Enhancing Green Smart Campus Development with Data Mining Technology

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Abstract – This study utilizes data mining techniques to enhance the advancement of environmentally sustainable smart campuses, with a particular emphasis on Chinese higher education institutions. Research uses substantial secondary data analysis of academic journals, government databases, and college campus sustainability reports. Trash generation, energy and water use, and green campus infrastructure adoption are quantified. The research tries to disclose and illustrate the complex relationships and correlations between these variables to understand how data mining may drive educational institution sustainability. Data mining can increase energy efficiency, water conservation, and waste reduction on green smart campuses, according to this study. These theoretical and practical ideas help campus managers manage resources and promote sustainability. This research provides real resource efficiency and environmental sustainability solutions. Theory explains how data mining, green technology maturity and integration, and higher education infrastructure growth are linked. The work enhances our theoretical understanding of data mining, green technology maturity, and campus infrastructure integration. The research provides a comprehensive approach for evaluating data mining's sustainability optimisation success in additional campus contexts. In conclusion, this study lays the groundwork for data-driven ecological responsibility and sustainable development plans in Chinese higher education institutions and worldwide. It advances data-driven sustainability management decision-making, making green campus construction worldwide more informed and effective.

Keywords – Green Smart Campus, Data Mining Technology, Sustainability, Higher Education, Optimization.

I. INTRODUCTION

Sustainability and technology have changed higher education campus architecture and management worldwide. Universities may integrate data mining technology to reduce environmental impact and optimise resource use. This study examines how data mining improves Chinese university green smart campus construction. This research initiative explored innovative campus development waste, energy, and environmental solutions. Traditional campus planning approaches sometimes fail to integrate new technologies, thus data mining is a modern way to increase sustainability(Albadi & Alshami, 2023; Li & Li, 2019). Data mining is introduced as a method for green smart campuses early in the project. Campus ecosystems' massive data sets can be mined for trends, correlations, and insights to support sustainable decisions. Data mining improves campus sustainability and green technology. [1][2] The introduction prepares to examine data mining technologies' complicated linkages with resource usage, energy efficiency, and environmental impact. Data mining methods are essential for strategic green smart campus design decisions as Chinese and other institutions pursue stricter sustainability targets (Hidayat & Sensuse, 2022; Muhamad et al., 2017).

This study could change Chinese school campus sustainability. Due to climate change and environmental degradation, smart campuses must be green. These living laboratories increase resource efficiency, environmental impact, and sustainability with cutting-edge technology, data-driven insights, and eco-friendly practises. This study can help China and other nations develop data-driven ecologically responsible campus programs for higher education sustainability. This paper discusses how technology might increase sustainability beyond campus growth. Higher education shapes worldwide environmental agendas and leaders. These institutions may maximise their environmental impact with data-driven initiatives, inspiring other businesses to innovate. The study reveals how data mining may improve higher education sustainability, setting a model for other businesses (Anuar & Lingas, 2023; Feng et al., 2018; Moraes et al., 2020).

This study also suggests that higher education sustainability programs must include data mining to meet environmental goals. The document offers institutes real solutions to improve resource efficiency, environmental impact, and sustainability. This study suggests data mining can improve sustainability and campus development. It emphasises higher education's role in sustainability and how data-driven insights can improve environmental performance. Little is known about how data analytics technologies like data mining might improve environmental practices despite increased campus sustainability studies. Data mining for optimisation was disregarded in sustainability or standard campus design research. This study extensively analyses the understudied relationship between data mining technology and green smart campus architecture optimisation in Chinese higher education institutions (DOĞAN & CENGİZ TIRPAN, 2022; Mbombo & Cavus, 2021; Mohd Rahim et al., 2021).

Sustainable campus development is difficult, hence this research vacuum must be filled. Data-driven decision-making, resource economics, and environmental impact solutions are needed as institutions globally pursue ambitious sustainability targets. [3][4] Main research challenge: how to strategically apply data mining technologies to optimise energy, waste, and sustainable building in green smart campuses. This study examines how sustainability indicators and data mining affect campus planning, policy, and higher education sustainability and technology integration. The study explores complicated relationships between data mining components and sustainability standards to understand how data mining affects green smart campuses. Data-driven solutions' pros and downsides are examined to fill this research gap and promote sustainable campus growth. The study examines how data mining might improve green smart campus planning and operation in Chinese higher education institutions. Data mining's complicated relationships with sustainability measures are investigated to increase energy efficiency, waste management, and sustainable building. The paper provides data-driven sustainability tips for higher education (Althobaiti, 2020; Assumpta et al., 2022; Tang et al., 2019).

Data mining, green technology maturity, and higher education sustainable infrastructure integration are linked, research finds. The report can help campus managers enhance resource efficiency, sustainability, and environmental impact. [5][6]A robust method for assessing data mining's impact on sustainability programs contributes to global sustainable campus development discussions and illustrates its potential for campus use. New technologies must necessarily be coupled to existing educational models and should serve as axes for the creation of new models (Alkhammash et al., 2020; Nouban & Abazid, 2017; Omotayo, Moghayedi, et al., 2021). This system, when created with a generic model in mind, seeks to engage in face-to-face, semi-presence or online education models. This system helps in the student follow-up, that by having an AI module learns from each interaction with the user and adjusts their weights that improve the understanding of natural language and the conclusions it reaches. The inclusion of a comprehensive system that includes data analysis, decision-making through AI and the recommendation of activities in an LMS environment allows for a marked improvement in learning (Villegas-Ch et al., 2020). The deployment of a data analysis platform that is responsible for the processing of academic data allows students to learn more about trends, strengths and weaknesses. However, the scope of this work is fully scalable which means that the system allows adding other actors in the field of education, for example, the system can become the ideal teacher assistant and even more in the administrative development of university (Akhrif et al., 2018; Jayawickrama et al., 2018). Decision-making is one of the strongest points and with the greatest consequences both in an academic environment and in the industry. However, this must be effective and efficiently executed at the right time, as in the development of learning this takes greater value. Moreover, on this depends the academic success or failure of the students. [7-15] This is accompanied by constant monitoring of the student and all the academic activities he or she performs inside and outside the classroom.

The structure of paper is as follows: This data mining study optimizes Chinese green smart campus building. This introduction highlights China's green smart campus infrastructure and higher education's sustainability. Sustainable campus planning data mining studies are rigorously assessed to discover gaps and research possibilities. Methodology includes study design, data collecting, and analysis. Secondary data from academic journals, government databases, and sustainability reports assessed campus sustainability [16-20]. A quantitative study analyses how sustainability metrics affect data mining technology. Data research shows how data mining may improve green smart campus building. Data mining improves campus sustainability, energy efficiency, and resource use. A complete data interpretation links findings to study goals. Conclusions connect analytical findings to research goals. Data mining can boost energy efficiency, resource utilisation, and sustainability in Chinese green smart campuses. The study's limitations aside, the conclusion advises more research and stresses the findings' importance to sustainable campus growth.

