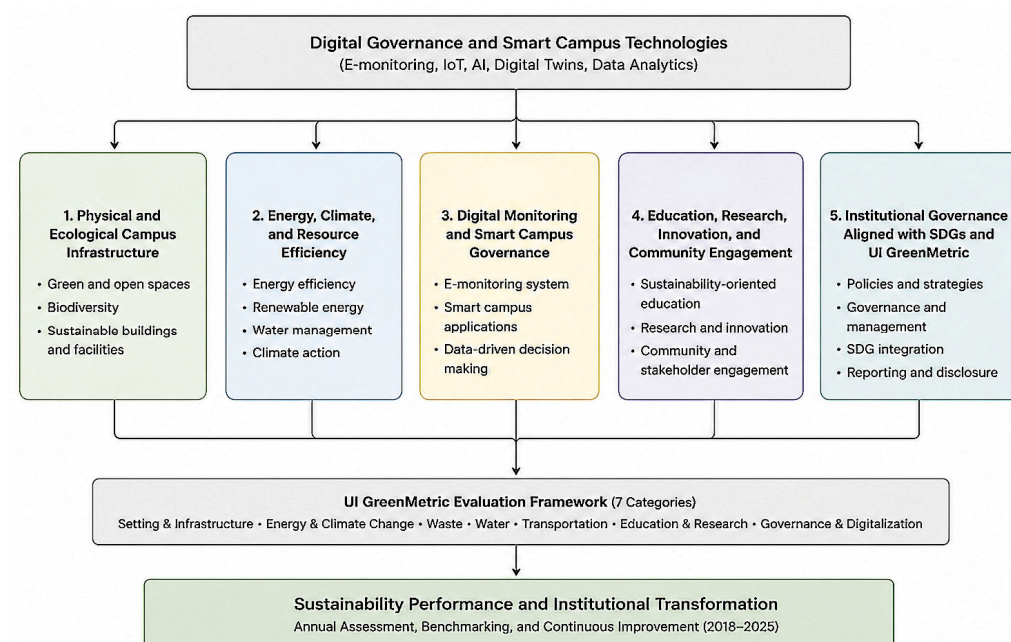
## 2. Materials and Methods

### 2.1. Research Design

This study applies a single-case study design to examine the integrated sustainability management model implemented at D. Serikbayev East Kazakhstan Technical University (EKTU), Kazakhstan. The case-study approach was selected because the Green Campus initiative represents an institution-wide transformation process combining infrastructure modernization, digital governance, environmental management, education, research, and stakeholder engagement.

The methodological framework is based on the UI GreenMetric Sustainable University Rankings approach, which evaluates university sustainability performance through structured indicators related to campus infrastructure, energy and climate change, waste, water, transportation, education and research, and, from 2026, governance and digitalization. The UI GreenMetric framework is suitable for this study because it is designed as a self-assessment and benchmarking tool for higher education institutions and captures policies, programs, and measurable sustainability outcomes.

The conceptual framework of the study (Figure 2) illustrates the relationships among the main analytical dimensions examined in this research. It positions digital governance and Smart Campus technologies as enabling mechanisms that connect institutional governance with environmental management, campus infrastructure, education and research, and stakeholder engagement, thereby supporting sustainability transformation. The framework guided the selection of data sources, the organization of the analytical dimensions, and the interpretation of the empirical results presented in the following sections.



**Figure 2.** Conceptual framework of the study.

## 2.2. Case Study Context

The object of the study is D. Serikbayev East Kazakhstan Technical University, a technical university in Kazakhstan established in 1958. The university operates seven facilities, including academic buildings, student hostels, and the Summer Expedition Campus “Prostor”. The total campus area reported in the GreenMetric evidence file is 539,163 m<sup>2</sup>, including urban campus facilities and a rural expedition campus located near the Bukhtarma reservoir.

The Green Campus project has been implemented at EKTU since 2018 and includes measures related to green infrastructure, biodiversity conservation, energy efficiency, smart campus technologies, waste and water management, sustainable transportation, education, research, and SDG-oriented governance [29].

## 2.3. Data Sources

The study is based on longitudinal institutional sustainability data collected at D. Serikbayev East Kazakhstan Technical University (EKTU) during the implementation of the Green Campus initiative from 2018 to 2025. The dataset includes internal university statistics related to campus infrastructure, energy consumption, renewable energy production, waste management, water management, transportation systems, sustainability financing, education and research activities, digital infrastructure, and SDG-oriented governance.

Data collection was carried out retrospectively using institutional records accumulated during the implementation of the Green Campus project. The dataset consists exclusively of administrative and operational data routinely collected by the university for management, sustainability reporting, and participation in the UI GreenMetric ranking. No surveys, interviews, or personal data collection were conducted as part of this study.

The primary empirical basis of the study consists of institutional monitoring and reporting data accumulated through the university’s digital E-monitoring system and Smart Campus infrastructure. The system integrates operational, environmental, educational, financial, and infrastructural information and enables continuous monitoring of sustainability indicators across university facilities. According to institutional documentation, the E-monitoring environment supports management analytics, environmental monitoring,

energy management, IT infrastructure monitoring, educational process management, and sustainability reporting.

To ensure comparability and methodological consistency, the study also uses official UI GreenMetric guidelines and methodological frameworks issued between 2019 and 2025, including the updated UI GreenMetric Sustainable University Rankings Guideline 2026. These documents were used to analyze the evolution of sustainability indicators, scoring systems, digitalization criteria, and governance-related requirements within the ranking methodology.

In addition, official EKTU UI GreenMetric Fact Files for 2020–2025 were analyzed as multiple documentary sources. These reports contain annual ranking results, category scores, indicator-level performance data, and historical ranking dynamics. The longitudinal analysis of the fact files made it possible to trace the university's sustainability trajectory and institutional performance improvements over time, including the increase in the overall global ranking from 152nd place in 2020 to 97th place in 2024 and 139th place in 2025.

The combined use of internal operational statistics, institutional sustainability evidence, ranking methodologies, and externally verified fact files enabled a comprehensive assessment of the EKTU Green Campus Model as an integrated sustainability management system within higher education.

#### 2.4. Analytical Framework

Guided by the conceptual framework presented in Figure 2, the analysis combines the UI GreenMetric methodological structure [27] with an integrated sustainability governance perspective. Accordingly, the empirical evidence was organized into five interrelated analytical dimensions that reflect the interactions between digital governance, environmental management, campus infrastructure, education and research, and institutional sustainability management.

In this study, integration refers to the coordinated interaction of these analytical dimensions through shared digital monitoring, institutional reporting, and decision-making processes, rather than to the implementation of isolated sustainability initiatives.

For 2026, the UI GreenMetric ranking framework consists of seven categories: Setting and Infrastructure, Energy and Climate Change, Waste, Water, Transportation, Education and Research, and Governance and Digitalization. These categories are weighted respectively as 11%, 20%, 17%, 11%, 17%, 13%, and 11% of the total score.

Although the updated UI GreenMetric Guideline 2026 is used to describe the current analytical structure of the ranking framework, the longitudinal assessment of the EKTU Green Campus project was conducted using the official UI GreenMetric methodologies and indicator definitions applicable to each respective reporting year (2018–2025). The 2026 framework was applied only to organize and interpret the empirical findings within a consistent analytical perspective, particularly with regard to the governance and digitalization dimension, and was not used to retrospectively recalculate or compare historical ranking scores.

