Journal of Sustainability Perspectives

journal homepage: https://ejournal2.undip.ac.id/index.php/jsp/

A Sustainability Dashboard: Utilization of ICT towards Effective Management of Sustainable Campus Infrastructure

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Article Info
Keywords:
ICT, Infrastructure, IPB University, Sustainable Campus, UI GreenMetric

Received:
17 July 2025
Accepted:
13 November 2025
Published:
31 August 2026

Abstract. Information and Communication Technology (ICT) has become a pivotal element in managing the sustainability parameters of higher education institutions. This study aims to presents the development of ICT as an effective management strategy for a sustainable campus at IPB University, aligned with the sustainable indicators used in the UI GreenMetric ranking system. Focusing on integrating digital tools and systems, this research explores how ICT enhances operational efficiency, resource management, and environmental impact. Through a qualitative approach, this study shows the implementation of ICT-driven initiatives, such as setting infrastructure, transportation, and energy management systems. The study highlights the significant benefits of ICT in promoting sustainability goals, such as monitoring land use, the carbon footprint, energy usage, and fostering a culture of environmental awareness among campus civitas. Moreover, this study identifies challenges and opportunities in advancing ICT adoption within the university's sustainability framework. The findings emphasize the strategic and beneficial use of ICT to enhance operational performance by providing a real-time and accurate monitoring system.

DOI: 10.14710/jsp.2026.28599

1. Introduction

IPB University is one of Indonesia's leading higher-education institutions. Established in 1963, with a focus on agriculture, the university has maintained a strong commitment to tackling key issues related to food security. Over time, it has broadened its academic scope and evolved into a comprehensive institution with the vision of becoming a Techno-Socio-Entrepreneurial University[1]. This vision underscores the dedication to integrating diverse disciplines and promoting innovation to make meaningful contributions to society. In line with this mission, IPB University prioritizes global sustainability and actively engages with critical environmental and socio-economic challenges[2,3].

Since its founding, IPB University has embedded sustainability as a core value, gaining recognition as a "green campus" as early as the 1970s. IPB University further institutionalized this commitment in the 2000s by introducing the Healthy Campus Movement and encouraging sustainable and health-conscious practices in the academic community. In 2015, IPB University formally adopted the status of a Green Campus, emphasizing energy efficiency, resource management, and environmental stewardship, and incorporated these principles into its academic, research, and community activities[4-6]. Looking ahead, IPB University aspires to achieve its vision of becoming a “Globalized Sustainable University” by 2028, aligning its initiatives with international sustainability standards, fostering interdisciplinary collaboration, and contributing to the realization of global Sustainable Development Goals (SDGs)[1]. Through these sustained efforts, IPB University continues to lead the advancement of ecological and social sustainability, both locally and globally.

IPB University has achieved notable recognition for its sustainability efforts, consistently standing out in the prestigious rankings. In the 2024 UI GreenMetric ranking, the university secured an impressive 29th position, highlighting its strong commitment to environmental stewardship and green campus initiatives[7]. This ranking underscores the IPB's ongoing dedication to global sustainability. Furthermore, from 2022 to 2024, IPB University was honored as the top university in Indonesia's SDGs Action Awards, celebrating its exceptional contributions to advancing the United Nations' Sustainable Development Goals (SDGs) through impactful programs and initiatives[8]. The university earned the 405th spot on the international stage in the QS World University Rankings: Sustainability, affirming its ongoing efforts to embed sustainability principles into its academic, research, and operational practices. These achievements position IPB University as a leader in sustainability in higher education, driving innovation and encouraging other universities to embrace sustainable practices.

One of the significant challenges in the ranking process for sustainability assessment is the comprehensive collection and management of relevant data[9-11]. The parameters include infrastructure, energy utilization, waste management, water conservation, transportation systems, and educational programs, which require precise and reliable data collection to accurately represent sustainability efforts. Regular monitoring and evaluation of these data are critical for understanding the effectiveness of the sustainability practices implemented and identifying areas requiring enhancement. This iterative process enables institutions to make informed decisions, align with best practices, and continuously improve sustainability strategies to meet evolving standards and objectives of the institution. An ICT-enabled Sustainability Dashboard was also developed for internal performance tracking and as a strategic decision-support tool[12].

IPB University has 18 campuses spread across West Java, Banten, and Jakarta, covering 1,669 hectares. Hence, managing sustainability indicators is challenging[13,14]. As a higher educational institution, IPB University has demonstrated notable advancements in integrating Information and Communication Technology (ICT) within its educational framework[8]. However, institutions face significant gaps in systematically monitoring, evaluating, and disseminating sustainability parameters across campuses. These shortcomings hinder the ability to track the progress of sustainability initiatives, measure their impact, and effectively communicate their achievements and challenges to stakeholders. Establishing robust systems for data collection, analysis, and reporting sustainability indicators is essential for fostering transparency, enhancing institutional accountability, and aligning with global sustainability standards in the construction industry. Recent studies have explored using ICT, such as dashboards, IoT-based sensors, and digital platforms to support sustainability monitoring in higher education institutions[15-17]. Although several universities have piloted tools to track energy consumption, mobility, and carbon emissions, comprehensive real-time multi-domain dashboards remain limited, particularly in developing countries.