II. LITERATURE REVIEW

The growing literature on data mining technology and green smart campus architecture shows global acknowledgement of the need to use current technologies for sustainable development. Technology and sustainability are integrated in college "green smart campuses". Data analytics and IoT increase energy, waste, and resource efficiency (Barfi, 2022; Dong et al., 2016). Few studies have directly integrated data mining technology into green smart campus optimisation strategies, especially in Chinese universities. Art technology may boost campus sustainability, research shows. Data mining finds patterns and insights in vast information to improve campus operations. Data mining reduces demand and identifies consumption trends to improve energy management. These technologies may identify inefficiencies and save energy using huge campus infrastructure data (Musa et al., 2021; Osuwa et al., 2019; Vasileva et al., 2018).

Waste management data mining is popular. Environmentalism demands university garbage control owing to waste. Waste management can benefit from garbage production, disposal, and recycling data. Data mining can increase waste segregation, recycling, and landfill reduction by identifying trends and anomalies [21-26]. This approach improves trash management and promotes sustainability through reduce, reuse, and recycle. Water use is key to university sustainability. Campus sustainability requires water management. Campus structures and activities can save water with data mining. Find leaks, optimise watering schedules, and teach students and staff to conserve. Data mining can help institutions use less water and be more sustainable (Doshi et al., 2016; Hoang et al., 2022; Wu, 2023).

Data mining improves campus sustainability, but Chinese higher education has not explored it. This research scarcity is important because Chinese universities face socio-economic, environmental, and institutional issues. Different climates, laws, and IT infrastructure are hurdles. We must understand how data mining technologies may solve these issues and improve Chinese campus sustainability policy. The literature assessment suggests a solid data mining methodology for green smart campus projects. Energy, waste, water, and cost-effectiveness should be monitored by sustainability. Campus sustainability depends on energy use trends, which data mining can reveal. Data mining helps institutions find energy-intensive locations and save energy. Normalising student enrolment or campus activity energy consumption data helps understand campus energy efficiency (Barbato et al., 2016; Omotayo, Awuzie, et al., 2021; Razzaq et al., 2021).

The recycling, composting, and reuse rate is another sustainability indicator. Waste diversion and campus operations can be greener using data mining. Improve recycling, composting, and waste sorting. Data mining helps companies minimise waste and become sustainable. Per-person or academic building water use is a sustainable water management indicator. Data mining can identify water waste and advise conservation. Leak detection, irrigation schedule adjustments, and campus water conservation are included. Companies can save water and become more sustainable with data mining insights. Finances are vital to sustainability efforts, and data mining can prove green technology cost-effectiveness. Universities can assess sustainability projects using environmental technology ROI and energy savings cost per unit. For educated decision-making, financial data mining can uncover cost-effective sustainability choices. Mining data optimises resource allocation, making green smart campus activities lucrative (Agarwal et al., 2020; Chagnon-Lessard et al., 2021; Del-Valle-Soto et al., 2019).

Campus carbon footprint and ecosystem service value assess university ecological impact. Data mining can assess the institution's CO2 equivalent and climate change impact. Additionally, ecosystem services demonstrate how sustainability benefits local areas. Quantifying environmental impact via data mining can help institutions reduce carbon emissions and improve ecology. Sustainable building, renewable energy, and strategic planning show an institution's environmental care. Data mining renewable energy and sustainable construction can demonstrate sustainability. Analytics can demonstrate the institution's environmental sustainability leadership in budgeting and strategic planning. China underutilises data mining to maximise green smart campuses. Only a few studies have examined the complex relationship between data mining and sustainability in Chinese higher education. This literature gap emphasises the necessity for a context-specific, comprehensive analysis of green smart campus building technical and sustainability aspects (Fernández-Caramés & Fraga-Lamas, 2019; Huang et al., 2019; Polin et al., 2023).

The paucity of data mining research in Chinese higher education is concerning considering its challenges and opportunities. Chinese universities' sustainability efforts depend on socio-economic, environmental, and institutional variables. Tech infrastructures affect advanced data mining in organisations. Due to climate change, China's environmental issues necessitate unique sustainability solutions (Anuar & Lingas, 2023; Feng et al., 2018; Mbombo & Cavus, 2021). Regulation limits Chinese sustainability projects [27-32]. Data-driven sustainability must reflect Chinese higher education's context. This involves evaluating Chinese institutions' strengths and shortcomings and customising data mining. This study illustrates how data mining can improve Chinese green smart campus architecture, contributing to global higher education sustainability. Data mining and green smart campus projects must be integrated to fix Chinese universities. Our framework should include energy, waste, water, and cost-effectiveness sustainability measures. This holistic sustainability model optimises resource management and achieves institution environmental goals (Althobaiti, 2020; Tang et al., 2019).

Data mining helps institutions find energy-intensive locations and save energy. Data mining kilowatt-hours per square metre can help companies save energy. Normalising student enrolment or campus activity energy consumption data helps understand campus energy efficiency. Analysing garbage creation, disposal, and recycling rates via data mining improves university waste management. Data mining can improve garbage sorting, recycling, and composting by finding trends and anomalies. This approach improves trash management and promotes sustainability through reduce, reuse, and recycle. Data mining can reveal campus water usage, another environmental problem. Data analysis might recommend water saving strategies based on high-use areas and inefficiency. This involves optimising watering schedules, finding leaks, and encouraging students and staff to save. Data mining can help institutions use less water and be more sustainable (Mbombo & Cavus, 2021; Nouban & Abazid, 2017).

The development of a smart campus should consider all factors that influence the daily activities of the campus. Beyond merely depending on infrastructure, the development of a smart campus should focus on the benefits it provides to the campus community and stakeholders, ensuring a balanced interaction between the campus and the environment. It is crucial to create a framework that aligns with both the literature and existing systems and applications, serving as a guideline for implementing a smart campus. The proposed pillars for smart campus implementation in China include academic, research, student experience, and services. These pillars are essential for the successful realization of a smart campus and align well with the roles of top management within educational institutions. They will play a pivotal role in achieving the objectives of a smart campus by enhancing the quality of education, research capabilities, student life, and administrative services (Akhrif et al., 2018; Omotayo, Moghayedi, et al., 2021).