For this article, the EKTU Green Campus Model is interpreted as an integrated management system consisting of five analytical dimensions:

- physical and ecological campus infrastructure;
- energy, climate, and resource efficiency;
- digital monitoring and smart campus governance;
- education, research, innovation, and community engagement;
- institutional governance aligned with SDGs and UI GreenMetric indicators.

### 2.5. Data Processing and Interpretation

Quantitative indicators were extracted from institutional evidence and grouped according to the UI GreenMetric categories. To ensure consistency of interpretation, the collected evidence was organized according to the analytical dimensions presented in Figure 3 and mapped to the corresponding UI GreenMetric categories. Examples include open space ratio, planted vegetation area, sustainability budget share, electricity consumption, renewable energy production, smart building implementation, and category-level GreenMetric scores.



**Figure 3.** Dynamics of EKTU's total sustainability score, global ranking position, and the number of participating universities, 2020–2025.

Qualitative institutional documents were examined through structured document analysis. The analysis focused on identifying documented evidence related to the five analytical dimensions defined in the conceptual framework, including digital governance, environmental management, campus infrastructure, education and research, and institutional governance. Rather than applying formal qualitative coding procedures, the documents were systematically reviewed and interpreted in relation to the study objectives and triangulated with quantitative institutional indicators and UI GreenMetric documentation.

Particular attention was given to evidence showing integration between sustainability actions and management mechanisms, such as E-monitoring, Smart Campus systems, ICT-based reporting, and SDG-oriented infrastructure planning. EKTU's evidence file indicates that ICT tools are used for monitoring and analytical data processing in management, security, environmental monitoring, finance, education, IT infrastructure, and other institutional processes.

### 2.6. Data Triangulation and Benchmarking

The reliability of the study was strengthened through methodological triangulation [30,31] by comparing cross-checked category scores, including institutional operational statistics, official sustainability reports, UI GreenMetric methodological documents, and published ranking results. In this context, the term “verified” refers to the benchmarking procedures applied by the UI GreenMetric organization during the ranking assessment process. It does not imply an independent external audit of all institutional data used in this study. Internal data obtained from the EKTU E-monitoring system and sustainability reporting databases were compared with annual UI GreenMetric Fact Files for 2020–2025, which contain published category scores, ranking positions, and performance indicators.

The benchmarking procedure also included consistency analysis of indicator definitions and scoring criteria using UI GreenMetric methodological guidelines issued between 2019 and 2026. Longitudinal comparison of annual ranking results assessed the consistency of sustainability trends and institutional transformation dynamics during the implementation of the EKTU Green Campus project from 2018 to 2025.

To reduce potential researcher bias, institutional data were interpreted using predefined analytical categories based on the UI GreenMetric framework and the conceptual model of the study. Findings were derived through triangulation of multiple documentary sources rather than relying on a single dataset or subjective interpretation. The analysis focused on identifying consistent patterns across data sources instead of evaluating individual sustainability initiatives in isolation.

Although the authors are affiliated with the case-study institution, the analysis was based on documented institutional evidence rather than personal observations. Quantitative results were derived from official institutional records and cross-checked against the corresponding annual UI GreenMetric evidence files and published ranking outcomes to ensure consistency of reporting and interpretation. Qualitative evidence was interpreted using the predefined analytical dimensions presented in Section 2.4, while institutional documents, official evidence files, and quantitative indicators were considered jointly to ensure a consistent interpretation of the findings.

## 3. Results

### 3.1. Longitudinal Development of the EKTU Green Campus Project (2018–2025)

#### 3.1.1. Evolution of Sustainability Strategy and Institutional Governance

The evolution of the EKTU Green Campus project demonstrates a transition from isolated environmental initiatives toward an integrated sustainability management system aligned with international sustainability frameworks and the Sustainable Development Goals (SDGs). Since 2018, D. Serikbayev East Kazakhstan Technical University (EKTU) has systematically incorporated sustainability principles into institutional governance, campus development, digital transformation, and educational modernization.

The strategic transformation was closely associated with participation in the UI GreenMetric World University Rankings, which served not only as a benchmarking instrument but also as a management framework for sustainability assessment and institutional improvement. The longitudinal ranking dynamics are consistent with the university's gradual

sustainability transformation and provide an indicator of institutional progress over the study period. EKTU improved its global position from 152nd place in 2020 to 97th place in 2024, while consistently maintaining 1st place among universities in Kazakhstan.

An important feature of the EKTU model is the integration of sustainability governance with digitalization processes. The university gradually developed a Smart Campus ecosystem supported by ICT-based monitoring, centralized digital services, environmental analytics, and institutional E-monitoring systems. According to institutional evidence, digital tools are currently used for environmental monitoring, infrastructure management, energy control, educational administration, financial analytics, and sustainability reporting.

The governance model also evolved toward a human-centered and SDG-oriented approach. This transformation included the expansion of inclusive infrastructure, health and well-being programs, biodiversity conservation initiatives, and sustainability-focused research projects. Strategic investments in green infrastructure, renewable energy systems, and digital educational platforms strengthened institutional resilience and sustainability performance.

The 2026 UI GreenMetric framework emphasizes governance, digitalization, and integrated performance as key dimensions of sustainable campus development. EKTU's experience suggests that integrating institutional governance with Smart Campus technologies and sustainability-oriented decision-making can support the development of an integrated sustainability management model that may be relevant for technical universities in emerging economies.

Overall, the longitudinal evidence indicates that the sustainability transformation at EKTU was driven by the gradual integration of governance, digitalization, and institutional planning rather than by isolated environmental initiatives. The observed improvement in ranking performance and the expansion of Smart Campus functions suggest that digital governance supported the coordination and continuity of sustainability measures across multiple operational domains. These findings provide empirical support for interpreting the Green Campus project as an integrated institutional management approach rather than a collection of independent sustainability activities.

### 3.1.2. Dynamics of UI GreenMetric Rankings and Sustainability Performance

The dynamics of EKTU's participation in the UI GreenMetric ranking demonstrate an overall long-term improvement in institutional sustainability performance during the implementation of the Green Campus project. According to official UI GreenMetric Fact Files, the university improved its global ranking position from 152nd place in 2020 to 105th in 2022, 100th in 2023, and 97th in 2024. In 2025, EKTU ranked 139th globally among 1745 participating universities from 105 countries.

Although the university's ranking position declined in 2025, this change coincided with a substantial increase in the number of participating universities and should therefore be interpreted within the context of increasing international competition rather than as a reversal of the overall long-term sustainability trajectory.

At the national level, EKTU consistently maintained 1st place in Kazakhstan throughout 2020–2025, confirming its leading role in sustainable campus development in the country. The university showed a substantial long-term increase in its total sustainability score, from 7100 points in 2020 to 8475 points in 2024, followed by a slight decrease to 8412.5 points in 2025 (Figure 3).

The strongest performance improvements were observed in the categories of Energy and Climate Change, Transportation, and Education and Research. High scores in these areas were associated with Smart Campus implementation, renewable energy systems, digital governance tools, sustainability-oriented education, and active research initiatives.

The university achieved maximum or near-maximum scores in several indicators related to sustainability education, open space management, smart buildings, and transportation policies (Tables 1 and 2).