Currently, IPB University manages a sustainability website that provides an overview of the university's efforts to address the United Nations' Sustainable Development Goals (SDGs) and publishes its annual Sustainability Report[8]. This platform highlights initiatives and activities that demonstrate IPB's commitment to sustainability in various domains. However, the university updates the website only once a year, significantly limiting its usefulness as a real-time tool for tracking progress or addressing immediate sustainability challenges. Additionally, the information presented is primarily in the form of static reports, lacking direct, detailed data on key sustainability parameters such as energy usage, waste management, water conservation, and other critical metrics. The absence of real-time dynamic data restricts the platform's potential for transparency, stakeholder engagement and informed decision-making. Developing a more interactive and data-driven system, such as an integrated sustainability dashboard, could significantly enhance the website's effectiveness as a comprehensive resource for monitoring and promoting sustainability initiatives[16,18].

In 2023, IPB University established the Sustainability Office, namely the Sustainable Campus Development Office, which transformed into the Directorate of Planning and Sustainable Campus Development at the beginning of 2025 as a dedicated unit tasked with overseeing and advancing sustainability efforts across campus[19,20]. This strategic move reflects the university's commitment to embedding sustainability into its institutional framework and ensuring systematic management of its environmental, social, and economic impacts. The sustainability office plays a critical role in coordinating initiatives, monitoring progress, and fostering a culture of sustainability within the academic community. One of its notable achievements is the development of a Sustainability Dashboard, a digital platform designed to aggregate, analyze, and visualize data related to key sustainability parameters, such as energy consumption, waste management, water usage, and carbon emissions. This tool not only enhances the transparency and accessibility of sustainability-related information but also serves as a decision-making resource for university leadership, enabling data-driven strategies to improve performance and achieve sustainability targets. By establishing this office and launching the Sustainability Dashboard, IPB University has laid a strong foundation for achieving its long-term vision of becoming a global leader in sustainable campus development in the future.

This paper presents a comprehensive overview of the development process, detailing each stage from the inception to the completion of the Sustainability Dashboard. The focus includes key aspects such as the digitalization of campus sites and land use changes, transportation measurement, electricity usage, carbon emission monitoring, waste generation, and water usage. This study contributes to this growing field by presenting a contextualized case from Indonesia. By addressing both technological and institutional dimensions, this study aims to bridge the gap in the literature and practice of ICT integration in sustainability management.

2. Methodology

The research approach is a case study appraisal of IPB University's efforts to use Information and Communication Technology (ICT) to manage sustainability parameters, including campus sites, land use change, transportation, energy and climate change, water resources, and waste. This research demonstrates the IPBS Sustainability Dashboard, including the frameworks and evolution of data management for each parameter, as well as the benefits, challenges, and opportunities for advancing ICT adoption within the university's sustainability dashboard. The research team conducted this study at the Dramaga Campus, the main campus of IPB University.

This study began by collecting sustainability data for each parameter, including the data sources and how to measure quality and data history year by year, from recent to present data. The evolution of the data source and collection process demonstrates the university's commitment to managing sustainable practices. The research began with data collection from relevant documents, including annual reports from the responsible units, the university's official dashboard (dashboard.ipb.ac.id), and related publications. Direct field observations and interviews were conducted to obtain information related to the operational workflows of each coordinating unit, including the Sustainability Office (SO), Directorate of General Affairs and Infrastructure (DUI), and Information and Communication Technology (ICT) Center.

3. Results and Discussion

3.1. Dashboard Integration & Visualization

Integrating various sustainability parameters into the IPB Sustainability Dashboard marks a significant step in advancing the university's data-driven environmental and operational management. Through a unified and interactive interface, the dashboard acts as a centralized digital platform that collects and displays key indicators such as electricity usage, transportation activity, water consumption, carbon emissions, land use, and waste generation. Staff from each responsible unit manually upload datasets or configure automated data retrieval systems, depending on the digital maturity of each domain.

As illustrated in Figure 1, several institutional units provide core data. The Directorate of General Affairs and Infrastructure (DUI) supplies electricity, transportation, water, and waste disposal data. The Sustainable Office (SO) manages carbon emission data, whereas DUI and SO contribute to land use data, including outputs from drone-based spatial mapping. After collection, the administrators stored the data in a centralized database. Administrators validate and structure the information before publishing it on the dashboard. The Information and Communication Technology (ICT) Center of IPB University developed and maintained the dashboard's technical framework. ICT developers continuously enhance system performance by adding new features, ensuring data connectivity, and responding to internal feedback. Data administrators from each domain verified the inputs to ensure their accuracy and consistency. Once verified, the dashboard presents real-time and historical data in various formats, including dynamic charts, spatial maps, and analytical graphics, enabling users to track trends, compare faculties, identify anomalies, and make strategic decisions.

Currently, access to the dashboard is limited to selected internal users, such as data providers, sustainability managers, and system administrators. The development team designed the platform to support future scalability. The university aims to gradually extend access to a broader range of stakeholders, including academic staff, students, and external partners. By fostering a culture of transparency and shared institutional responsibility—even at this early stage—the system lays the groundwork for broader engagement and cross-sectoral collaboration[21].