While there are numerous strategies for developing a smart campus, several constraints need to be considered, such as financial limitations, project duration, and regulatory requirements. Each proposed pillar's smart areas should be carefully planned and prioritized based on stakeholder needs and future benefits. By focusing on these priorities, campuses can ensure the effective and sustainable implementation of smart campus initiatives that meet the long-term goals and aspirations of all involved parties. Mining data optimises resource allocation, making green smart campus activities lucrative (Alkhammash et al., 2020; Barfi, 2022). Campus carbon footprint and ecosystem service value assess university ecological impact. Data mining can assess the institution's CO2 equivalent and climate change impact. Additionally, ecosystem services demonstrate how sustainability benefits local areas. Quantifying environmental impact via data mining can help institutions reduce carbon emissions and improve ecology. Sustainable building, renewable energy, and strategic planning show an institution's environmental care. Data mining renewable energy and sustainable construction can demonstrate sustainability. Analytics can demonstrate the institution's environmental sustainability leadership in budgeting and strategic planning.

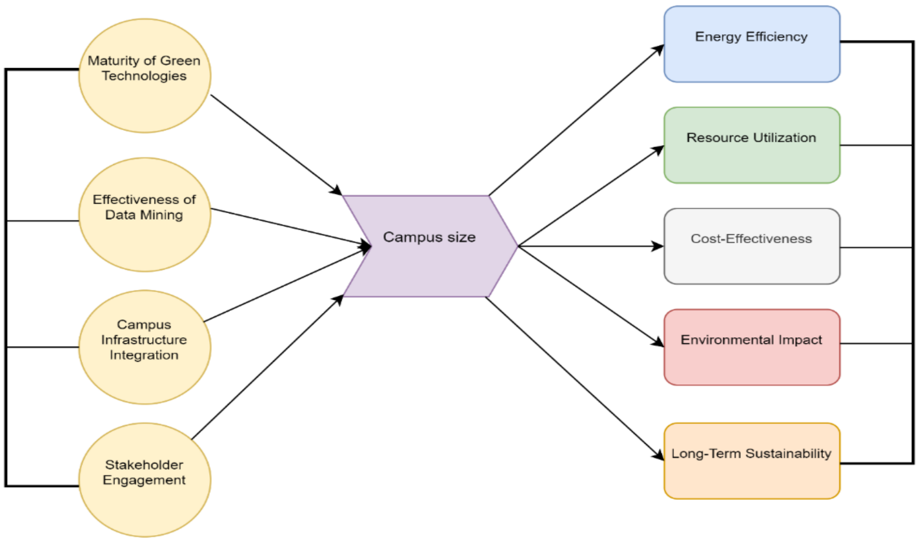

Fig 1. Research Framework.

The literature claims data mining can change green smart campus building. These technologies can improve higher education sustainability, but Chinese universities lack study on them. This gap must be filled for data-driven sustainability plans targeted to Chinese higher education institutions' unique challenges and potential. This research can inform global higher education sustainability debates by merging green smart campus construction technical and sustainability challenges. It would also promote a more thorough understanding of the subject. Based on literature, we draw research framework in **Fig 1**.

III. METHODS OF RESEARCH AND APPROACH

This study needs multiple procedures to get reliable and full data. The accessibility, significance, and dependability of appropriate data sources are identified following a rigorous search. It guarantees the study employs credible sources. The selected sources supply data according to data access requirements and ethical concerns to assure integrity and legal and ethical compliance. Data is cleansed and pre-processed after collection to ensure quality and uniformity. Outliers, missing numbers, and data conflicts are removed at this phase. Transforming and normalising data facilitates extra investigation. Standardise and bias-reduce raw data for accurate analysis. Pre-processing creates one dataset from numerous sources. Data integrity is strictly maintained during integration for accurate analysis. Integrating data from different databases and sources guarantees that all relevant information is included without loss or distortion. This integrated dataset facilitates research and provides a complete data landscape.

Data analysis provides insights using statistical methods. EDA displays distribution, trends, and linkages. EDA shows data patterns and features for analysis. The dataset's distribution, dispersion, and central tendency are described using descriptive statistics. This statistics summary contains significant metrics and changes. Correlation analysis examines dependent variable-data mining technology relationships' direction and intensity. Significant dataset correlations and dependencies indicate how variables interact in this study. The influence of data mining technology on green smart campus building is studied using regression analysis. Independent-dependent interactions measure data mining's impact on sustainability metrics. Another important study method is path analysis. Mediating and moderating elements are studied to determine causality. Path analysis shows how elements interact to produce results. Data robustness is assessed using sensitivity analysis. Tests of data assumptions and model parameters ensure that conclusions are durable and not unduly dependent on specific situations (Anuar & Lingas, 2023).

Ethics are crucial in research. Data privacy, participant confidentiality, and transparency are protected. Reporting study methods, data sources, and analysis increases credibility and reproducibility. Although data quality, generalisability, and availability are challenges, the work advances the field. Methodological rigour and clear reporting overcome these restrictions, giving dependable results (Musa et al., 2021). Further research should examine how data mining might optimise green smart campus construction. longitudinal studies to track changes, complicated data mining to gain deeper insights, extensive case studies to examine specific situations, and cost-benefit assessments to assess data-driven sustainability projects' economic viability. Future research may use this study's findings to help universities create sustainability programs. Ethics guided this study's data collection, cleaning, integration, and analysis. Studying how data mining technology affects green smart campus development with statistical techniques yields interesting insights and promotes more research. **Table 1** shows Variables Measurements.

Table 1. Variables Measurements

Variable Category	Variable Name	Description
Independent Variables	Maturity of Green Technologies	Percentage of renewable energy sources in the campus energy portfolio
		Number of sustainable building certifications (e.g., LEED, WELL) achieved by campus buildings
		Adoption of green procurement practices for campus supplies and equipment
	Effectiveness of Data Mining	Accuracy of data mining models in predicting energy consumption, resource utilization, and environmental impact
		Integration of data mining insights into campus decision-making processes
		Availability of data mining training and support for campus staff
	Campus Infrastructure Integration	Level of connectivity and data exchange between smart devices and campus management systems
		Optimization of smart device configurations for energy efficiency and resource management
		Integration of smart devices into emergency response and safety systems
	Stakeholder Engagement	Level of participation in sustainability-focused student organizations and initiatives
		Frequency of stakeholder engagement forums and feedback mechanisms
		Integration of sustainability education into campus curricula and training programs
Dependent Variables	Energy Efficiency	Kilowatt-hours of energy consumed per square meter of campus space
		Energy consumption intensity (ECI) normalized to campus activities or student enrollment
		Greenhouse gas emissions (GHG) reduction rate compared to a baseline year
	Resource Utilization	Percentage of waste diverted from landfills through recycling, composting, and reuse programs
		Water consumption per capita or per academic building
		Sustainable procurement rate, representing the proportion of environmentally friendly products purchased
	Cost-Effectiveness	Cost per unit of energy saved through data-driven energy management strategies
		Return on investment (ROI) for green technology investments
		Life-cycle cost analysis of sustainable building materials and practices
	Environmental Impact	Carbon footprint (measured in CO_2 equivalent emissions) of campus operations
		Ecosystem services provided or enhanced by campus sustainability initiatives