**Table 1.** Change in EKTU scores by year and category of the questionnaire.

| Year                     | Max *  | 2020 | 2021 | 2022 | 2023 | 2024 | 2025   |
|--------------------------|--------|------|------|------|------|------|--------|
| <i>Total score</i>       | 10,000 | 7100 | 7650 | 8175 | 8350 | 8475 | 8412.5 |
| Setting & Infrastructure | 1500   | 1200 | 1250 | 1300 | 1275 | 1350 | 1350   |
| Energy & Climate Change  | 2100   | 1600 | 1400 | 1700 | 1800 | 1850 | 1850   |
| Waste                    | 1800   | 1125 | 1200 | 1275 | 1350 | 1350 | 1225   |
| Water                    | 1000   | 550  | 800  | 750  | 700  | 600  | 662.5  |
| Transportation           | 1800   | 1350 | 1450 | 1500 | 1550 | 1550 | 1525   |
| Education & Research     | 1800   | 1250 | 1550 | 1650 | 1675 | 1775 | 1800   |

\* The highest possible score in the ranking.

**Table 2.** Percentage of EKTU points from the maximum possible score.

| Year                     | Max * | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|--------------------------|-------|------|------|------|------|------|------|
| <i>Total score</i>       | 100   | 71   | 77   | 82   | 84   | 85   | 84   |
| Setting & Infrastructure | 100   | 80   | 83   | 87   | 85   | 90   | 90   |
| Energy & Climate Change  | 100   | 76   | 67   | 81   | 86   | 88   | 88   |
| Waste                    | 100   | 63   | 67   | 71   | 75   | 75   | 68   |
| Water                    | 100   | 55   | 80   | 75   | 70   | 60   | 66   |
| Transportation           | 100   | 75   | 81   | 83   | 86   | 86   | 85   |
| Education & Research     | 100   | 69   | 86   | 92   | 93   | 99   | 100  |

\* The highest possible score in the ranking.

Tables 1 and 2 indicate that EKTU consistently maintained a high proportion of the maximum attainable UI GreenMetric score throughout the study period. While the total score decreased slightly in 2025, the university retained 84% of the maximum possible score, only one percentage point below the 2024 level, despite the substantial increase in the number of participating universities. This pattern suggests that the institutional sustainability measures implemented under the Green Campus project remained effective over time and that the change in ranking position should be interpreted in the context of increasing international competition rather than as evidence of a decline in sustainability performance.

The observed ranking dynamics suggest that sustainability progress at EKTU was achieved across multiple assessment categories rather than through improvements in a single area. The consistently high performance in energy and education-related indicators reflects the coordinated implementation of infrastructure modernization, digital governance, and sustainability-oriented management practices. While ranking results alone cannot fully capture institutional sustainability, they provide a consistent benchmark for assessing the university's long-term development within the UI GreenMetric framework.

### 3.2. Sustainable Campus Infrastructure Transformation

#### 3.2.1. Campus Spatial Development and Green Infrastructure

The spatial transformation of the EKTU campus focused on increasing open green areas, improving environmental quality, and integrating biodiversity conservation into campus development. The university manages seven facilities with a total campus area of 539,163 m<sup>2</sup>, including urban academic buildings and the rural Summer Expedition Campus "Prostor".

One of the notable outcomes of the Green Campus project was maintaining a very high open space ratio of 97.9%, while 58.1% of the campus area is covered by planted

vegetation and 23.4% by forest vegetation used for research and educational purposes. The campus includes an arboretum park, a dendrological garden, and natural areas along the Ulba River and Bukhtarma reservoir.

EKTU also initiated reconstruction projects aimed at creating pedestrian zones, recreational spaces, sports grounds, and environmentally friendly public areas. These initiatives supported improvements in environmental quality, biodiversity conservation, and the overall ecological functionality of the university campus.

The spatial transformation demonstrates that campus planning at EKTU extended beyond landscape improvement to support broader sustainability objectives. The combination of extensive green areas, biodiversity conservation, and multifunctional recreational spaces indicates that green infrastructure was integrated into education, research, and campus management rather than implemented as an isolated environmental measure. This integrated approach strengthens the ecological functions of the campus while enhancing its educational and social value.

### 3.2.2. Inclusive, Health, and Safety Infrastructure

EKTU developed inclusive and human-centered campus infrastructure as part of its sustainability strategy. The university implemented facilities for persons with disabilities, including ramps, accessible pathways, support call buttons, dedicated parking spaces, and adapted sanitary facilities. Additional social infrastructure includes maternity support rooms, baby care facilities, and children's rooms for temporary childcare.

Health and well-being initiatives are coordinated through the university Medical Center and the Health and Sports Center. These units provide preventive healthcare, emergency assistance, psychological support, wellness programs, and physical activity promotion for students and staff. The "EKTU.Otbasy-Well-being" project further strengthened the university's human-centered sustainability approach.

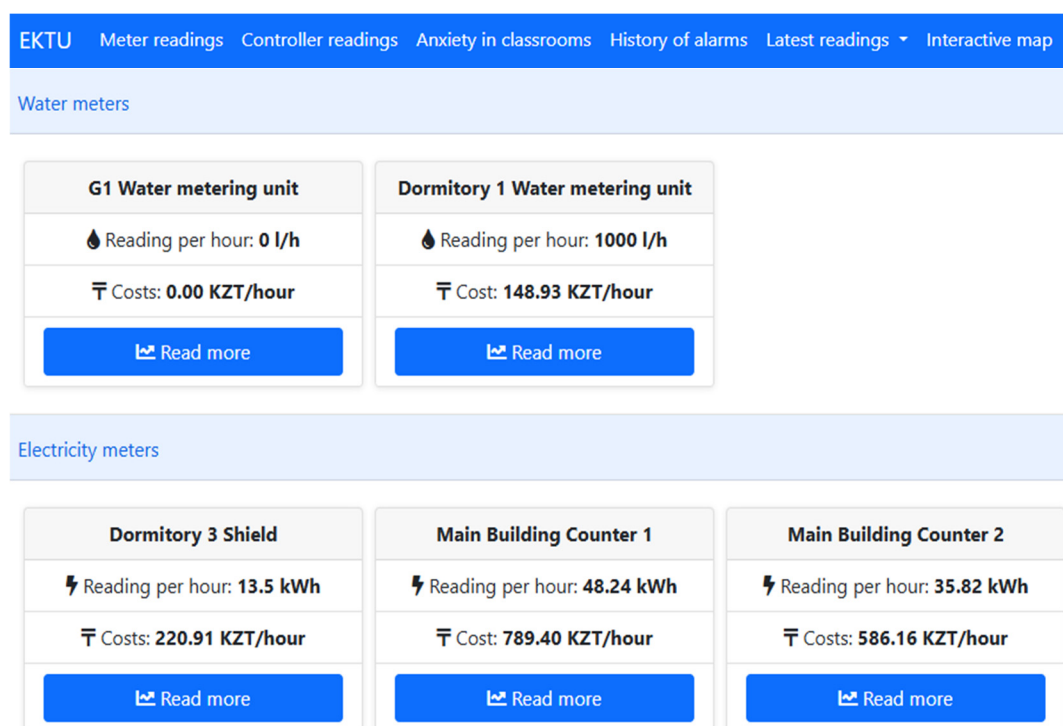
Campus safety infrastructure includes video surveillance systems, biometrics, emergency alarms, fire protection systems, and regular emergency evacuation exercises. According to institutional reports, emergency response and evacuation procedures are integrated into the university's digital monitoring and security management system.