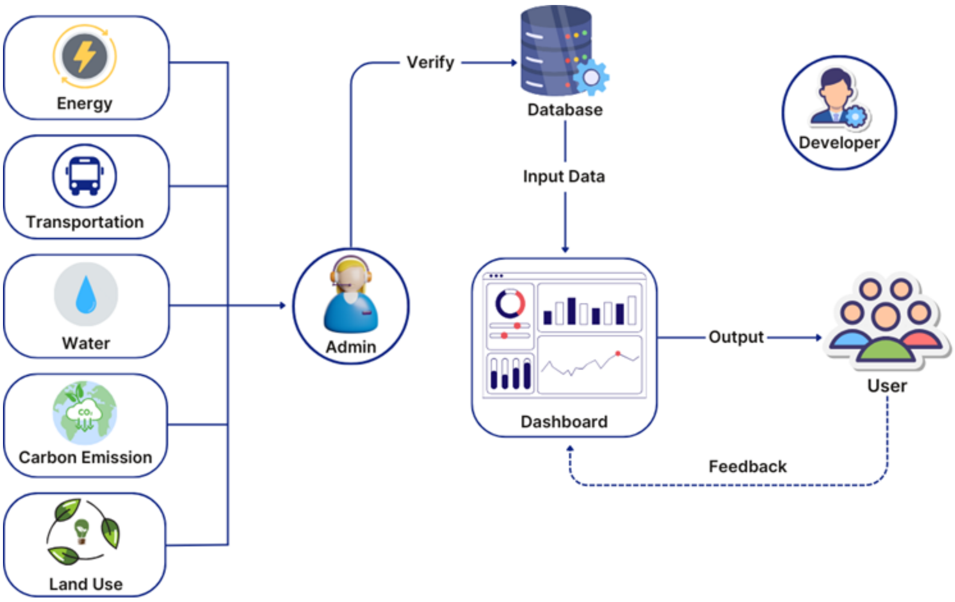

Figure 1. Workflow architecture of the IPB Sustainability Dashboard System

In summary, the IPB Sustainability Dashboard is a real-time environmental monitoring tool and strategic platform that guides the university's transformation into an innovative, sustainable, and resilient institution. By embedding cross-domain integration, internal data validation, and responsive design into a single ecosystem, the dashboard provides a strong digital foundation for IPB University to lead sustainable governance. As sustainability challenges grow in complexity, this system positions the university to serve as a center of knowledge and a living laboratory for systemic transformation.

IPB University actively links data from different sustainability domains within the dashboard to reveal the operational interdependencies. For example, when campus mobility increases, the dashboard simultaneously registers changes in both the transportation and carbon emission indicators. Similarly, land-use changes often influence energy demand because of shifts in surface temperature and shading. By connecting these parameters, the university enables its administrators to make holistic and evidence-based decisions.

By comparing before-and-after data, the dashboard demonstrated measurable improvements in monitoring accuracy, operational responsiveness and cross-sectoral insights. For example, correlating transportation data with emission outputs now allows sustainability officers to pinpoint policy impacts in near real time, such as vehicle restrictions that reduce CO2 emissions by an estimated 5.7% during trial periods. Although currently accessible only to internal stakeholders (e.g., administrators and sustainability managers), the dashboard is designed for future scalability. Planned expansions will include student, faculty, and external stakeholder access to enable crossfunctional transparency and community engagement in the future. This initiative contributes directly to multiple SDGs, especially SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). Moreover, it aligns with the UI GreenMetric indicators, such as energy, water, waste, transportation, education, and research components. Furthermore, the dashboard reinforces smart campus principles by integrating Internet of Things (IoT) sensors, GIS-based decision tools, and data-driven policies.

3.2. Land Use Management

The university initiated the use of ICT by digitalizing campus sites and employing drone technology to map areas and land use patterns as a replacement for conventional map-based documentation. High-resolution cameras and other drone sensors were used to capture the aerial images of the target area. The acquired image data were analyzed using image processing software and Geographic Information System (GIS) tools to generate up-to-date land-use changes. This approach allows for faster, cost-effective, and repeatable mapping, facilitating regular updates of land use information over time.

Additionally, this study integrated OpenStreetMap (OSM) as a platform to promote public participation in land use mapping. Through OSM, local communities can contribute by updating or adding relevant land-use information for specific regions. Drone-acquired data were incorporated into the OSM maps, allowing users and stakeholders to access the most current and detailed information on land conditions[22]. This approach also aids sustainable development planning by providing a collaborative mapping framework. The integration of drone technology and OSM in land-use mapping offers significant advantages in improving data accuracy and expediting information updates. Public involvement in data collection made the resulting maps more representative and inclusive of broader areas. Moreover, drones and OSM make land use mapping more transparent and accessible, supporting better natural resource management and informed decision making.

Land use management is a critical component of the broader framework of sustainable campus development, particularly for higher-education institutions that continue to expand, both physically and functionally. IPB University initially collected land-use data from manual sources, including cadastral maps and land ownership certificates. Although these documents are official references, their static nature limits their applicability in supporting dynamic campus planning and sustainability monitoring processes. To address these limitations, the university adopted drone-based mapping technologies that enable the acquisition of high-resolution aerial imagery that captures the current land conditions with greater precision and efficiency.

