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**Article**

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# Strategic Energy Management and Carbon Footprint Reduction in University Campuses: A Comprehensive Review

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**ABSTRACT**

This review paper offers a detailed analysis and summary of current studies related to energy management and carbon footprint reduction in university campuses. Using insights from different research papers, the review highlights the necessity for strategic and sustainable energy management approaches. The research reviewed explores a wide range of methodologies, including the examination of energy consumption, the identification of areas for improvement, the application of energy management and optimization techniques, and the use of renewable and sustainable energy strategies. It is evident from the review that successful energy management and carbon footprint reduction depend on energy management systems, integration of renewable energy, encouraging behavioural changes, and efficient resource use. The review paper is divided into six sections: understanding and enhancing energy consumption, Techniques for Energy Management and Optimization, random and systematic approaches to energy management, Energy Management Systems and their Applications, approaches for sustainable and renewable energy and carbon footprint reduction techniques. The review also identifies areas of future research in the field. It aims to serve as a valuable guide for university administrators, energy managers, and researchers seeking to implement sustainable energy practices and reduce carbon emissions on university campuses.

**Keywords:** Energy Management, Carbon Footprint Reduction, University Campuses, Energy Optimization Techniques, Energy Management Systems
**JEL Classifications:** Q40, Q43, P18, P48, P28, L94

## 1. INTRODUCTION

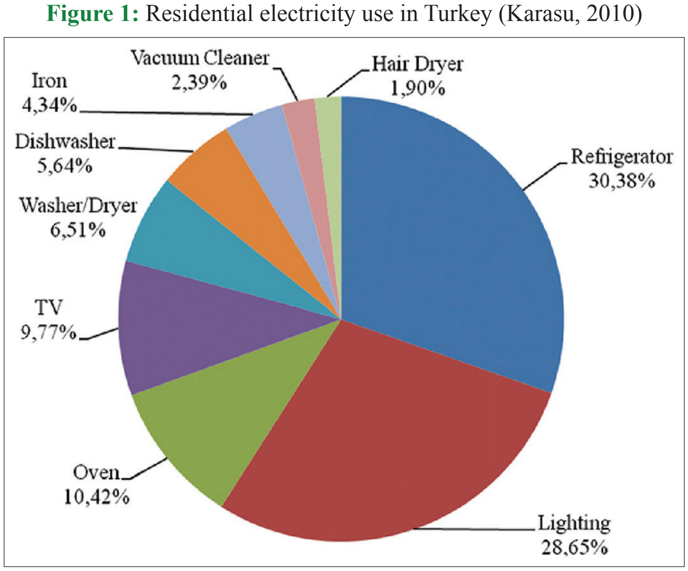
Universities are at the forefront of global climate change solutions, as they not only consume significant amounts of energy but also shape the future leaders who will guide the world's energy policies and practices. Consequently, understanding energy management and carbon footprint reduction on these campuses is critical. This review paper delves into this pivotal issue, examining recent research focused on enhancing energy efficiency and reducing carbon emissions in university settings. This comprehensive study reviews various implemented strategies and technologies from campuses around the world. The paper not only emphasizes the importance of energy management systems, renewable energy sources, behavioural adaptations, and efficient resource utilization, but also acknowledges the growing concern of carbon footprints in these institutions.

This paper categorized meticulously reviewed research articles into six critical sections. These include understanding and enhancing energy consumption, techniques for energy management and optimization, random and systematic approaches to energy management, energy management systems and applications, approaches for sustainable and renewable energy, and carbon footprint. These classifications provide a comprehensive perspective on the current research scenario, highlight the importance of sustainable and renewable resources, and identify gaps warranting future exploration. The understanding derived from this review can guide university administrators, energy managers, and researchers in establishing effective energy management practices and substantially reducing carbon footprints on their campuses.