These findings suggest that sustainability at EKTU was implemented through a broader institutional perspective that incorporates social inclusion, health, and campus safety alongside environmental objectives. The integration of digital monitoring with health and safety management illustrates how Smart Campus technologies can support not only resource efficiency but also the well-being and resilience of the university community.

### 3.2.3. Smart Campus and Digital Energy Management

One of the most significant components of the EKTU Green Campus project was the development of the Smart Campus ecosystem and digital energy management infrastructure. Since the beginning of the Green Campus transformation, the university has integrated ICT technologies into sustainability governance, environmental monitoring, and resource management.

The university implemented Building Management Systems (BMS), Building Information Modeling (BIM), and Building Automation Systems (BAS) across campus facilities. By 2025, the Smart Building implementation level reached 95.55% of the total building area. The E-monitoring system (Figure 4) enabled real-time monitoring of electricity consumption, infrastructure operation, security systems, and environmental indicators through platforms such as Zabbix and Grafana.



**Figure 4.** Example of E-monitoring data.

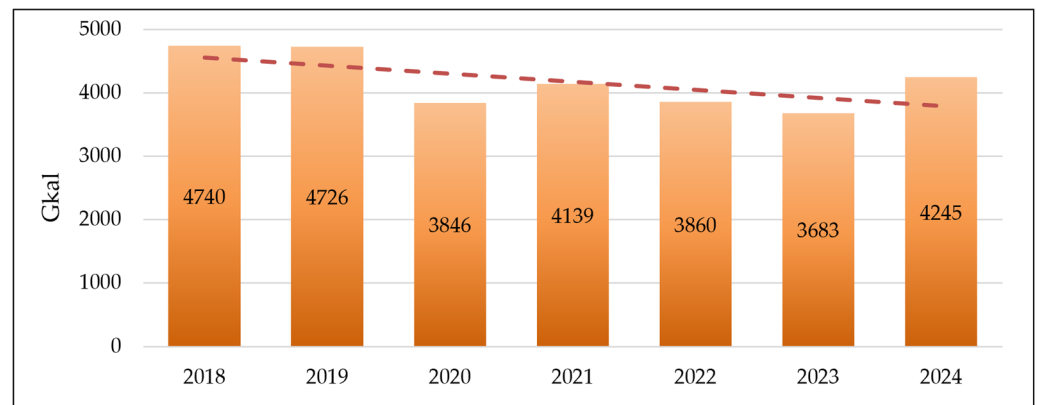
The digital infrastructure includes 15 servers, centralized data storage, cloud technologies, Kubernetes clusters, and integrated educational and administrative platforms. These systems support automated sustainability monitoring and facilitate data-informed decision-making related to campus management and sustainability [32].

These results indicate that Smart Campus technologies at EKTU functioned not only as operational tools but also as an institutional mechanism for sustainability governance. The integration of digital monitoring across multiple campus systems enabled continuous data collection and supported coordinated decision-making in energy, infrastructure, and environmental management. This illustrates the role of digital governance as a cross-cutting component of the university's sustainability transformation.

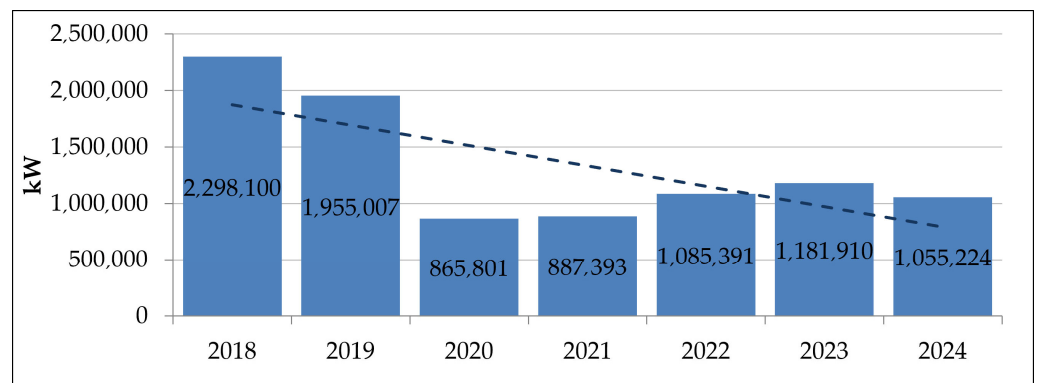
### 3.2.4. Energy Efficiency and Resource Optimization

EKTU implemented a comprehensive energy-efficiency program focused on reducing electricity and thermal energy consumption across campus facilities. A key component of the energy-efficiency program was the replacement of outdated equipment with energy-efficient technologies. By 2025, LED lighting accounted for 94.6% of all campus lighting systems, while the share of energy-efficient office and household appliances exceeded 88%. Automated thermal control units installed in university buildings enabled regulation of heating depending on outdoor temperature conditions and reduced thermal energy consumption by 10.5% (Figure 5).

The implementation of energy-saving technologies and Smart Campus monitoring tools contributed to a long-term decrease in campus energy consumption. Electricity usage declined from 2,298,100 kWh in 2018 to 1,055,224 kWh in 2024, representing an overall reduction of approximately 54% (Figure 6). Energy consumption data are continuously monitored through the E-monitoring system, allowing the university to optimize infrastructure operation and support data-driven sustainability management.



**Figure 5.** Statistics on the consumption of thermal energy by the campus.



**Figure 6.** Statistics on the consumption of electric energy by the campus.

The observed reduction in energy consumption suggests that improvements resulted from the combined implementation of energy-efficient technologies and continuous digital monitoring rather than from isolated technical upgrades. The integration of operational data into the E-monitoring system also provided a basis for adaptive management of campus energy resources over the study period.

### 3.2.5. Renewable Energy and Climate Initiatives

The gradual deployment of renewable energy technologies formed an integral part of the university's broader climate strategy. The university operates two solar energy systems located in the main campus building and the SEC "Prostor" expedition campus. In addition, heat pump systems are used for hot water supply at the Prostor campus. Total annual renewable energy production reached 129,960 kWh, including 111,240 kWh generated by solar systems and 18,720 kWh by heat pumps. The renewable energy infrastructure contributed to reducing dependence on conventional electricity sources and improving campus energy sustainability.