Integrating drone imagery into spatial planning workflows represents a significant advancement, allowing for the accurate identification of building footprints, vegetation cover, open spaces, and infrastructure. The data generated through this method were subsequently processed using Geographic Information System (GIS) tools to update the digital campus maps. However, staff members still update the data manually whenever the university constructs new buildings or alters the spatial layout, such as converting open areas into built environments; the Sustainable Office staff must verify and edit the data through regular field inspections. This semi-automated process introduces time lags and depends heavily on human resources for validation and mapping.

In addition to drone imagery, the university complements spatial data management through OpenStreetMap (OSM), a collaborative mapping platform based on the volunteer geographic information (VGI). OSM offers frequently updated geospatial data that users contribute to worldwide, making it a valuable land-use information baseline (23). However, because anyone can edit the OSM, IPB University applies a quality control process before integrating these data into its internal dashboard. Figure 2 illustrates how the university integrates OSM-based geospatial data into the IPB Dashboard through a workflow that involves external contributors and internal reviewers.

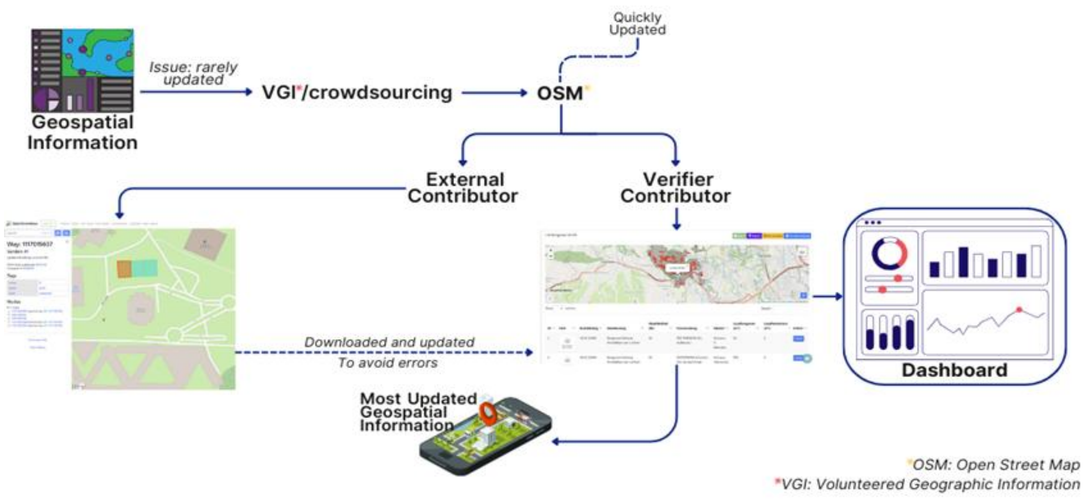

Figure 2. Land use data curation process for Dashboard Integration

Instead of displaying live OSM updates, the Sustainability Dashboard presents a curated version that the university has internally validated and approved. This workflow prevents data inconsistencies and ensures that only reliable spatial information is available. After verification, internal contributors can upload the revised version to the OSM to improve public maps. By distinguishing between external contributors and internal verifiers, the IPB combines the openness of VGI platforms with the institutional accuracy required for campus decision-making. This controlled integration approach aligns with the findings of Ramadhanis et al. (2025), who emphasized the importance of internal validation when using VGI platforms[24]. Their study highlighted how OSM accessibility provides timely spatial data, but the data quality depends heavily on contributor expertise, justifying institutional oversight for official planning.

The university operationalizes its institutional approach to land-use monitoring by integrating it into a dashboard. As shown in Figure 3, the Asset Management Dashboard overlays validated building assets, represented as red polygons, onto an OpenStreetMap (OSM) basemap, linking each spatial feature with attribute information, such as building name, function, floor area, and location. This integration enhances transparency in asset tracking and supports infrastructure audits, planning, and decision-making. Designated personnel from the Directorate of General Affairs and Infrastructure regularly update spatial data to ensure accuracy.

As illustrated in Figure 4, the mapped assets span multiple campus locations, including Dramaga, Baranangsiang, and Taman Kencana. These visualizations offer a comprehensive overview of IPB University's spatial footprint and enable administrators to make data-informed decisions regarding land-use optimization, development priorities, and sustainability reporting. IPB University has established a robust, dynamic, and institutionally curated digital land-use governance ecosystem using an integrated system.