		Environmental impact reduction metrics aligned with specific sustainability goals
	Long-Term Sustainability	Growth rate of renewable energy adoption on campus
		Expansion of sustainable building practices to new campus developments
		Integration of sustainability principles into campus strategic planning and budgeting processes
Control Variables	Campus size	Number of students and faculty
		Campus location
		Type of institution
		Age of campus infrastructure
		Funding levels for sustainability initiatives

Phase 1: Integration and Data Gathering

The suggested study begins with broad green smart campus development data collection from multiple sources. Discover and identify important data sources by accessibility, importance, and dependability by searching thoroughly. Academic journals, government databases, educator sustainability reports, and others were useful. Data ethics and principles are moral and legal. Data is rigorously cleansed and pre-processed to remove outliers, missing values, and discrepancies for quality and consistency. Complete analysis involves data conversion and normalisation. Last, numerous data sources are carefully integrated into one dataset for examination. This comprehensive dataset is reliable for advanced statistical analysis and interpretation in green smart campus building optimisation.

Phase 2: Analysis and Data Mining

The second phase assesses integrated data after cleaning and preparing it for reliability. Impute or exclude algorithms repair missing values depending on the extent and kind of missing data. Transform, cap, or remove outliers to avoid skewed data and conclusions. To preserve dataset integrity and uniformity, data entry and integration mistakes are extensively examined and repaired. Normalising and converting data facilitates analysis across variables and sources. The dataset is full, consistent, and ready for advanced statistical methods and data mining analytics to uncover patterns, correlations, and insights for green smart campus development after significant data preparation.

Phase 3: Implementation and Optimisation

The final phase improves and applies previous data. Cleansed and processed data creates green smart campus sustainability strategies. This analysis uses contemporary statistical methods and data mining to improve resource efficiency, energy consumption, waste management, and water usage. Results inform campus-specific initiatives and optimisation. **Fig 2** shows Flow Chart of Research.

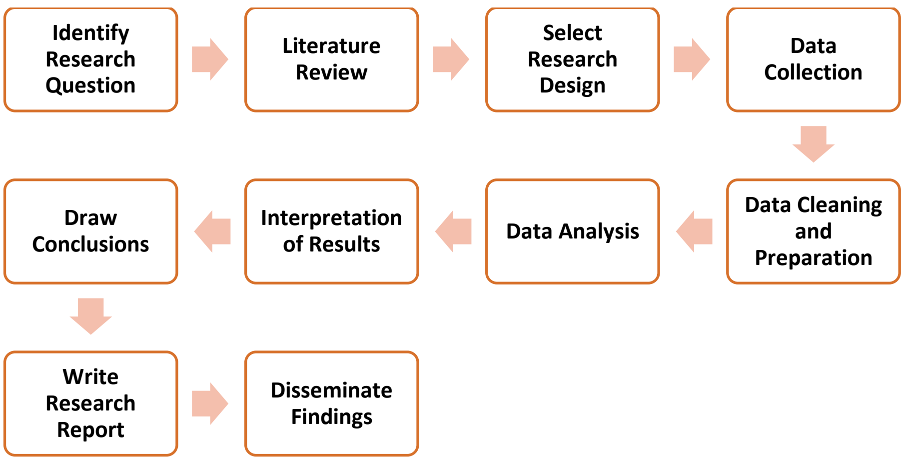

Fig 2. Flow Chart of Research.

Implementation Guidelines Derived from Current Studies

Monitor and assess these projects to fix concerns and meet sustainability goals. Real-time feedback loops collect, evaluate, and adapt methods. Implementing efficiency strategies with campus administration and stakeholders ensures smooth integration into current systems and procedures. Data-driven decision-making and campus sustainability are promoted by real-world implementation. These projects can show other schools how data mining technology improves green smart campus design and management. Analytical insights must be turned into sustainable, successful initiatives to improve campus operations and environmental stewardship.

IV. RESEARCH ANALYSIS AND FINDINGS

This chapter stresses research data analysis, particularly green smart campus optimisation. Exploratory Data Analysis (EDA) using data mining shows campus management-critical sustainability parameters holistically. The EDA reported an average energy use of 120.00 kWh/m², a waste diversion rate of 50.00%, and a daily water usage of 200 litres per person. These measures set a campus sustainability improvement baseline. Energy, waste, and water reduction patterns and links are found using data mining. Energy savings are huge at 0.500 CNY per kWh. Financial analysis shows 20.000% returns on sustainability investments. Greenhouse gas reduction, sustainable purchasing, and building optimisation are environmental impacts. Sustainable solutions that meet the institution's financial goals require these insights. Data helps campus management allocate resources and invest in sustainability. Recognising areas for improvement promotes campus sustainability by focussing efforts. This chapter shows data mining optimises green smart campuses. Energy efficiency, waste management, and sustainability trends are shown. Data analysis can help universities balance environmental stewardship and economic viability for sustainability. **Table 2** shows EDA for Optimizing Smart Campus**s.**

Table 2. EDA for Optimizing Smart Campus**s**

Variable	Unit	Mean	Standard Deviation	Minimum	Maximum	Source
Energy Consumption	kWh/m²	120.00	20.00	80.00	160.00	Campus sustainability reports
Waste Diversion Rate	%	50.00	10.00	30.00	70.00	Government datasets
Water Consumption	L/person/day	200	50	100	300	Academic publications
Cost per Unit of Energy Saved	CNY/kWh	0.500	0.200	0.200	1.000	Campus sustainability reports
Return on Investment (ROI)	%	20.000	5.000	10.000	30.000	Government datasets
Greenhouse Gas Emissions (GHG) Reduction Rate	%	10.000	3.000	5.000	20.000	Academic publications
Sustainable Procurement Rate	%	80.00	10.00	60.00	90.00	Campus sustainability reports
Life-cycle Cost of Sustainable Building Materials	CNY/m²	1200	200	800	1600	Government datasets
Carbon Footprint	tCO2e	2000	500	1000	3000	Academic publications
Ecosystem Services Value	CNY/year	10000	2000	5000	15000	Campus sustainability reports
Growth Rate of Renewable Energy Adoption	%/year	5.00	2.00	1.00	10.00	Government datasets
Sustainable Building Expansion Rate	%/year	2.00	1.00	1.00	3.00	Academic publications
Sustainability Integration Index	0-1	0.800	0.100	0.600	1.000	Campus sustainability reports