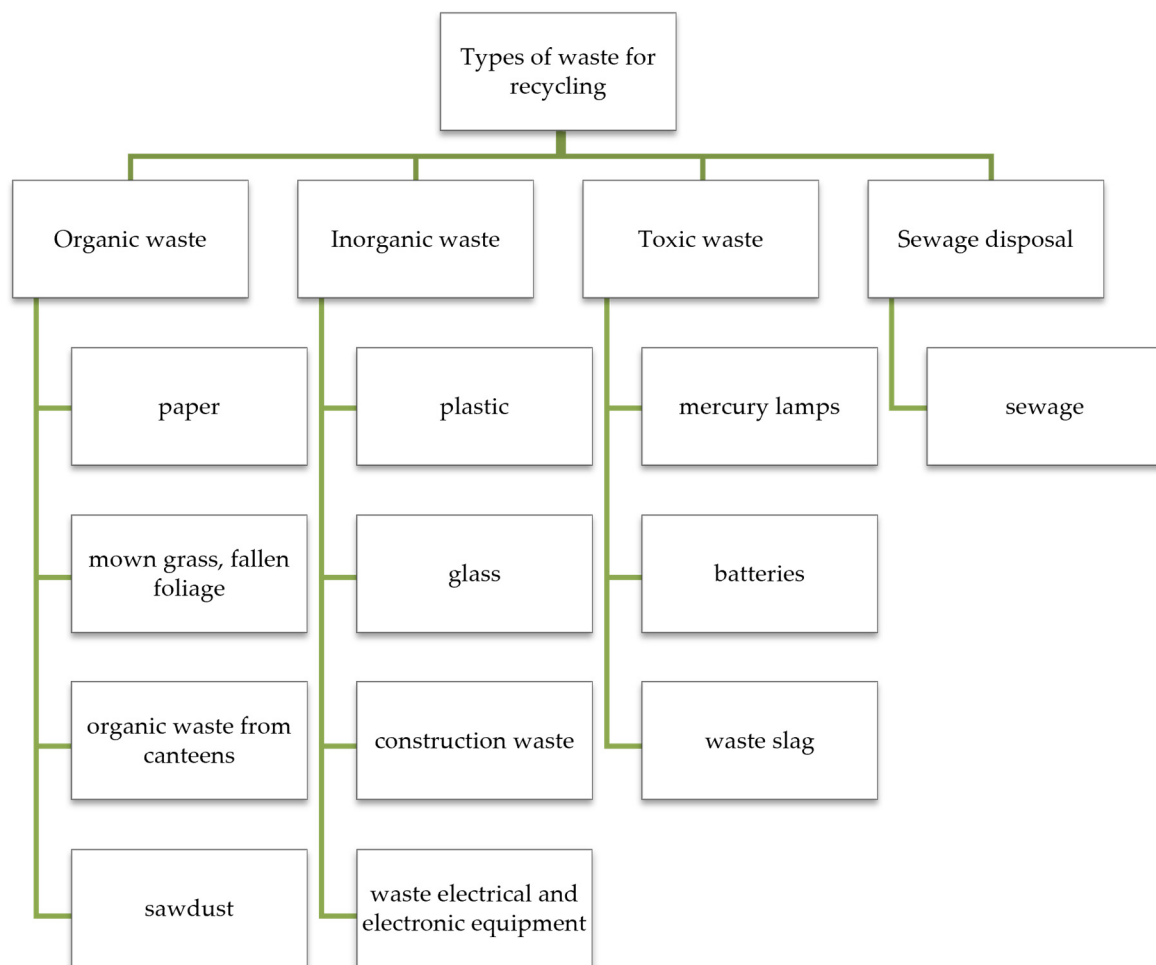
Climate initiatives at EKTU are integrated with institutional sustainability and greenhouse gas reduction policies. The university implemented measures aimed at reducing indirect emissions through energy-saving technologies, Smart Campus management, green building solutions, waste reduction, sustainable transportation, and water conservation programs. In parallel, EKTU established a Carbon Center focused on research and educational activities related to carbon neutrality, greenhouse gas mitigation, and regional climate sustainability. The university also expanded climate-oriented educational and research projects associated with renewable energy, environmental monitoring, and sustainable urban development.

The integration of renewable energy systems with climate-related research and institutional policies demonstrates that the energy transition at EKTU extended beyond technological modernization. By combining renewable energy deployment, carbon-related research, and sustainability governance, the university linked operational improvements with its broader educational and strategic objectives.

### 3.3. Sustainable Environmental and Resource Management

#### 3.3.1. Waste Management and Circular Economy Practices

Waste management at EKTU is based on the principles of circular economy and the 3R concept (Reduce, Reuse, Recycle). The university implemented programs aimed at reducing paper and plastic consumption, improving waste separation, and increasing recycling activities across campus facilities (Figure 7).



**Figure 7.** EKTU waste management system based on circular economy.

The university introduced separate treatment systems for organic, inorganic, and toxic waste, while digitalization significantly reduced paper use through online educational platforms, electronic document management, and integrated Smart Campus services. Waste management practices are supported by ICT-based monitoring and sustainability reporting tools integrated into the E-monitoring system. These measures contributed to the development of a more resource-efficient campus environment and strengthened the integration of environmental sustainability into daily university operations.

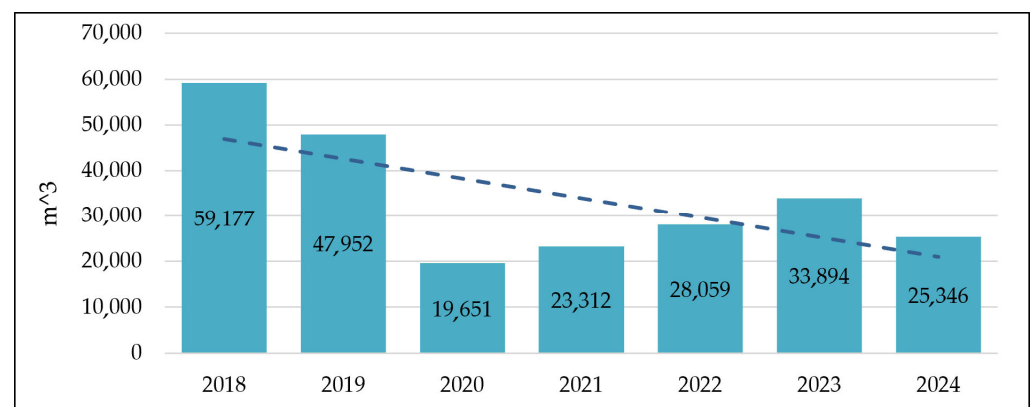
The implementation of circular economy practices indicates that waste management at EKTU was integrated into broader institutional sustainability processes rather than limited to waste collection and recycling activities. The combination of digitalization,

resource-efficient practices, and ICT-based monitoring supported the transition from operational waste management to a more systematic approach to resource governance across the campus.

### 3.3.2. Water Management and Conservation

Water conservation became an integral component of the EKTU Green Campus strategy in response to growing attention to sustainable resource management in higher education. The university implemented water conservation programs, water-efficient appliances, and water pollution control measures across campus facilities. According to institutional data, dedicated water absorption areas occupy more than 11,000 m<sup>2</sup> of campus territory, supporting natural drainage and ecosystem stability.

EKTU also integrated water management into its Smart Campus and environmental monitoring systems. Water-related indicators are monitored through the university's digital E-monitoring infrastructure, enabling more efficient resource management and sustainability reporting. The combined implementation of these measures was accompanied by a reduction in campus water consumption of nearly 50% over the study period (Figure 8).



**Figure 8.** Statistics on water consumption on campus.

Additional water-saving measures include the installation of water-efficient sanitary equipment, drip irrigation systems for campus landscaping, and the use of rainwater collection practices for irrigation and technical purposes. Parking areas are equipped with drainage and filtration solutions that reduce contamination of surface runoff before discharge into the surrounding environment. Environmental monitoring activities are also conducted in natural water bodies adjacent to the campus territory, including the Ulba River and the Bukhtarma reservoir near the SEC “Prostor” campus, where students and researchers regularly participate in ecological monitoring and water quality assessment programs.

The observed reduction in water consumption suggests that conservation measures were most effective when combined with continuous monitoring and infrastructure improvements. Integrating water management into the Smart Campus environment also enabled more systematic tracking of resource use and supported evidence-based decision-making for campus sustainability management.