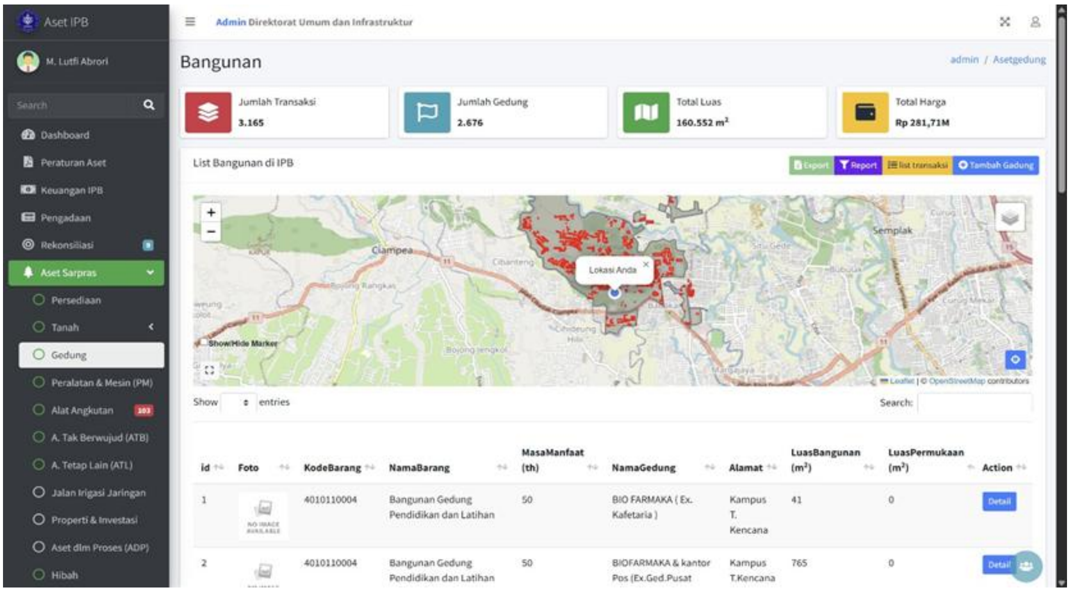

Figure 3. Integrated view of IPB's building assets using OpenStreetMap on the Asset Management Dashboard

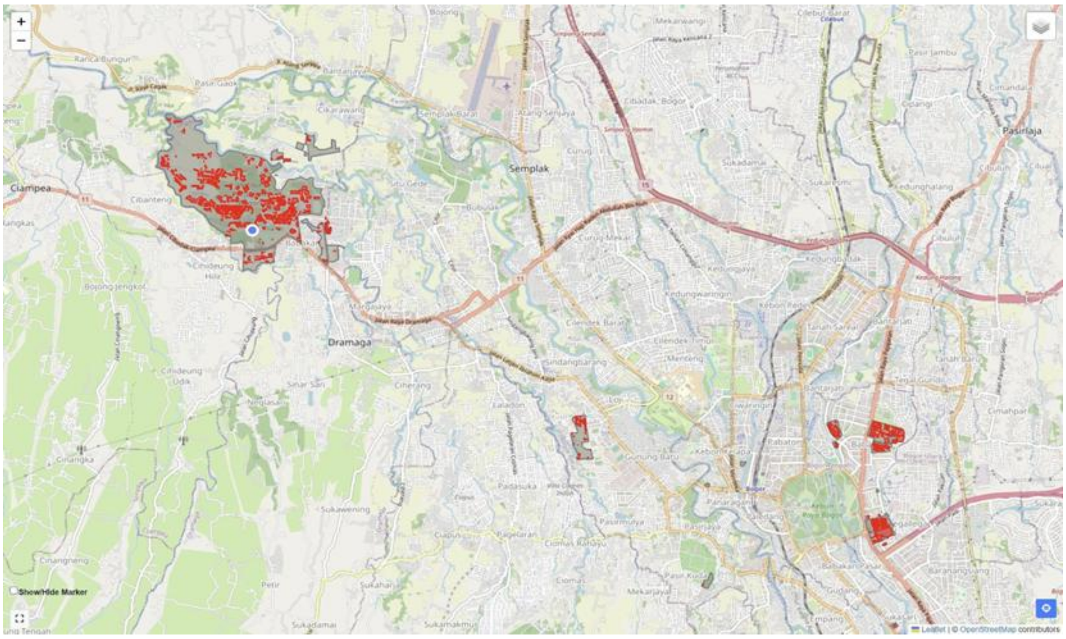

Figure 4. Spatial distribution of IPB University's land and buildings across multiple campuses, visualized with OSM

3.3. Transportation Management

Efficient transportation management is essential to ensure operational sustainability on university campuses, particularly for managing mobility, reducing congestion, and minimizing carbon emissions. At IPB University, early efforts to monitor transportation activities relied heavily on manual monitoring methods. Staff recorded vehicle entry and exit logs using spreadsheets, such as Microsoft Excel, based on ticket stubs or through on-site observations. This labor-intensive process limits the granularity and reliability of mobility data, making it challenging to generate timely insights or support evidence-based planning in the field.

IPB University implemented an automated gate access system equipped with RFID-based identification to improve monitoring accuracy. Students and staff use institutional ID cards, and the visitors receive printed tickets. Each time a vehicle enters or exits, the system records the time stamp, vehicle type, and access method. These data were transmitted to a centralized parking server, allowing continuous storage and retrieval. The university uses the gate access system as the primary data source for monitoring vehicle flow and has gradually integrated it into the Sustainability Dashboard (Figure 5). The dashboard allows campus administrators to track daily traffic volumes, peak mobility periods, and modal shares. Over time, this longitudinal data also facilitates calculations of transportation-related emissions and evaluations of transport policy impacts, such as vehicle restrictions or incentives for greener mobility options[25].