Ramapragada et al. (2022) studied the patterns of air conditioning usage and its impact on electricity consumption in Indian residential buildings located in a tropical wet and dry climate zone. Their goal was to understand the key factors affecting electricity use in homes, especially air conditioning settings and usage hours. Another objective was to evaluate the contribution of air conditioning to the overall household electricity usage and examine these trends across seasons. They monitored 25 city dwellings for 9 months in 2019, collecting data on electricity usage, air conditioning habits, and indoor environment during summer, monsoon, and winter. Their analysis showed that air conditioning accounted for 39% of total electricity consumption in summer, with peak usage during sleep hours averaging at 6.2 h. They found the average indoor temperature when the air conditioner was on to be 26.9°C and the peak load to be 1.7 kW. Homes with air conditioning used more electricity annually than those without, indicating a significant increase in power use during the summer season. Their research provides useful information for energy management in university campuses, but it has limitations, including a geographically specific focus and lack of consideration for other factors such as occupant behavior or use of other appliances. The paper suggests further research to include broader scope, different air conditioning technologies, energy-efficient strategies, occupant behavior, and real-time energy efficiency feedback systems (Ramapragada et al., 2022).

Karasu (2010) studied the effect of Daylight Saving Time (DST) on electricity use for lighting in buildings throughout Turkey. Category wise residential electricity use in Turkey was reported in this paper as shown in Figure 1. His goal was to identify the most energy-saving DST scenario by comparing five different scenarios to the existing situation. He used a quantitative research approach to analyze the impact of various DST scenarios on electricity

**Figure 1:** Residential electricity use in Turkey (Karasu, 2010)




consumption, considering factors like daily routines, societal norms, weather conditions, and architectural design. He found that moving the clock forward by 30 min from April to October could provide the highest electricity savings countrywide. The results showed a minimum of 0.7% savings in lighting electricity usage under this scenario, suggesting that the current practice underutilized daylight, leading to higher electricity usage. Although the research does not directly contribute to energy management in university campuses, its findings can help campuses in Turkey conserve energy and minimize electricity usage. The paper did not examine the impact of DST on other energy-intensive activities such as heating, cooling, or transportation (Karasu, 2010).

Nasriddinovna (2022) researched methods to increase energy savings in industrial power supplies by harnessing unconventional energy sources, with a focus on solar power plants. The aim was to assess the potential of unconventional energy sources to enhance energy savings and improve the reliability of electricity supply for high-demand consumers. The paper suggests the installation of a solar power plant as an additional independent power source in the KTN feed scheme, operating in parallel with the primary inputs from transformers. This study argues that integrating a solar power plant can result in considerable energy savings and increase the reliability of power supply for high-demand users. Despite the focus being more on industrial settings, the recommendations can be applied to various sectors, including universities, to improve energy savings and reliability of power supply. However, the study lacks detailed description and does not provide specific suggestions for further research. Transitioning to solar power plants may require significant investment and infrastructure modifications, which should be thoroughly evaluated before implementation (Nasriddinovna, 2022).

Madlener et al. (2022) examined the effectiveness of energy efficiency programs in small and medium enterprises and common areas of buildings, specifically looking at the differences between predicted (ex-ante) and actual (ex-post) energy savings. They proposed a simple method to compare these predictions by analyzing the energy savings deficit, which is the normalized difference between reported and actual savings. They applied this method to a dataset of lighting renovation measures to evaluate the calculated savings against the utility meter data. They found a considerable energy savings deficit, averaging 39% for measures in small to medium enterprises and 28% in common areas of buildings. This overestimation was attributed to notable calculation errors and rebound effects. While the study does not focus specifically on university campuses, its methodology and findings can be used in various settings, including educational institutions, to manage energy more effectively. The limitations of the study include a focus on a specific dataset and geographical region, which may limit broader applications (Madlener et al., 2022).

Fu et al. (2021) explored the role of positive and negative perceptions in shaping people's willingness to save electricity. They examined how individuals' understanding of price and subsidy policies influenced their intention to conserve electricity. They developed a model using the theory of planned behavior (TPB) and the norm activation model (NAM), which they tested using data from 658 urban residents in the Yangtze River Delta region collected via a questionnaire. The findings revealed that perceived monetary and environmental benefits positively influenced residents' willingness to conserve electricity, whereas perceived inconvenience had a negative effect. Furthermore, understanding of electricity price and subsidy policies positively moderated the relationship between intentions and conservation behaviors. The paper suggests policy recommendations to promote energy conservation and emissions reduction at the household level, though the research conclusions might have been affected by social expectations bias (Fu et al., 2021).