### 3.4. Sustainable Mobility and Transportation Policies

EKTU implemented sustainable transportation policies aimed at reducing private vehicle use, lowering campus carbon emissions, and improving pedestrian accessibility. The university developed pedestrian-oriented infrastructure, including walking paths, recreational zones, and car-restricted campus areas, while parking spaces were intentionally limited in relation to the total campus area. The transportation strategy also includes shuttle

services and initiatives promoting environmentally friendly and zero-emission mobility alternatives. The relocation of administrative departments into the main university building additionally reduced inter-campus travel and associated transport-related emissions.

Transportation management is integrated into the broader Smart Campus and climate governance framework of the university. Campus carbon footprint assessments include emissions related to electricity consumption and transportation activities, while transportation indicators are continuously monitored through the E-monitoring system, enabling data-driven mobility and environmental management. The opening of the “Luban Workshop” educational and laboratory complex dedicated to electric vehicle technologies and maintenance further strengthened the integration of sustainable mobility into engineering education and applied research (Figure 9).



**Figure 9.** “Luban Workshop” educational and laboratory complex dedicated to electric vehicle technologies and maintenance.

The implementation of sustainable mobility measures demonstrates that transportation policies at EKTU were integrated with broader campus planning, climate governance, and educational objectives. Rather than focusing solely on reducing transport-related emissions, the university combined infrastructure planning, digital monitoring, and engineering education to support a more comprehensive approach to sustainable mobility management.

### 3.5. Education, Research, and Community Engagement for Sustainability

#### 3.5.1. Sustainability-Oriented Educational Transformation

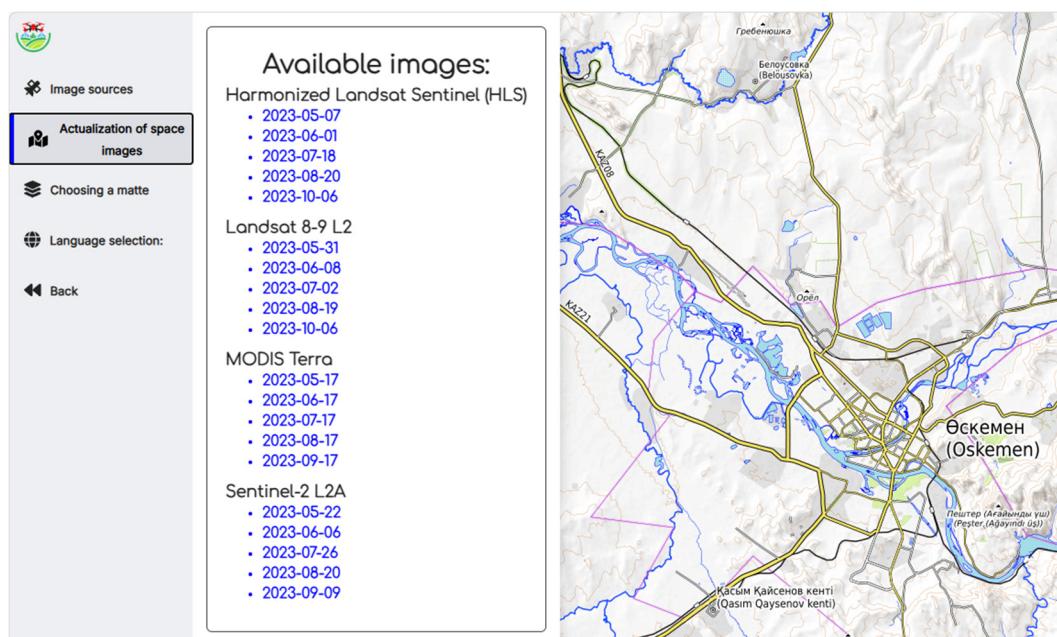
The EKTU Green Campus project contributed to the transformation of educational processes toward sustainability-oriented learning and SDG integration. The university expanded the number of sustainability-related courses and educational programs in areas such as ecology, environmental protection, forestry, climate change, smart agriculture, renewable energy, and sustainable engineering. The university implemented an integrated digital educational ecosystem combining its own educational portal and E-monitoring systems with platforms such as Moodle, Open edX, and Google Workspace, enabling blended learning, digital academic management, and sustainability-oriented educational support.

These developments indicate that sustainability became progressively embedded in both the curriculum and the university's digital learning environment. The integration of SDG-oriented content with digital educational platforms supported a more systematic approach to sustainability education and facilitated the incorporation of sustainability principles into teaching and learning processes across different disciplines.

### 3.5.2. Sustainability Research and Innovation Ecosystem

Sustainability-oriented research and innovation became one of the core components of the EKTU Green Campus model. The university actively expanded scientific projects related to ecology, climate change, biodiversity conservation, renewable energy, smart agriculture, environmental monitoring, and sustainable urban development. According to institutional data, EKTU currently implements dozens of fundamental and applied sustainability-related research projects, including commercialization initiatives focused on eco-innovation and green technologies.

An important direction of the research ecosystem is the integration of digital technologies into sustainability projects. EKTU developed research initiatives in smart agriculture, geoinformation systems, remote sensing, AI applications, and digital environmental monitoring. Projects such as “Smart Agronom” (Figure 10), precision agriculture systems, and the Industrial AI Competence Center demonstrate the university's focus on combining sustainability with digital transformation. The innovation ecosystem is further supported through student startups, interdisciplinary laboratories, the Carbon Center, and international research collaborations, strengthening the university's capacity to contribute to regional sustainability and innovation initiatives.



**Figure 10.** Screenshot from the Smart Agronom program [33].

The research and innovation activities demonstrate that sustainability at EKTU extends beyond campus operations to include scientific knowledge generation and technology development. The integration of digital technologies with sustainability-oriented research illustrates how the university links innovation, applied research, and regional environmental challenges within a unified institutional framework.

Community engagement is an important dimension of the EKTU Green Campus project and supports the university's role as a regional center for sustainable development.

EKTU actively cooperates with local authorities, environmental organizations, schools, and public institutions through ecological campaigns, sustainability fairs, biodiversity conservation projects, and educational outreach activities. The university also participates in regional initiatives such as the “Comfortable City” project, environmental monitoring programs, and public ecological actions under the “Taza Kazakhstan” campaign.

International collaboration was strengthened through participation in the UI GreenMetric network and sustainability-related academic partnerships. EKTU regularly takes part in international GreenMetric workshops, conferences, and sustainability initiatives, contributing to global discussions on sustainable campus development. EKTU also expanded international cooperation through joint educational and scientific projects in smart technologies, climate sustainability, and green engineering.