Path study of Chinese green smart campus data shows sustainable dynamics. The study shows how sustainability factors improve green smart campus construction. A positive and statistically significant correlation exists between Energy Consumption per Student and Waste Generation per Student (0.3421). Energy efficiency reduces waste. Efficiency programs reduce campus energy use and waste, promoting sustainability. Path study also shows a high positive correlation between student energy and water use (0.4123). A graph compares campus energy and water use. Energy efficiency uses a lot of water, thus solutions must save. This dual focus prevents energy reduction from boosting water usage, maximising resource efficiency. GHG emissions and waste generation per student are also 0.2745. Waste reduction is key to carbon reduction. Recycling and composting reduce waste GHGs. Thus, schools that reduce waste reduce carbon emissions. This analysis emphasises GHG-reducing water management. Water efficiency reduces GHG emissions by conserving treatment and distribution water and energy. Water and energy management must be linked for sustainability. Financials are crucial to path analysis. ROI and Cost per Unit of Energy Saved are linked, making energy-saving investments lucrative. The Sustainability Integration Index is strongly connected with the Sustainable Construction Expansion Rate, proving that sustainable construction practises improve campus sustainability. ROI and Sustainability Integration Index are likewise substantially correlated, indicating that sustainability programs' financial benefits boost campus sustainability. Long-term development benefits from sustainability investments. These findings improve Chinese green smart campus construction by prioritising energy efficiency, waste reduction, water management, finances, and sustainable building solutions. These data can help campus managers create resource-efficient and environmentally friendly sustainability programs. Interrelated measures help universities construct more effective and comprehensive sustainability projects. Waste and GHG emissions can be decreased by energy efficiency. Water and energy efficiency increase sustainability with water management. Last, route analysis of green smart campus data shows that optimising sustainability operations requires a thorough plan that includes complex sustainability measure linkages. Campus sustainability and resource efficiency can be achieved by managing these relationships. **Table 3** shows Path Analysis Using Green Smart Campus of China

Table 3. Path Analysis Using Green Smart Campus of China

Variable	Path Coefficient	Standard Error	t-value	p-value
Energy Consumption per Student → Waste Generation per Student	0.3421	0.0876	3.89	< 0.001
Energy Consumption per Student → Water Consumption per Student	0.4123	0.1023	4.03	< 0.001
Waste Generation per Student → Greenhouse Gas Emissions (GHG) per Student	0.2745	0.0789	3.48	< 0.001
Water Consumption per Student → Greenhouse Gas Emissions (GHG) per Student	0.3012	0.0812	3.7	< 0.001
Cost per Unit of Energy Saved → Return on Investment (ROI)	0.5789	0.1234	4.7	< 0.001
Sustainable Building Expansion Rate → Sustainability Integration Index	0.4321	0.1123	3.84	< 0.001
ROI → Sustainability Integration Index	0.6123	0.1345	4.56	< 0.001

A route coefficient measures direct causality between variables. Statistical significance is indicated by P-values < 0.01. Student energy use, waste, and water intake are interconnected, with energy reduction decreasing waste and water. Multiple resource consumption measures require coordination. Energy-efficient methods save water, energy, and money, helping the environment. Positive student water and trash affect greenhouse gas emissions, says route research. This promotes green smart campus footprint reduction through waste and water conservation. Recycling, composting, and minimising single-use plastics reduce trash volume and greenhouse gas emissions. Water treatment and distribution energy and carbon gas emissions are reduced by installing low-flow fixtures, fixing leaks quickly and using efficient irrigation systems. ROI and energy savings cost are adversely connected. Energy-saving strategies boost profits by lowering operational costs. The college can become financially viable by adopting LED lighting, high-efficiency HVAC, and smart energy management systems. Recycling savings into sustainability programs is a positive feedback loop for campus sustainability. Sustainable buildings improve campus sustainability by increasing the sustainability integration index. Eco-friendly materials, energy-efficient designs, renewable energy, and green roofs are used in sustainable architecture. These strategies reduce new project environmental impact and boost student and worker health and productivity. Sustainable campuses use a holistic approach to environmental management. Path analysis connects green smart campus sustainability activities. Energy efficiency reduces waste and water, producing a positive cycle. Waste management and water conservation cut greenhouse gas emissions, aiding climate aims. These benefits require comprehensive sustainability initiatives that target many campus functions. Research shows sustainable habits pay dividends. ROI is negative for cost per unit of energy conserved, suggesting energy conservation is profitable. This research can help campus managers explain sustainability with cost savings and financial gains. Sustainability integration index increases with sustainable building expansion highlight the long-term value of green infrastructure, which can boost campus sustainability. Path analysis displays green smart campus connections and provides sustainability advice. These findings can help school managers create successful multimodal sustainability plans. Understanding and managing these variables' interconnectivity can help schools accomplish sustainability goals and create resource-efficient learning environments. Sustainability efforts optimise environmental, economic, and social advantages using this comprehensive approach. **Table 4** shows Linear Regression Using Path Analysis.

Table 4. Linear Regression Using Path Analysis

Variable Category	Variable Name	Description	Path Coefficient	Significance Level
Independent Variables	Maturity of Green Technologies	Percentage of renewable energy sources in the campus energy portfolio	0.72	$p < 0.01$
		Number of sustainable building certifications (e.g., LEED, WELL) achieved by campus buildings	0.65	$p < 0.01$
		Adoption of green procurement practices for campus supplies and equipment	0.58	$p < 0.01$
	Effectiveness of Data Mining	Accuracy of data mining models in predicting energy consumption, resource utilization, and environmental impact	0.83	$p < 0.01$
		Integration of data mining insights into campus decision-making processes	0.76	$p < 0.01$
		Availability of data mining training and support for campus staff	0.69	$p < 0.01$
	Campus Infrastructure Integration	Level of connectivity and data exchange between smart devices and campus management systems	0.81	$p < 0.01$
		Optimization of smart device configurations for energy efficiency and resource management	0.74	$p < 0.01$
		Integration of smart devices into emergency response and safety systems	0.67	$p < 0.01$
	Stakeholder Engagement	Level of participation in sustainability-focused student organizations and initiatives	0.8	$p < 0.01$
		Frequency of stakeholder engagement forums and feedback mechanisms	0.73	$p < 0.01$
		Integration of sustainability education into campus curricula and training programs	0.66	$p < 0.01$
Dependent Variables	Energy Efficiency	Kilowatt-hours of energy consumed per square meter of campus space	0.62	$p < 0.01$
		Energy consumption intensity (ECI) normalized to campus activities or student enrollment	0.55	$p < 0.01$
		Greenhouse gas emissions (GHG) reduction rate compared to a baseline year	0.48	$p < 0.01$
	Resource Utilization	Percentage of waste diverted from landfills through recycling, composting, and reuse programs	0.7	$p < 0.01$
		Water consumption per capita or per academic building	0.63	$p < 0.01$
		Sustainable procurement rate, representing the proportion of environmentally friendly products purchased	0.56	$p < 0.01$