Da Silva et al. (2018) designed a sustainable campus model for the University of Campinas in Brazil, integrating renewable energy generation, electric mobility, energy efficiency, monitoring, and energy demand management based on the principles as shown in Figure 2. They introduced the Living Lab concept, to be implemented in collaboration with a local utility company, CPFL. Their methodology involved literature review, case study, and proposal development. The main proposal was to establish a sustainable campus model at the University of Campinas by integrating various energy-related aspects into a Living Lab, divided into six interrelated subprojects as shown in Figure 3 the limitations include handling large volumes of data for efficient action by the control centre. The study suggests further research focusing on the development and implementation of the Living Lab model across other university campuses and public-private institutions, as well as designing more efficient control centres for effective data management (Da Silva et al., 2018).

Shafie et al. (2021) identified the main factors causing high energy consumption at Universiti Utara Malaysia (UUM) and proposed energy efficiency strategies to reduce the university's electricity usage. The study used a qualitative model approach to gain a thorough understanding of energy use at the university. The research identified factors contributing to high energy consumption at UUM and proposed strategies to mitigate these, potentially lowering the energy use and overall energy cost for the university. The study highlights the importance of commitment and support from top management in implementing energy conservation programs on campuses. However, it has limitations, such as a small sample size for expert interviews and reliance on secondary data. Additionally, it did not consider the impact of weather conditions on energy consumption. Future research

**Figure 2:** Principles of the International Sustainable Campus Network (Da Silva et al., 2018)

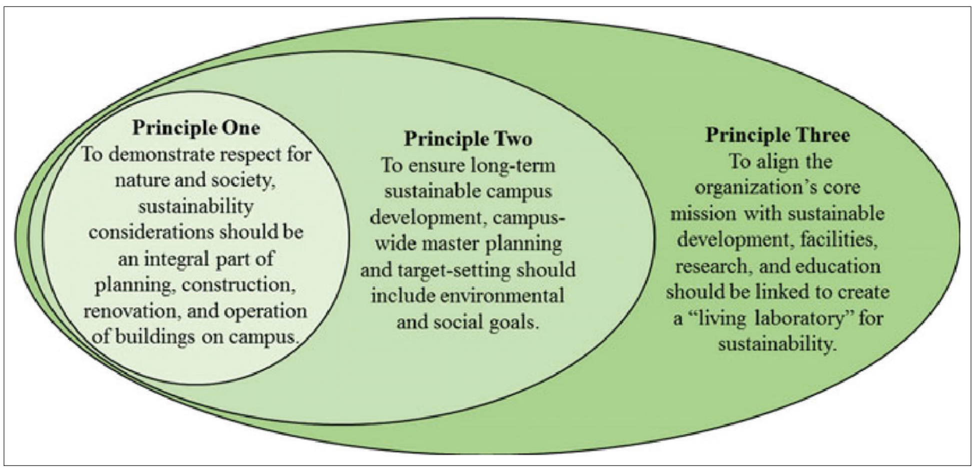
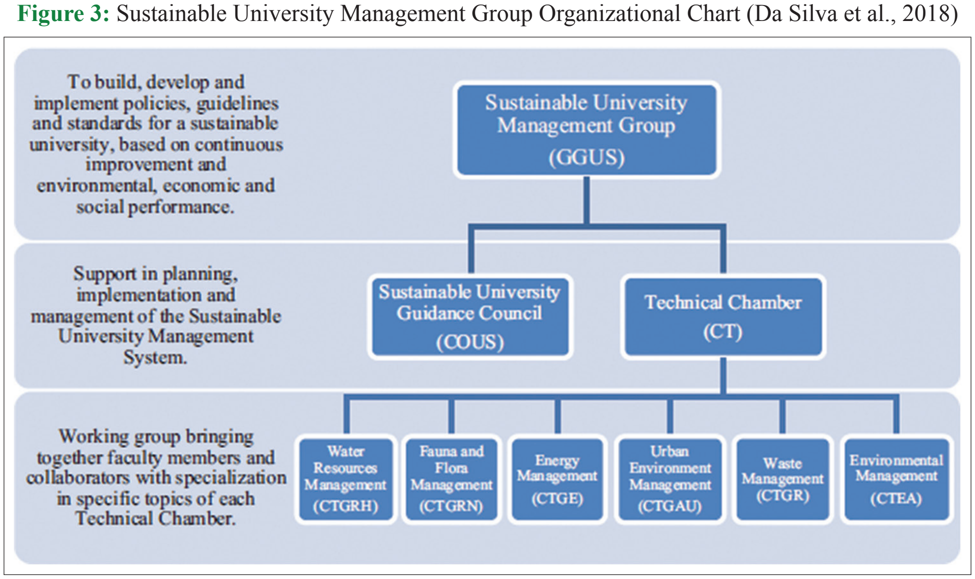



**Figure 3:** Sustainable University Management Group Organizational Chart (Da Silva et al., 2018)



suggestions include studying the influence of weather on energy consumption, the effectiveness of proposed strategies, the role of technology in energy management, and the potential of renewable energy sources (Shafie et al., 2021).