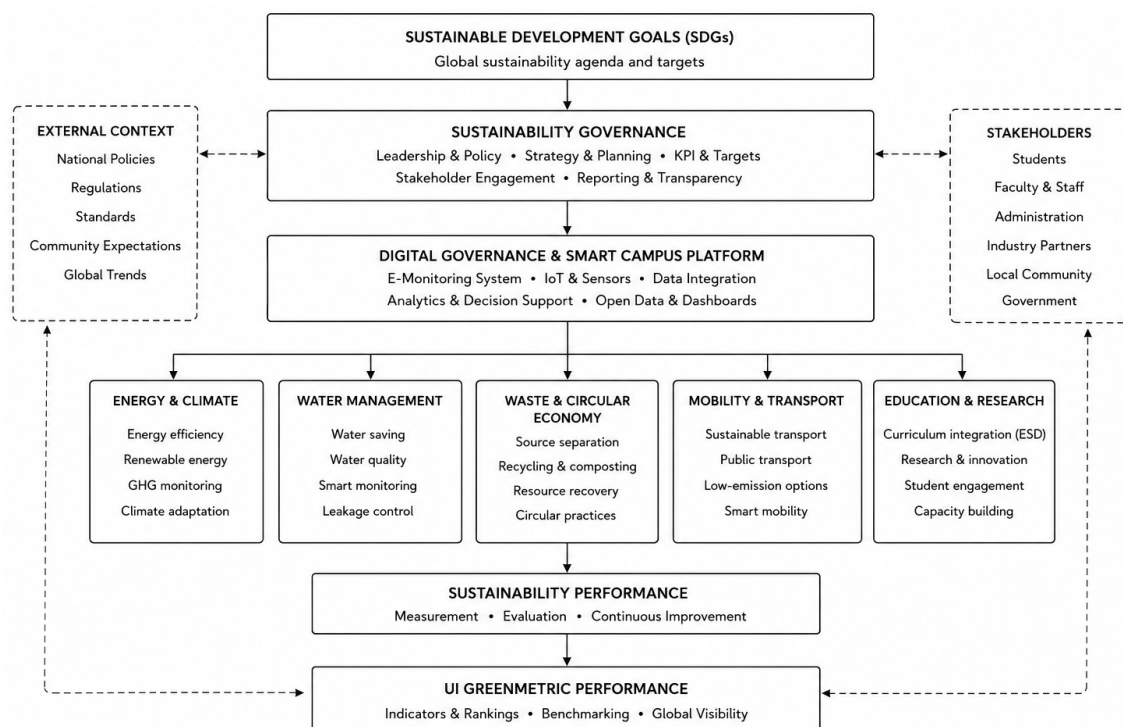
### 3.5.3. Community Engagement and International Collaboration

These activities suggest that the sustainability transformation at EKTU was supported not only by internal institutional changes but also by active collaboration with external stakeholders. Regional partnerships and international cooperation strengthened knowledge exchange, promoted the dissemination of sustainability practices, and enhanced the university’s capacity to implement and continuously develop its Green Campus initiatives.

## 3.6. Integrated Sustainability Management Model of EKTU

### 3.6.1. Interaction Between Governance, Digitalization, and Sustainability

The EKTU Green Campus model is based on the integration of institutional governance, digital infrastructure, and sustainability management into a unified operational system (Figure 11). Sustainability initiatives at the university are coordinated through interconnected administrative, academic, infrastructural, and digital management mechanisms aligned with SDG-oriented institutional policies. The governance structure combines strategic planning, environmental monitoring, financial management, and educational administration within the Smart Campus ecosystem.



**Figure 11.** Integrated EKTU Green Campus Sustainability Management Model.

Digitalization became a key enabling factor for sustainability governance at EKTU. The university implemented centralized E-monitoring systems, ICT-based analytical platforms, digital educational services, and automated infrastructure management tools that support real-time monitoring and data-driven decision-making. The integration of systems such as Zabbix, Grafana, Moodle, Open edX, and internal digital platforms allowed the university to monitor energy consumption, environmental indicators, educational processes, and sustainability performance across campus facilities.

The observed interaction between governance, digitalization, and sustainability illustrates how these components functioned as mutually reinforcing elements of the EKTU Green Campus model. The integration of digital monitoring with institutional governance supported coordinated sustainability management and data-informed decision-making across multiple operational domains. This integrated approach is consistent with the governance and digitalization perspective introduced in the 2026 UI GreenMetric framework.

### 3.6.2. Transferability of the EKTU Green Campus Management Approach

The EKTU Green Campus model illustrates how a technical university in an emerging economy integrated environmental infrastructure, Smart Campus technologies, sustainability-oriented education and research, inclusive social policies, and SDG-oriented governance within a unified institutional management approach. The longitudinal changes observed in the UI GreenMetric indicators between 2020 and 2025 are consistent with the progressive implementation of this integrated approach across multiple dimensions of university sustainability.

An important characteristic of the model is the integration of digitalization into sustainability governance. Unlike traditional campus greening approaches focused mainly on infrastructure modernization, the EKTU framework uses digital monitoring systems, centralized data management, and Smart Campus technologies as core management instruments. This approach supports institutional adaptability, improves resource efficiency, and supports evidence-based sustainability decision-making.

The EKTU experience provides a practical example of how digital governance and Smart Campus technologies can be integrated with sustainability management in a technical university operating under the conditions of an emerging economy. Although the findings are derived from a single-case study and should be interpreted within this context, they suggest that combining governance, digitalization, environmental management, education, and stakeholder engagement may support sustainability transformation in higher education institutions facing similar institutional and regional conditions.

Overall, the empirical findings support the conceptual framework presented in Figure 2 by illustrating the interdependence between digital governance, Smart Campus technologies, environmental management, education, stakeholder engagement, and institutional sustainability management throughout the EKTU Green Campus transformation.

## 4. Discussion

The results of this study suggest that sustainable campus transformation is most effective when environmental initiatives, digital technologies, institutional governance, and educational modernization are implemented as interconnected components of a unified management system. Unlike many previous studies focused on isolated aspects of campus sustainability, such as energy efficiency, waste management, or Smart Campus technologies, the EKTU Green Campus project demonstrates the practical integration of these elements within a long-term institutional framework. The longitudinal dynamics of UI GreenMetric indicators and ranking performance between 2018 and 2025 indicate that sustainability

transformation in higher education requires not only infrastructural modernization but also organizational adaptation, digital governance, and stakeholder engagement.

These findings are also consistent with the Socio-Technical Systems (STS) perspective, which emphasizes that organizational change emerges from the interaction between technological infrastructure, organizational processes, and human actors rather than from technological innovation alone. In the EKTU case, Smart Campus technologies contributed to sustainability transformation because they were embedded within institutional governance, management routines, and stakeholder engagement rather than implemented as isolated digital solutions.

From a theoretical perspective, these findings support the view that sustainability transformation in higher education depends not only on the adoption of individual digital technologies but also on their integration within institutional governance processes. In this regard, digital governance can be interpreted as an enabling mechanism that links environmental management, operational decision-making, and stakeholder participation into a coherent sustainability management system.

The findings further demonstrate the growing importance of Smart Campus technologies as instruments of sustainability governance rather than solely technical infrastructure solutions. The implementation of e-monitoring systems, digital dashboards, ICT-based management platforms, and Smart Building technologies enabled EKTU to integrate sustainability monitoring into everyday institutional decision-making processes. This supports previous research emphasizing the role of digitalization in sustainable campus management while extending existing evidence through a longitudinal case study from a technical university in an emerging economy. Digital transformation contributes not only to operational efficiency and energy optimization but also to transparency, adaptability, and institutional resilience.

From a theoretical perspective, these findings are consistent with socio-technical approaches to digital governance, which view sustainability transformation as the outcome of interactions between technological infrastructure, organizational processes, and institutional decision-making rather than technological innovation alone. In this respect, the EKTU case extends previous Smart Campus research by illustrating how digital monitoring systems can function not only as operational tools but also as governance mechanisms supporting the coordination of sustainability initiatives across multiple institutional domains. The findings also reinforce the sustainability management literature, suggesting that long-term institutional progress depends on the integration of governance, digitalization, and organizational practices rather than on isolated environmental interventions.