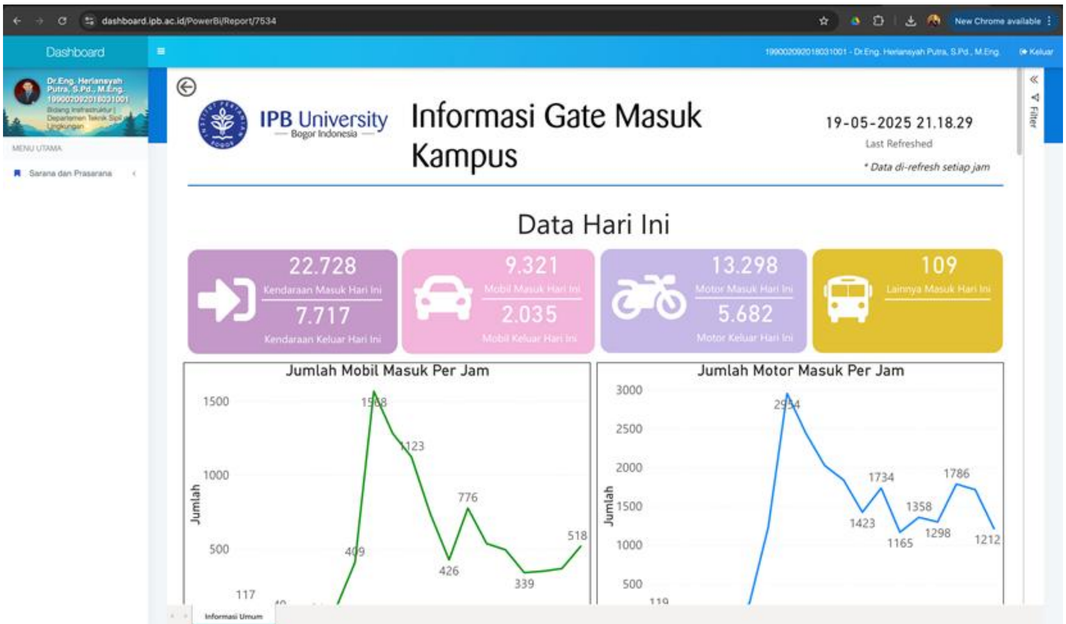

Figure 5. Transportation data visualization on the IPB Sustainability Dashboard

This study applied a system analysis approach to assess the performance of the current gate infrastructure at the IPB Dramaga Campus. Entry and exit data from the parking server were collected and categorized according to the vehicle type and access method (student card or visitor ticket). The researchers verified these data by removing incomplete records and cross-checking anomalies. The resulting dataset enabled the analysis of usage trends and vehicle movement patterns, helping assess the responsiveness of the existing system to the university's sustainable transport goals. Despite these advancements, several limitations of this study remain. The current system does not differentiate trip purposes, such as academic, operational, or service-related, and does not include spatial movement data, such as routes travelled or parking duration. Additionally, integration with the dashboard still requires partial manual verification, which slows down real-time reporting and visualization.

IPB University plans to expand its transportation system to address these gaps by developing modules that classify trip purposes and integrate gate data with geospatial analyses. The university also intends to embed advanced data visualization and scenario-based simulation tools within the dashboard. Administrators will continue to verify the selected data to ensure their integrity before manually integrating them. These digital enhancements align with IPB University's Transportation Master Plan, which envisions a shift toward sustainable mobility on campus.

A central feature of this plan is the construction of designated parking areas near key campus entry points, such as Gate 1 and Gate 2, to intercept private vehicles. The university designated these zones to reduce internal congestion and promote the use of campus shuttle buses for intra-campus mobility purposes. Linking gate access logs with spatial analytics allows the university to monitor traffic volumes, assess parking utilization, and analyze modal shifts in real-time.

These improvements will enhance campus operational efficiency while supporting IPB University's long-term commitment to reducing transport-related emissions and promoting sustainable and low-carbon mobilities. The cooperation between ICT-based monitoring systems and physical infrastructure planning underscores the university's dedication to building a more innovative and environmentally responsible campus.

3.4. Energy Management

This study applied a system analysis approach to improve the monitoring of electricity consumption at IPB University. Previously, the university estimated usage by dividing monthly electricity bills by tariff rates, which limited the accuracy of building-level analysis. To address this, the study collected electricity usage data directly from digital meters provided by PLN, focusing on the actual kWh values per faculty and building. The researchers documented monthly kWh data and categorized them by faculty and building type. They verified the recorded data by comparing them with the total consumption figures in the monthly electricity bills and identified discrepancies where applicable. This process enabled the team to prepare a clean dataset for analyzing the campus consumption patterns.

Energy management remains vital to IPB University's sustainability efforts, particularly in tracking electricity usage and informing future energy-saving strategies that can be implemented. Until recently, the university relied solely on monthly electricity bills from the national utility provider (PLN) to estimate overall electricity consumption. The energy used, measured in kilowatt-hours (kWh), was calculated by dividing the total bill by the corresponding tariff. Although practical, this method does not allow for detailed tracking at the building or faculty level and lacks the granularity required for effective energy monitoring and analysis.

Staff members have manually recorded these kWh values in spreadsheet-based reports for several years. The university transferred the manually collected data to the IPB Sustainability Dashboard to improve the process (Figure 6). This initiative represents an early stage of digitalization; however, the available data still reflect only aggregated campus-wide figures, as the system cannot yet identify electricity usage at the level of individual buildings.