## 2. TECHNIQUES FOR ENERGY MANAGEMENT AND OPTIMIZATION

Negash Getu et al. (2016) embarked on a study to understand energy consumption patterns in university campuses and highlighted the importance of energy audits. The study followed a systematic process of identifying the types and quantities of electrical appliances in a campus building block, noting their power consumption and collating 10 months of energy usage data. This process resulted in the discovery that air conditioning units were the main energy consumers, and replacing these with more efficient models, along with traditional fluorescent lamps with LED fixtures, would significantly reduce energy consumption. The study also identified that changes in usage behavior within the campus community could further decrease energy use. The research also acknowledged that a comprehensive energy audit requires time and accurate data for all electrical and electronic appliances. Further study could investigate technical measures and behavioural strategies for lowering energy use, ultimately providing a roadmap for executing energy audits and identifying energy-saving mechanisms on university campuses (Negash Getu et al., 2016). Fuentes et al. (2022) evaluated the implications of introducing new energy storage within the Gulf Cooperation Council (GCC) countries' electricity policies. The study's primary focus was to understand how energy storage could facilitate the integration of renewable energy sources and promote market restructuring. The paper identified potential regulatory challenges associated with the deployment of such technology. An in-depth, country-specific quantitative analysis was suggested to evaluate the impact of these elements. The research findings, while not directly influencing university campus energy management, provide insights that could be applicable within the context of these nations (Fuentes et al., 2022).

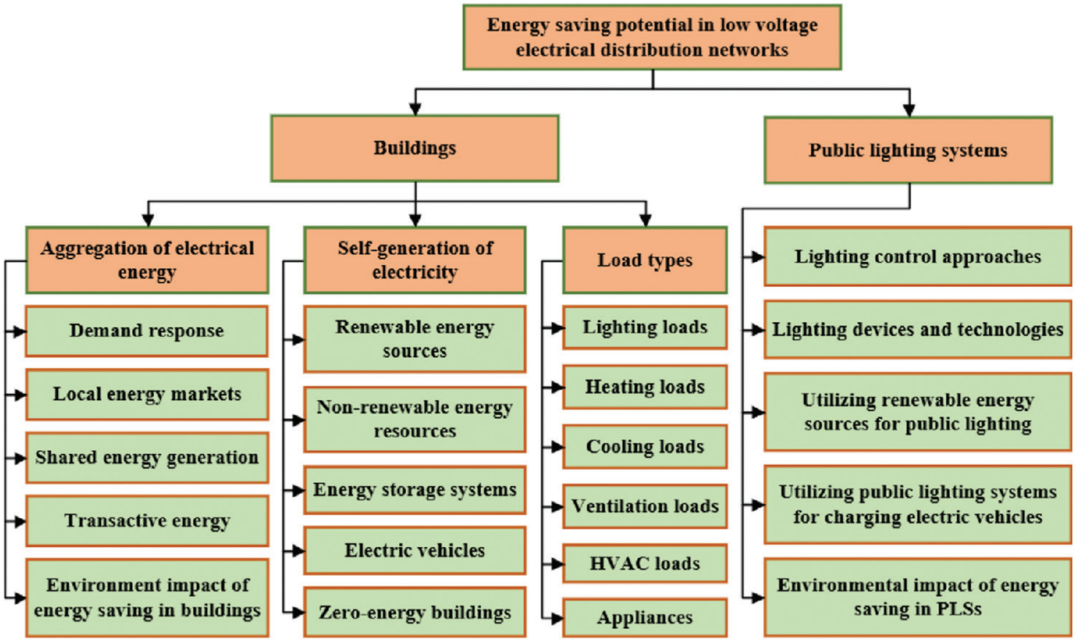
Zaidan et al. (2022) proposed a new framework for analyzing electricity usage in residential buildings, considering factors such as occupant motivation, preference, socioeconomic characteristics, and building attributes (MPSEB). Using a face-to-face survey questionnaire and machine learning techniques, the study identified key factors influencing residential energy consumption within Qatar's diverse population. The study, while not directly applicable to university campus energy management, offers valuable insights for university housing settings (Zaidan et al., 2022). Bhattarai et al. (2023) conducted a systematic review of studies exploring the correlation between electricity consumption and night-time light (NTL) satellite imagery. They identified a need for refining methodologies and approaches in this domain of research. The paper highlights the potential for AI and machine learning in estimating electricity consumption, suggesting future work in this area could improve energy management on university campuses (Bhattarai et al., 2023).