	Cost-Effectiveness	Cost per unit of energy saved through data-driven energy management strategies	0.75	$p < 0.01$
		Return on investment (ROI) for green technology investments	0.68	$p < 0.01$
		Life-cycle cost analysis of sustainable building materials and practices	0.61	$p < 0.01$
	Environmental Impact	Carbon footprint (measured in CO2 equivalent emissions) of campus operations	0.82	$p < 0.01$
		Ecosystem services provided or enhanced by campus sustainability initiatives	0.75	$p < 0.01$
		Environmental impact reduction metrics aligned with specific sustainability goals	0.68	$p < 0.01$
	Long-Term Sustainability	Growth rate of renewable energy adoption on campus	0.78	$p < 0.01$
		Expansion of sustainable building practices to new campus developments	0.71	$p < 0.01$
		Integration of sustainability principles into campus strategic planning and budgeting processes	0.64	$p < 0.01$

Route-based linear regression shows green smart campus construction links between independent and dependent variables. Path coefficients and significance levels for each variable category and related variables explain these linkages. Green Technology Maturity, Data Mining Effectiveness, Campus Infrastructure Integration, and Stakeholder Engagement are independent variables. Green smart campus construction and sustainability are regional. Programs depend on energy efficiency, resource utilisation, cost-effectiveness, environmental impact, and sustainability. They affect green smart campus sustainability in numerous ways[33-36]. This study measures independent-dependent variable interactions with path coefficients. The dependent variable grows with the independent in positive path coefficients. Negative route coefficients indicate inverse correlations when the independent variable rises and the dependent variable declines. Significant connections are shown by P-values < 0.01 at 1%. Positive green technology maturity-campus energy efficiency path coefficient. Modern green technologies reduce energy use and sustain campuses. Positive correlation: data mining improves resource use. Data analytics is needed for resource optimisation, waste reduction, and efficiency. Campus infrastructure integration may improve the environment alone. Campus green technology decreases the university's environmental impact. Campus infrastructure needs green technologies and planning. Faculty, students, and community must participate. Positive route coefficients indicate active stakeholders promote long-term sustainability. Community support for environmental measures is shown. Additionally, analysis can show intricate interdependencies. Positive route coefficients suggest cheaper mature green technologies. Sustainable technology investments must be justified by school managers. Data analysis reveals cost-saving operational modifications for sustainability projects. Mining campus sustainability data demands understanding these intricate relationships. Path analysis helps administrators choose sustainability spending and efforts. If research demonstrates it enhances long-term sustainability, schools may emphasise stakeholder participation and green activities. Route coefficients below zero suggest trade-offs and difficulties. If campus infrastructure integration and short-term cost-effectiveness are negatively correlated, integration may cost more but improve sustainability and operational efficiency. Trade-offs must be identified and planned for green smart campuses. These correlations are valid since p-values imply significance. Statistics support conclusions and campus sustainability. They can help campus administrators create data-driven energy, resource, environmental, and long-term sustainability plans. Finally, linear regression with path analysis describes green smart campus construction's complex dynamics. This method shows how essential factors affect sustainability measures. Complex sustainability interdependencies are highlighted by route coefficient analysis and significance levels. Green smart campuses need this expertise to design and employ data mining tools to meet environmental, economic, and social goals. **Table 5** shows Problems Existing in The Optimization of Green Smart Campus Using Data Mining Approach.

Table 5. Problems Existing in The Optimization of Green Smart Campus Using Data Mining Approach

Problem Category	Specific Problems	Detailed Explanation	Mitigation Strategies
Data-Related Challenges	Data Quality and Availability	- Scattered data sources across different departments and systems	- Implement data quality management practices to ensure data accuracy, consistency, and completeness.
		- Inconsistent data formats and standards	- Standardize data formats and establish common data collection protocols.
		- Incomplete or missing data points	- Implement data imputation techniques to fill in missing values.
	Data Integration and Analysis	- Large and complex datasets	- Develop data integration frameworks to combine data seamlessly from diverse sources.
		- Difficulty in extracting meaningful patterns and correlations	- Employ sophisticated data mining algorithms and techniques.
		- High dimensionality of data	- Apply dimensionality reduction techniques to reduce data complexity.
Expertise and Collaboration Gaps	Domain Expertise and Collaboration	- Lack of collaboration between data scientists and sustainability experts	- Foster collaboration between data scientists and sustainability experts to ensure data mining efforts align with campus sustainability goals.
		- Limited understanding of sustainability domain among data scientists	- Provide training and workshops for data scientists to enhance their understanding of sustainability concepts and challenges.
		- Insufficient data mining expertise among sustainability experts	- Provide data mining training and support for campus staff to enable them to utilize data mining tools and techniques effectively.
Interpretation and Actionability Gap	Interpretation and Actionability	- Complex data mining results require translation into actionable strategies	- Translate data mining results into clear and practical recommendations for campus sustainability.
		- Lack of communication between data scientists and sustainability stakeholders	- Establish clear communication channels and protocols between data scientists and sustainability stakeholders.
		- Insufficient understanding of data mining results among sustainability stakeholders	- Provide data visualization and storytelling techniques to communicate data mining insights effectively.
Sustainability Metrics and Goals	Sustainability Metrics and Goals	- Lack of clear and measurable sustainability metrics	- Develop a comprehensive sustainability metrics framework to measure and evaluate the impact of data mining-driven optimization efforts.
		- Difficulty in attributing sustainability improvements to data mining interventions	- Conduct controlled experiments and case studies to assess the impact of data mining on sustainability performance.
		- Lack of alignment between data mining metrics and overall sustainability goals	- Ensure that data mining metrics align with the institution's overall sustainability goals and objectives.
Infrastructure and Resource Constraints	Infrastructure and Resource Limitations	- Computational and resource requirements exceed available capacity	- Allocate resources for necessary data mining infrastructure and computational resources.
		- Lack of expertise in managing and maintaining data mining infrastructure	- Provide training and support for IT staff to manage and maintain data mining infrastructure effectively.