To address this limitation, the university introduced a system of bar-coded meters in the selected buildings. These barcodes facilitate more precise electricity usage tracking by enabling building-specific meter readings to be taken. However, the implementation of this system remains incomplete, with only a few buildings currently equipped and integrated into the monitoring framework. Consequently, IPB University still lacks a comprehensive overview of electricity consumption in all faculties.

Figure 6. Electricity usage data visualization on the IPB Sustainability Dashboard

The university's active real-time energy monitoring system operates through the installation of solar panels. These panels, located on the selected rooftops, were equipped with digital inverters that provided energy production data. These data have already been incorporated into the dashboard, offering insights into renewable energy generation; however, they do not account for electricity consumption from conventional sources such as fossil fuels.

Given these challenges, IPB University recognizes the need for innovative and integrated solutions. Future developments will focus on enabling the automatic acquisition of building-level electricity data through innovative metering systems or wireless sensors that can be directly fed into the dashboard. Such a system would allow universities to monitor, analyze, and manage electricity usage in real time at the faculty level[26]. Administrators compare recorded meter readings with utility-provided billing data to ensure data accuracy, although discrepancies still occur because of partial implementation. Through this advancement, the university aims to implement more targeted energy conservation policies, improve transparency in resource management, and strengthen its commitment to sustainable operations.

3.5. Carbon Operational and Carbon Balance

Understanding and managing carbon emissions is a key pillar of IPB University's sustainability agenda. The university has initiated efforts to estimate its operational carbon footprint, primarily based on data related to energy consumption and transportation activities on the campus. The emission calculations followed standard methodologies using established emission factors to convert electricity usage (in kWh) and transport-related activities into equivalent carbon dioxide (CO_2) emissions. These estimations provided an overview of the environmental impacts associated with routine campus operations.

Electricity consumption remains the most significant contributor to carbon emissions at IPB University, particularly because of the continued reliance on grid-based energy sources from fossil fuels. The university estimated the total annual emissions from electricity usage using monthly billing data and extrapolated these figures using the appropriate emission coefficients. To calculate transportation-related emissions, the university assessed the volume and types of vehicles entering the campus, including shuttle buses, private cars, and motorcycles. Each vehicle category was assigned a specific emission factor based on the estimated travel distance and fuel efficiency, allowing for a comprehensive approximation of the emissions generated by the campus mobility.

Although this estimation process laid the groundwork for institutional carbon accounting, several limitations exist. The university has not implemented building-level energy tracking or vehicle-based emission monitoring for real-time dynamic carbon output calculations yet. Additionally, the current carbon inventory does not fully account for other emission sources, such as those from construction activities, material procurement, or waste treatment processes.

In parallel with these estimations, IPB University has taken steps to build a carbon balance framework by analyzing the carbon sequestration potential of its campus landscape. Land use mapping conducted using drone imagery enabled the classification of campus vegetation and surface cover, including forest patches, agricultural plots, green spaces, and built-up areas. These spatial datasets provide a foundation for estimating the capacity of campus ecosystems to absorb and offset the carbon emissions. However, the methodology for quantifying sequestration is still under development, and universities have not yet adopted standardized models for carbon sink assessment, such as biomass-based carbon-stock estimation.

The university has significantly enhanced its monitoring capacity by deploying real-time air quality sensors at multiple key locations near the main campus gate, in academic buildings, and in agricultural experimental fields. These devices provide continuous data on ambient air conditions, offering a more immediate perspective on atmospheric pollution and localized carbon levels. Although these tools do not replace complete carbon flux measurement systems, they represent a significant step forward in building a responsive environmental monitoring infrastructure. IPB University plans to directly link land-use classifications and air quality data to the Sustainability Dashboard to strengthen this system. The long-term goal is to develop a dynamic model that combines real-time environmental indicators, carbon emission inventories, and carbon sequestration estimates, ultimately enabling the university to chart measurable pathways to achieve carbon neutrality[27].

The dashboard allows decision-makers to visualize carbon output from multiple operational sources in near-real time. For example, by combining gate access logs with fuel-based emission factors, the team estimated transport-related emissions with daily precision. The platform also overlays building-specific energy data with carbon conversion rates to highlight emission hotspots. This function helps sustainability managers prioritize energy retrofitting and behavioral campaigns in high-impact zones[28].

3.6. Future Plan: Waste and Water Monitoring

To advance campus sustainability, IPB University prioritizes waste and water management as key areas for future enhancements to its Sustainability Dashboard. The university plans to strengthen both domains using digital tools and data-driven approaches. The research team applied a quantitative method to monitor waste generation using portable axle scales on the dump trucks. Each axle was weighed separately to ensure accurate source measurements. First, they positioned the truck such that the rear axle rested on the scale and recorded the weight as W_{rear}. Subsequently, they moved the truck forward to place the front axle on the scale and recorded the weight as W_{front}. The team repeated this process for all dump trucks operating during the data collection period and integrated the processed data into the IPB Sustainability Dashboard. This platform consolidates various data streams into a centralized database, allowing stakeholders to access real-time waste-related data.