Philip and Chow (2007) investigated energy conservation opportunities in commercial buildings in Hong Kong, with a specific focus on mechanical ventilation and air-conditioning (MVAC) systems. By using energy auditing, energy simulation software, and correlation analysis, the research identified potential energy-saving strategies. These strategies, although derived from a single commercial building's study, could be applied to various commercial entities, including universities. However, limitations exist due to a focus on electricity consumption and lack of consideration for other energy sources. The research suggests that implementing daylighting strategies and improving the MVAC systems could result in substantial energy savings on university campuses (Philip and Chow, 2007).

In a detailed review by Sadeghian et al. (2021), the authors explored various energy-saving strategies and assessed their environmental impact on buildings across different sectors, including public lighting systems (PLSs) within low-voltage electricity distribution networks. The research provides policy-makers with practical energy-saving measures derived from current methods and technologies. It also aims to increase the understanding of researchers in the energy conservation field. Flowchart of a study to review the existing procedures for energy saving in buildings and Public Lighting Systems is shown in Figure 4. In their methodology, the authors conducted a broad analysis of earlier studies, focusing on their geographical locations. They evaluated the energy-saving potential and environmental implications of various strategies applied to different buildings and PLSs, considering current control strategies and technologies. The study found significant energy-saving potential within low-voltage areas of distribution systems, including buildings and PLSs. Several direct energy-saving techniques, such as renewable energy sources and energy-efficient lighting, as well as indirect methods like transactive energy, energy storage systems, and demand response programs, were identified. The paper concludes that there's a literature gap concerning energy conservation, especially in the discussed cases, which requires further research. The findings of this study are notably applicable to energy management in university campuses, potentially reducing energy consumption and promoting sustainable energy practices (Sadeghian et al., 2021).

Kang et al. (2022) investigated the influence of sunrise and sunset time fluctuations throughout the year on Spain's daily electricity demand profile. Their research aimed to understand the correlation between electricity demand shifts and daylight hours, and to examine the possible impacts of changing Daylight-Saving Time (DST) policies. The study uses an hourly load model to determine daylight's impact on Spain's inland electricity system's consumption and to simulate varying DST policy outcomes. The findings reveal that daylight time changes shape daily load profiles, offering overall, monthly, and hourly energy savings for each DST scenario to aid informed policy design and implementation. Although this research doesn't directly contribute to university campus energy management, it offers valuable insights into electricity demand and policy considerations for managing daylight hours. However, the

**Figure 4:** Flowchart of a study to review the procedures for energy saving in buildings and public lighting systems (Sadeghian et al., 2021)




study is only applicable to Spain's inland electricity system and assumes a steady annual electricity demand profile, which might not reflect reality (Kang et al., 2022).

Xin-gang and Pei-ling (2020) studied the potential of energy efficiency advancements to reduce residential electricity consumption in China, given the country's significant increase in residential electricity use due to urbanization and changes in consumption structure. The research utilized China's data from 2010 to 2016 and employed both the panel linear model and the panel threshold model to scrutinize the direct rebound effect (RE) of residential electricity consumption. While the research found that improvements in energy efficiency decrease residential electricity use, it could only achieve around 15.06% of the projected target due to China's average RE of 84.94%. The study found variations in RE across different income and population regimes and identified that energy efficiency efforts have a higher impact in high-income regimes. Despite its relevance, the research's limitations include its reliance on the exogenous hypothesis of energy efficiency and its focus only on the residential sector's direct RE, leaving room for future exploration of direct RE in other sectors and indirect RE of electricity use (Xin-Gang and Pei-Ling, 2020).

Wang et al. (2020) evaluated China's step tariff policy for electricity to understand its effectiveness and the role of policy cognition in promoting electricity-saving behavior. Their research found that policy cognition was more effective in encouraging electricity-saving behavior than the step tariff policy. While the study is not directly applicable to energy management in university campuses, its findings and methodology can provide insights into the evaluation of energy-saving policies and the role of policy cognition in promoting energy-saving behavior within such settings. The study, however, focused only on China's step tariff policy and did not consider other factors such as income, education, and culture on electricity-saving behavior, which could be addressed in future research (Wang et al., 2020).