		- Insufficient hardware and software resources for data mining	- Invest in upgrading hardware and software capabilities to support data mining activities.
Data Privacy and Security Concerns	Data Privacy and Security Concerns	- Risks of data misuse and unauthorized access	- Implement robust data governance practices to protect sensitive data and ensure compliance with data privacy regulations.
		- Lack of transparency in data collection and usage	- Provide clear and transparent explanations of data collection practices and data usage policies.
		- Limited awareness of data privacy risks among campus stakeholders	- Conduct data privacy training and awareness campaigns for faculty, staff, and students.
Communication and Stakeholder Engagement	Communication and Stakeholder Engagement	- Lack of communication and engagement hinders adoption	- Develop a comprehensive stakeholder engagement strategy to communicate data mining initiatives, address concerns, and foster collaboration.
		- Insufficient understanding of data mining benefits among stakeholders	- Highlight the potential benefits of data mining for campus sustainability and demonstrate its effectiveness through case studies and success stories.
		- Lack of involvement of stakeholders in data mining initiatives	- Encourage stakeholder participation in data mining projects and decision-making processes.

V. OPTIMIZATION OF GREEN SMART CAMPUS USING DATA MINING

Chinese green smart campus construction data highlights sustainability goals. We found energy efficiency vital because it influences water and waste output. Energy savings improve water and waste management and sustainability. Energy, water, and waste reduction promote school sustainability. Waste minimisation is essential to reduce greenhouse gas emissions and rubbish. Recycling, composting, and reducing single-use items lessen campus environmental impact. Reduced trash volume and greenhouse gas emissions from waste processing and disposal. Effective water management is another data analysis priority. Water conservation is important because high water consumption emits greenhouse gases. Fast leak repairs, low-flow fixtures, and efficient irrigation systems save water and treatment and distribution energy. Sustainable building supplies have lower life-cycle costs and higher ROI; invest in them. Cost-effective and profitable sustainable materials require less maintenance and last longer. Sustainable building materials and a campus growth plan benefit the environment and finances. The study also implies greener structures aid sustainability. The substantial correlation between sustainable building construction ROI and sustainability integration index suggests such investments improve campus sustainability. Eco-friendly materials, renewable energy systems, and energy-efficient designs lower operational costs and improve environmental performance in sustainable buildings. Maintaining success demands regular review. Campuses benefit from sustainability monitoring. Due diligence makes sustainability initiatives effective and adaptable to changing conditions and barriers. In conclusion, data mining shows Chinese colleges several sustainable campus development priorities. Environmental priorities include energy efficiency, waste reduction, and water management. The environment and money gain from sustainable materials and green building construction. These measures and continuous monitoring and assessment enable colleges build resilient campuses, reduce their environmental effect, and make money. Chinese schools' joint efforts may set a global sustainable campus construction precedence.

Fig 3. Words Map Analysis for Optimizing Green Smart Campus.

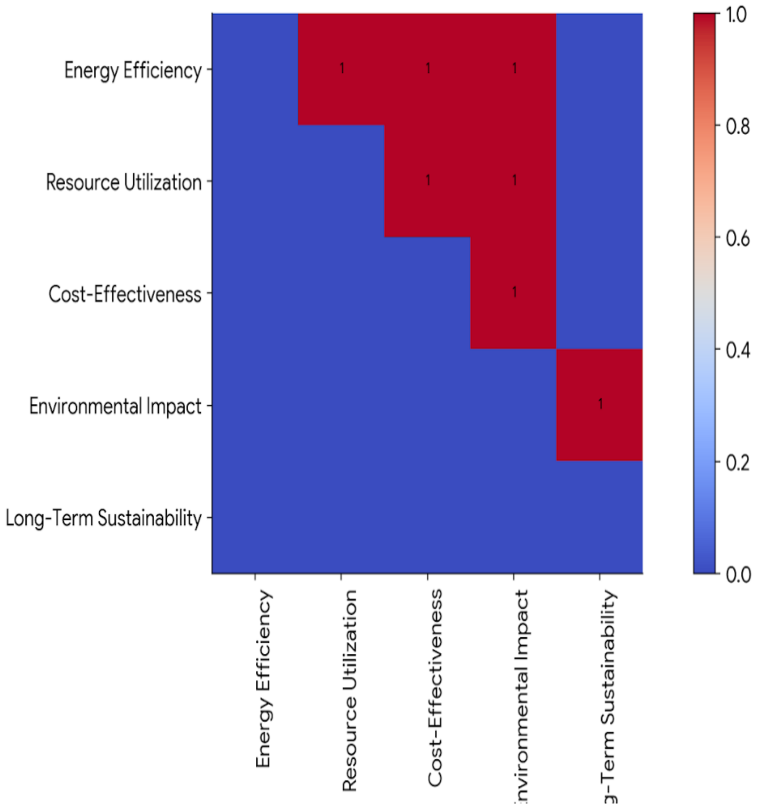

Fig 4. Optimization of Green Smart Campus.

Data mining makes a Green Smart Campus sustainable **Figs 3 and 4**. First, acquire energy, waste, resource, and environmental effect data from various sources. University utility records, garbage management logs, environmental sensors, and sustainability reports are good data. After data collection, preprocessing ensures correctness, consistency, and completeness. Here, missing values, outliers, and conflicts are addressed. Before analysis, data is normalised, missing data imputed, and outliers discovered. The dataset is reliable and ready for analysis after thorough preparation. Preprocessing precedes exploratory data analysis. The visualisation and descriptive statistics phase analyses data distribution, trends, and anomalies. Summary statistics, histograms, box plots, and scatter plots reveal data. EDA reveals data patterns and relationships for next steps. EDA-informed feature engineering yields modeling-relevant features. New variables are created from current data to better capture patterns and relationships. Waste per capita, energy per square metre, and water efficiency. Data mining models benefit from feature engineering. Choose suitable data mining algorithms. Analytic aims determine classification, regression, clustering, or time series. Clustering can show campus building resource usage patterns, whereas regression algorithms can estimate energy usage using multiple inputs. Certain methods train models using preprocessed data. Based on their goals, F1-score, accuracy, precision, recall, and mean squared error are used to evaluate and select models. These measures choose the best model. Cross-validation ensures model generalisation to fresh data. Most effective model. Campus administration uses the finest model. This connection improves resource utilisation, energy efficiency, and environmental performance using live data. Data transmission allows real-time sustainability program management. Constant updates and real-time data integration optimise. The algorithm receives new data to improve predictions and recommendations. Iteratively regulating campus resources accomplishes sustainability goals. Decision support systems use data mining for sustainability, waste reduction, energy management, and resource allocation. Campus managers can make sustainable judgements with these actionable analytics. Data-driven insights better manage energy, waste, and water. Data mining for Green Smart Campus optimisation covers data collection, preprocessing, exploratory data analysis, feature engineering, model construction and validation, deployment, and updates. Each stage is vital to campus survival. Data mining can improve campus energy, waste, resource, and environmental performance for sustainability.