The EKTU experience is consistent with international trends in Green Campus development while reflecting distinct regional characteristics. A comparative overview of selected international Green Campus models is presented in Table 3. Similar to leading Chinese universities, EKTU employs digital monitoring systems and infrastructure modernization to improve resource efficiency; however, its approach relies on scalable and cost-effective solutions rather than large-scale state-funded investments [34]. In comparison with South-east Asian universities, where sustainability is often integrated into research, community engagement, and living-lab initiatives, EKTU demonstrates a stronger focus on technical modernization and operational management [35]. At the same time, its governance approach increasingly resembles European universities, where sustainability is embedded into institutional strategy and aligned with Sustainable Development Goals [36,37].

Overall, the comparison with international Green Campus models suggests that the main distinction of the EKTU case lies not in the adoption of individual sustainability practices, which are widely reported in previous studies, but in their progressive integration within a single institutional management framework under the resource constraints typical

of an emerging economy. This finding extends previous research by illustrating how digital governance can facilitate the coordination of multiple sustainability dimensions in a longitudinal institutional context.

**Table 3.** A comparative overview of international Green Campus models.

| University                                         | Digital Systems                                                                                                                                          | Governance Model                                                                                                                                                                     | Measurable Outcomes                                                                                                        | Funding/ Finance                                                                                                     | Replicability                                                                                                                                                            |
|----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| D. Serikbayev EKTU (Kazakhstan)                    | Integrated digital campus services, academic portal, LMS-based learning environment, and digital monitoring elements supporting Green Campus initiatives | Green Campus program and Sustainability Policy integrated into institutional strategy and management processes [32]                                                                  | Continuous improvement in UI GreenMetric rankings and reduced energy/resource consumption through Green Campus initiatives | State funding, national research grants, international programs, and industry-supported projects                     | High: sustainability and Green Campus practices are adaptable to technical universities in emerging-region contexts                                                      |
| Tsinghua University (China)                        | Extensive IoT sensor network, smart grid technologies, and integrated campus management applications.                                                    | University-wide sustainability governance coordinated through dedicated institutes (e.g., Institute for Carbon Neutrality) and aligned with national carbon neutrality policies [38] | High share of renewable and low-carbon electricity use, strong performance in international sustainability rankings [39]   | Significant government investment complemented by industry partnerships and research collaborations.                 | Moderate. Digital and governance practices are transferable, but large-scale implementation depends on substantial financial resources and supportive national policies. |
| Nanyang Technological University (Singapore)       | Integrated Smart Campus platform with IoT sensors, autonomous Electric Vehicle EV mobility, smart parking, and data-driven campus management             | University-wide sustainability governance through the EcoCampus program and Sustainability Framework, supported by industry partnerships [40]                                        | Achieved a 35% reduction in energy, water, and waste intensity relative to 2011 baseline [41,42]                           | Government funding, research grants, industry co-investment, and philanthropic support                               | Moderate–High: transferable Smart Campus and Living Lab model requiring advanced digital infrastructure and stakeholder collaboration                                    |
| Wageningen University & Research (The Netherlands) | Building energy management systems, smart building monitoring, and data-driven sustainability management                                                 | Sustainability embedded in institutional strategy and campus operations; ISO 50001- [43] certified energy management [44,45]                                                         | Climate-neutral campus target by 2030; ranked #1 in UI GreenMetric [46]                                                    | EU research grants (Horizon 2020/Horizon Europe), Dutch public funding, and industry-supported research partnerships | Moderate: transferable governance and energy-management practices, but dependent on policy and funding context                                                           |

The results also highlight the importance of considering regional conditions when evaluating campus sustainability performance. Universities in Central Asia operate within a unique context characterized by aging post-Soviet infrastructure, harsh continental climatic conditions, and limited financial resources. Many campus facilities were originally designed under different energy and management paradigms, resulting in relatively high energy consumption and substantial modernization requirements. Extreme seasonal temperature variations further increase demand for heating and cooling, making energy-efficiency measures particularly important. Under these conditions, sustainability transformation often follows a gradual and resource-constrained pathway. The EKTU case demonstrates that meaningful progress can nevertheless be achieved through phased infrastructure upgrades, digital monitoring systems, sustainability-oriented education, and strategic institutional governance.

It should also be noted that part of the reduction in electricity and water consumption observed in 2020 coincided with the COVID-19 pandemic, when restrictions on on-campus activities and the temporary transition to online education reduced campus occupancy and operational intensity. These circumstances were documented in the corresponding annual UI GreenMetric evidence submitted by the university. Therefore, the short-term changes recorded during this period should not be attributed solely to Green Campus measures

or digital governance initiatives but should be interpreted within the broader context of pandemic-related operational conditions.

Another important implication of this study concerns the potential applicability of the integrated management approach developed at EKTU for universities operating under similar institutional and regional conditions. The findings suggest that the combination of gradual infrastructure modernization, sustainability-oriented education, Smart Campus digitalization, and participation in international sustainability benchmarking systems may contribute to improving institutional sustainability performance and global visibility. These findings also suggest that participation in the UI GreenMetric ranking may support institutional learning by providing a structured framework for monitoring sustainability progress, identifying priority areas for improvement, and aligning campus management practices with the Sustainable Development Goals.

At the same time, the results should be interpreted with consideration of several limitations. Although UI GreenMetric provides a useful framework for assessing campus sustainability performance, previous studies have identified limitations associated with self-reported data, differences in institutional reporting practices, and the comparative nature of ranking systems. The methodology places greater emphasis on campus operations and infrastructure than on broader educational, social, and research impacts, while ranking positions may also be influenced by variations in participation across countries and regions. Consequently, improvements in ranking performance should be interpreted alongside actual environmental and organizational outcomes rather than as standalone indicators of sustainability achievement [47].

This study is also limited by its focus on a single institutional case. While the longitudinal analysis provides valuable insights into the dynamics of sustainability transformation, the findings may not be fully generalizable to universities operating under different regulatory, economic, or climatic conditions. Future research could extend the analysis through comparative studies of universities across Central Asia and other emerging economies, providing a broader understanding of how regional contexts influence Green Campus development and Smart Campus implementation.

## 5. Conclusions

This study examined the long-term transformation of the EKTU Green Campus project between 2018 and 2025 and showed that sustainability transformation at a technical university can be supported through the integration of digital governance, Smart Campus technologies, environmental management, sustainability-oriented education, and institutional planning within a unified management framework. The longitudinal analysis indicates that the coordinated implementation of these components was accompanied by continuous improvements across multiple sustainability dimensions, including resource management, digitalization, education and research, and institutional governance.

The findings also highlight the role of digital governance as an enabling mechanism that supports data-informed decision-making and the coordination of sustainability processes across different operational domains. Rather than functioning solely as technical infrastructure, Smart Campus technologies contributed to the institutional integration of sustainability management. From a practical perspective, the EKTU experience provides an example of how universities operating under the financial and infrastructural constraints typical of emerging economies can progressively strengthen sustainability governance through phased implementation and continuous monitoring.

This study has several limitations. The analysis is based on a single institutional case and relies primarily on institutional data and UI GreenMetric indicators, which may limit the transferability of the findings to other higher education contexts. In addition, the

study adopts a descriptive longitudinal approach and does not statistically evaluate causal relationships between individual sustainability measures and institutional performance.

Future research could extend this work through comparative analyses of universities in Central Asia and other emerging economies, as well as by applying quantitative methods to examine the relationships between digital governance, Smart Campus implementation, and sustainability performance over time.

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