Previously, the university estimated solid waste volumes manually, which yielded only rough figures and lacked information about waste types. IPB University adopted portable wheel scales as a weight-based monitoring solution to improve the accuracy of weight measurement. In this system, operators place each wheel on a digital pad that captures the axle load data. The system then aggregates the measurements to calculate the total waste transported off campus. Because this method requires minimal infrastructure, it is suitable for operational environments with limited facilities. The university color-coded its waste trucks to support automatic classification during data entry: red for paper, green for organic, and yellow for inorganic waste. The team visualizes all collected data through a dashboard, enabling trend analysis by waste categories.

IPB University currently relies on billing records to track building-level water consumption. While these records support financial reconciliation, they lack the details necessary to detect inefficiencies, such as leaks or excessive usage. To address this issue, the university plans to install digital metering systems that automatically collect, process, and display water usage data. By integrating this information into the dashboard, administrators can monitor usage patterns, set reduction targets, and identify opportunities to improve efficiency at the faculty and building levels.

To strengthen this system, the development team plans to integrate water consumption data with other contextual indicators, such as occupancy levels, building types, and weather conditions. By doing so, the university will be able to normalize water usage per capita and identify buildings that significantly deviate from the expected standards. Moreover, the dashboard includes alert functions to detect anomalies in real time, such as sudden spikes in consumption that may indicate undetected leaks or malfunctioning plumbing systems.

The university also aims to use this module to support long-term conservation efforts. For instance, administrators can evaluate the effectiveness of behavior-based campaigns (e.g., low-flow fixtures or signage in restrooms) by tracking changes in water usage over time. These features enable sustainability managers to design more precise and targeted interventions at the building or department level. Several universities worldwide have adopted similar ICT-based water monitoring systems to improve operational efficiency and reduce water waste[29,30]. IPB University draws on these best practices while adapting its approach to the local infrastructure and data availability. IPB University aims to expand the Sustainability Dashboard beyond energy and transportation through these initiatives. The university supports data-informed decision-making and reinforces institutional accountability across all resource domains by building comprehensive and integrated monitoring systems.

4. Conclusions

The development and deployment of the IPB Sustainability Dashboard signifies a critical advancement in how higher education institutions manage, evaluate, and improve their environmental performance. Through cross-domain data integration, the university has established a comprehensive digital system that enhances real-time monitoring, supports stakeholder collaboration, and strengthens decision-making in resource-intensive processes. Quantitative evaluations revealed significant improvements in the accuracy and management of data. Electricity monitoring, previously based on aggregate monthly bills, now supports building- and faculty-level analyses, allowing more precise energy conservation initiatives. Transportation data collection has evolved from manual logs to radio frequency identification-based tracking systems, enabling daily carbon footprint estimates. Land use visualization has improved through drone-acquired imagery and OpenStreetMap (OSM) integration, which facilitates timely spatial planning and management. Waste tracking now relies on axle-scale measurements rather than subjective estimates, which improves the data accuracy and classification. Planned smart water metering and anomaly detection systems will enhance the responsiveness to consumption irregularities such as leaks or excessive use.

Although the dashboard shares common features with international systems, it remains uniquely adapted to a resource-constrained context. The dashboard leverages a combination of high-tech tools and low-cost strategies, such as portable scales and semi-automated verification, making it practical and scalable for campuses across Indonesia and in similar regions. The dashboard contributes significantly to institutional commitments related to sustainability reporting, UI GreenMetric performance, and the broader smart campus agenda. It also directly addresses key global priorities through alignment with the SDGs, particularly in energy efficiency, emission reduction, responsible resource consumption, and digital infrastructure development.

However, this study has several limitations must be acknowledged. Automation has not yet been fully implemented in all domains, particularly in energy and water systems, where manual verification is still necessary. The current carbon accounting approach does not include indirect emissions from activities such as procurement, construction, and supply chains. Furthermore, reliance on human oversight continues to slow real-time data integration in certain areas, thereby limiting dashboard responsiveness. To address these challenges, IPB University has outlined future development strategies, including the campus-wide deployment of smart meters, integration of AI-based anomaly detection, and expansion of dashboard modules for advanced scenario simulations. Additional efforts will be directed toward improving carbon sink modelling, standardizing emission estimation methods, and increasing public access to the dashboard interface to foster wider institutional and community engagement.

In summary, the IPB Sustainability Dashboard is more than just a monitoring tool for sustainability. This is a strategic platform for institutional transformation. This enhances environmental governance, enables data-informed policymaking, and supports long-term sustainability goals. As a replicable and scalable system, IPB University serves as a living laboratory for sustainability and a model of best practices for other institutions seeking to advance smart campus initiatives.

Acknowledgment
The authors gratefully acknowledge the support of the Directorate of General and Infrastructure and Information Management and Digital Transformation Center of IPB University for their supports.

Conflict of Interest
The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors Contribution
All the authors contributed substantially to the work. **H.P.** conceived the research idea, designed the methodology, and wrote the manuscript. **I.Q.** supervised the work. **A.D.U.** performed the data collection. **Z.R.** conducted data analysis and interpretation. **M.L.** contributed to manuscript writing and data collection. **H.W.** supervised the work. **A.S.S.** supervised the work. All the authors have reviewed and approved the final version of the manuscript.

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