He et al. (2021) proposed a new methanol-electricity polygeneration system based on a staged coal gasification technique, aiming to improve the polygeneration system's performance and reduce energy consumption. The research found that the new system's energy efficiency was higher than that of the traditional system. The study offers a unique approach to energy management on university campuses, but it only evaluates the energy-saving potential of the proposed system and does not consider its economic feasibility, which could be addressed in future research (He et al., 2021). Guven et al. (2021) examined the combined effects of daylight saving time (DST) and daily weather variations on cooling usage in Australia over two decades. They found that DST's effect on electricity consumption strongly depended on weather conditions and cooling usage. While the study does not directly contribute to energy management in university campuses, its findings can guide energy management during high temperatures and cooling usage periods. However, the study does not consider DST's effects on other energy-consuming activities or its winter impacts on energy consumption (Guven et al., 2021).

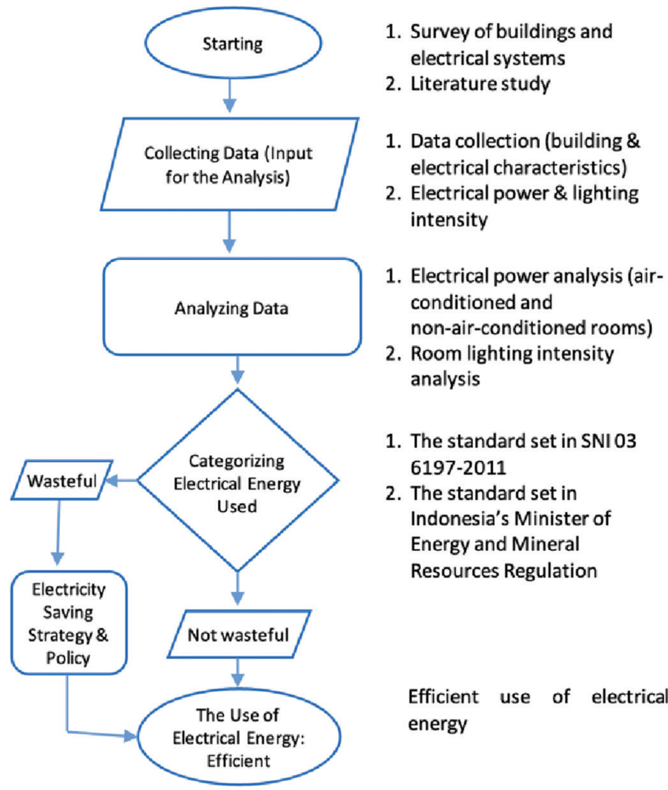
Kota (2021) proposed a microgrid system for a university in the Netherlands, leveraging on-site Photovoltaics (PV), Fuel Cell Electric Vehicles (FCEVs) for backup generation, and a flow battery for storing excess PV-generated energy. The study found that the proposed system could increase the university's self-sufficiency, reduce costs and carbon emissions, and address the challenges of seasonal Renewable Energy Sources (RES) production variability. However, the study acknowledged limitations such as the university-specific nature of the proposed system and the potential insufficiency of only renewable sources to meet increased electricity demand during colder months. The practical implications of the research include increased self-sufficiency, cost reduction, decreased carbon emissions, and the ability to counter the effects of seasonal RES production fluctuations (Kota, 2021).

## 3. RANDOM AND SYSTEMATIC APPROACHES TO ENERGY MANAGEMENT

Moran et al. (2013) studied electricity consumption patterns in public buildings, focusing on university campuses. Their research utilized dimensionality reduction techniques to map high-dimensional data, aiming to reveal correlations between consumption and environmental parameters like temperature, humidity, and solar radiation. The results highlighted significant variations in electricity consumption across different buildings and underscored the impact of environmental variables on energy usage. However, the study's limitations included potential lack of generalizability and a single-year analysis time frame. The research encouraged further studies to improve predictive models and consider user behaviour effects on energy consumption (Moran et al., 2013). Moving on to specific energy-saving solutions, Attia et al. (2016) proposed a system to minimize energy consumption in university classrooms. The system integrated an authorized timer with efficient LED lamps and air conditioning units. Simulations showed a significant reduction in daily energy consumption and working hours, thereby decreasing the campus's electricity bill. Despite not detailing any limitations or recommendations for future research, this study clearly provides practical applications for managing energy consumption in university campuses (Attia et al., 2016).