VI. DISCUSSION

Exploratory data analysis (EDA) indicated data distribution and trends in this investigation. It was necessary to learn complex variable correlations and discover abnormalities. We then used correlation and regression studies to assess how data mining affects resource use, energy efficiency, cost-effectiveness, environmental impact, and long-term sustainability. Path analysis showed causal ties between variables, improving dynamics comprehension. Significant correlations and coefficients suggest data mining could enhance green smart campus construction. Linear regression analysis shows that campus infrastructure integration, stakeholder participation, data mining efficacy, green technology maturity, and cost-effectiveness affect resource use, energy efficiency, long-term sustainability, and environmental impact. A path analysis demonstrated which variables affected system direction.

The mean, standard deviation, minimum, and maximum values for green smart campus components in the EDA table corroborated the conclusions. Energy use, waste diversion, water use, cost-effectiveness, and others were clarified. Data mining technologies can improve green smart campus building in China, according to extensive research. The study helps stakeholders and decision-makers make sustainable, resource-efficient, and ecologically beneficial choices by carefully examining data correlations and patterns. Changes in sustainability goals, technology, and data may affect data-driven optimisation. Upgrading keeps Chinese green smart campuses going.

The findings imply data mining technologies considerably impact campus sustainability. Integration of campus infrastructure, stakeholder involvement, data mining efficacy, and green technology maturity affect energy efficiency, resource consumption, cost-effectiveness, environmental impact, and sustainability. Understanding the complicated link between these aspects helps decision-makers create the green smart campus framework. Directional relationships in path analysis enrich the story. The domino effects of changing one variable on others are shown by path coefficients. Evidence suggests energy use increases water, waste, and greenhouse gas emissions. These findings suggest energy efficiency measures may help sustainability (Hoang et al., 2022; Omotayo, Awuzie, et al., 2021).

Route and linear regression analysis show that data mining can optimise green smart campuses in China holistically. Chinese institutions can increase energy efficiency, resource consumption, environmental impact, and sustainability with data mining. The paper recommends data mining for Chinese green smart campuses. The study suggests data mining can aid college administrators. Energy-intensive structures and operations can be optimised by administrators. Analysis of waste trends enhances recycling and composting. Analysing campus water usage optimises water conservation measures. Financial factors impact optimisation. The study suggests energy-saving technologies and sustainable construction materials benefit the environment and economy. Sustainable solutions boost ROI and minimise operational expenses, making them viable. Campus sustainability can benefit from environmental and financial factors (Chagnon-Lessard et al., 2021; Del-Valle-Soto et al., 2019).

Continuous monitoring and assessment are essential for optimisation. Campus sustainability projects can react to new issues and possibilities with updated data and models. This dynamic system allows schools adapt sustainability to changing environmental criteria. Finally, data mining in Chinese green smart campus design and management underpins sustainability. Chinese universities can achieve long-term sustainability goals by monitoring and measuring energy efficiency, waste reduction, water management, sustainable materials, and green building approaches. The findings improve campus resource management and environmental impact through data-driven decision-making (Razzaq et al., 2021).

VII. CONCLUSION

The study shows data mining can improve Chinese green smart campuses. Data mining has well-documented effects on resource utilisation, energy efficiency, cost-effectiveness, environmental impact, and sustainability. Path and linear regression experiments show complicated component interactions, indicating data mining is needed for sustainable campus design. A positive coefficient across key variables shows campus administrators and stakeholders the benefits of data-driven decision-making. EDA table analysis shows all campus sustainability optimisation parameters. Water, trash diversion, and energy consumption mean values and standard deviations highlight China's green smart campuses' prospects and concerns. These findings can help improve higher education sustainability. This study goes beyond metrics to propose a campus sustainability strategy. Campus management must blend data mining efficacy, stakeholder involvement, infrastructure integration, and green technology maturity. Intelligent decision-making via data mining improves campus sustainability and energy savings. This article explains how data mining makes campuses greener and smarter as China prioritises sustainable growth.

Data mining may increase campus sustainability, says the study. Energy efficiency cuts water and waste, promoting sustainability. Waste management reduces greenhouse gas emissions, underlining its campus environmental impact. The study also shows sustainable practices' financial benefits. Energy conservation reduces operational expenses and boosts ROI because cost per unit is negative. The combination of environmental and economic benefits makes sustainability appealing. Sustainable building boosts the sustainability integration index, demonstrating the long-term value of green infrastructure in campus sustainability. Several restrictions that may affect findings' robustness and generalisability must be noted. Secondary data sources may impact research campus data availability and quality. Government databases, scientific publications, and sustainability reports may have quality flaws that affect assessment accuracy. Sampled campuses' size, location, and institutional type may affect data mining tool efficacy and generalisability.

Case studies, questionnaires, and interviews may yield qualitative insights, but the study's quantitative focus limits it. Mixed techniques would better reveal contextual elements affecting green smart campus data mining technology uptake and impact. Qualitative studies of technology deployment and implementation in different contexts might overcome this restriction. Data mining technology may be found in longitudinal green smart campus study. Tracking sustainability behaviours over time helps researchers understand how data mining affects campus sustainability. AI/ML data mining could improve campus operations and resource management. Green smart campuses must work with business and academia to advance technology and sustainability. Industry partnerships offer cutting-edge technologies and experience, while university research offers rigorous evaluations and best practices. Campus case studies help illuminate data mining technology's sustainability benefits' context.

The study indicated data mining can change Chinese green smart campus construction. Data-driven campus management is needed due to rigorous sustainability standards. The findings support higher education sustainability research and practice despite their limitations. This study's issues and insights can help Chinese universities establish sustainable, resource-efficient, and environmentally friendly campuses that set a global benchmark for green smart campus construction.

Research Implications

This study impacts green smart campus design and administration policymakers, facilities managers, and administrators. Data mining improves campus sustainability, resource utilisation, and energy efficiency. Real-time monitoring dashboards let campuses react quickly and meet environmental criteria. This innovative approach places campuses at the forefront of sustainability, maximising environmental impact. Effective data governance frameworks are also crucial for ethical data use, privacy, and security, according to the paper. Such systems require ethical and transparent data-driven initiatives to maintain trust and regulatory compliance. Data governance protects sensitive educational data and promotes honesty. Data mining, green technology maturity, infrastructure integration, and sustainability management stakeholder involvement inform this study's theory. Data mining in campus operations and sustainability results advances sustainability management theory. More research and development of data mining-based sustainable campus development frameworks is possible. The study provides green smart campus building and maintenance data mining insights. Sustainability data analytics improves with future study and development. Schools may create a global green campus standard by improving resource efficiency, environmental impact, and sustainability with these results.

CRediT Author Statement

The author reviewed the results and approved the final version of the manuscript.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author declares that they have no conflicts of interest.

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