In a residential setting, Amega et al. (2022) investigated how energy efficiency policies affect electricity consumption and carbon dioxide emissions in Lomé, Togo. Utilizing system dynamics modeling, they found significant energy savings and $CO_2$ emission reductions achievable by replacing inefficient appliances. The study's limitations include its focus on a predominantly informal economy and neglect of factors like climate change and technological advancements. Future research could look into the impact of energy efficiency policies on other sectors and examine the effects of other influencing factors (Amega et al., 2022). Delving into energy audit analysis, Salim et al. (2022) aimed to identify wasteful electrical energy usage in the Faculty of Engineering at Universitas Negeri Gorontalo. They proposed energy-saving policies to alleviate the university's financial pressure. However, the study was limited to one building and 233 rooms, suggesting the need for future investigations into energy use in other buildings and comparative analyses with other universities (Salim et al., 2022). The flowchart of the implementation of the Energy Use Intensity audit and analysis at Universitas Negeri Gorontalo (UNG) as proposed by the authors is shown in Figure 5.

**Figure 5:** Research flowchart (Salim et al., 2022)




Laghari et al. (2023) studied the complex relationship between electricity consumption, environmental degradation, and economic growth in China. Their research utilized Tapio's decoupling method and found that environmental decoupling impacts electricity consumption and GDP growth. However, the study was constrained by data availability and its narrow focus on selected factors. Future research was suggested to explore additional factors and develop a theoretical framework for decoupling in the context of emerging economies (Laghari et al., 2023). Ahmed et al. (2007) developed an energy conservation method using fuzzy logic for centralized air conditioning systems in non-residential structures such as administrative buildings, shopping malls, and institutions. The technique aims to maintain optimal temperature and humidity in each room while reducing the power consumption of the air conditioning unit. The system uses a fuzzy logic-based approach to manage complex temperature impacts on humidity, adjusting thermostat settings accordingly. Information from sensors in each room is compared with target values and differences are fuzzified to determine the necessary adjustments to the AC settings. This strategy achieved comfortable temperature and humidity levels while reducing energy consumption, even under extremely hot and humid outdoor conditions. However, this research was conducted in Malaysia over a period of 4 months, with daily thermostat adjustments, limiting the generalizability of the results. Future research is needed to further investigate the system's effectiveness (Ahmed et al., 2007).

López (2020) explored the impact of daylight on electricity demand in Spain, specifically focusing on the influence of various Daylight Saving Time (DST) policies on energy consumption. An hourly load model was developed to quantify daylight's effect on electricity usage and simulate the outcomes of different DST policies. The model, tailored to Spain's inland electricity system, simulates three potential DST scenarios. The results show that changes in sunrise and sunset times affect daily load profiles and, therefore, have implications for reducing peak demands.

However, the study focused on Spain's inland electricity system, suggesting that the proposed DST policies may not universally apply. Future research should consider the effect of daylight on electricity usage and the impact of DST policies across different regions (López, 2020).

Mi et al. (2020) conducted a 20-week controlled field experiment in Xuzhou, Jiangsu Province, China, to examine the effectiveness of personalized information interventions on promoting energy conservation among urban households. The study employed eight distinct strategies and used the Difference in Differences (DID) method and regression analysis to evaluate their impacts. The results showed significant effects on energy conservation for environmental contribution feedback and cost-benefit feedback. However, the study faced limitations such as a small sample size, short experimental duration, and no account for seasonal electricity consumption impacts. Despite focusing on Chinese urban households, the study's findings could be relevant for energy management strategies on university campuses (Mi et al., 2020).

Sadooghi (2022) analyzed the performance of an innovative switchable window to reduce the HVAC energy usage in a typical dwelling in Toronto, Canada. The study utilized Energy Plus software and the international glazing system database (IGDB) to simulate and estimate the heating and cooling loads of the house. The results indicated that the proposed switchable glazing system significantly decreased the building's HVAC energy usage. However, the study was limited to a house in Toronto, Canada, and did not consider the cost of the proposed system or its impact on overall thermal comfort. While not directly related to university campuses, these findings could enhance energy performance in new and retrofitted buildings on campuses (Sadooghi, 2022). Wang et al. (2021) conducted a study in four major Chinese cities to understand residents' energy-saving behavior. The study used a structural equation model to estimate the relationship between residents' energy-saving actions, their willingness to save energy, and the perceived value of conserving energy. Higher-educated and higher-income respondents were found to be more aware of energy-saving. However, the study was conducted exclusively in four top-tier Chinese cities, focusing only on household electricity saving and neglecting other forms of energy consumption. The research didn't address energy management on university campuses specifically and didn't suggest further research in this area (Wang et al., 2021).

In a study by Qiu et al. (2022), the researchers investigated the difference between farmers' intended and actual use of electricity-saving tricycles in Dazu District, China. The research involved 234 rural households, chosen through stratified random sampling, and the data was collected via personal interviews. The study used cross-analysis and a binary logit model to examine the gap between intent and behavior and the factors affecting this divergence. The findings showed a significant difference, with only 52 out of the 193 farmers who expressed an interest in using the tricycles actually doing so. The analysis indicated that factors such as age, being a village cadre, and the residential terrain positively impacted this discrepancy. On the other hand, aspects like the number of permanent residents, income diversity, dwelling area, climate change awareness, energy-use behaviours, and participation in rural cooperatives had a negative impact. The study's scope was limited to a specific region, and it also relied on self-reported data, which could have introduced bias (Qiu et al., 2022).

The effectiveness of the Daylight-Saving Time (DST) policy in Brazil was studied by Giacomelli-Sobrinho et al. (2022). The researchers compared the effects of DST with a theoretical Energy Trading Scheme (ETS) on energy efficiency. They used data from 2006 to 2017 and examined the impact of energy and cost savings from trading energy permits on electricity consumption. The results showed that an ETS could potentially achieve greater energy savings and cost benefits than DST. For instance, ETS could lead to an average of 22.78% electricity savings, much higher than the 7.42% observed under DST. However, the study was limited to Brazil and only focused on electricity consumption. Despite these limitations, the methodological approach could provide a reference for future studies on energy efficiency (Giacomelli-Sobrinho et al., 2022). Norton and Conlon (2016) aimed to optimize energy management for a university campus by integrating a Battery Energy Storage System (BESS) with a Photovoltaic Charging Station (PV-CS). They developed a numerical model for the PV-CS and used it to determine the optimal BESS size to meet daily load demands. The results indicated that the optimal BESS size, between 6-8 kWh, depends on energy tariffs and load demand. The study suggested that the proposed BESS sizing method could contribute to energy management in university settings (Norton and Conlon, 2016).

Sima et al. (2021) aimed to optimize energy consumption and reduce costs in educational buildings with photovoltaic installations and hybrid systems. The researchers developed an integer linear programming model, which they tailored to different energy production and consumption patterns. The model was tested on a group of university buildings in southeast Romania. The results showed that the model was effective in reducing operational costs for these buildings. However, the study had some limitations, including its reliance on data from a single day in 2019 and the assumption of accurate photovoltaic production forecasts. The researchers suggested that future studies should focus on long-term energy utilization and cost-saving analysis, explore different renewable energy sources, and develop better forecasting models (Sima et al., 2021).

## 4. ENERGY MANAGEMENT SYSTEMS AND APPLICATIONS

The study conducted by Angelim and Affonso (2018) focused on energy management in a university campus in Brazil. The study aimed to reduce energy consumption costs through the optimal operation of a battery system. Their approach included the use of the Simulated Annealing algorithm to coordinate the use of photovoltaic (PV) generation and a battery energy storage system (BESS). They used actual demand data, local utility energy tariffs, and region-specific meteorological information for the PV system. The researchers' economic analysis included considerations of investment costs, project cash flow, net present value, and payback period. Their results indicated that a combination of PV generation and BESS could effectively decrease energy costs. While this study offers significant contributions to energy management strategies, it is primarily based on a single case study in Brazil, limiting its generalizability. Moreover, the environmental impact of their proposed system remains unassessed. Future studies should investigate the environmental implications and compare this system with other energy management strategies (Angelim and Affonso, 2018).

The research by Ullah et al. (2021) explored an optimal energy management system for university campuses using a hybrid Firefly Lion Algorithm (FLA). The model system architecture was proposed as shown in Figure 6 Their goal was to reduce energy costs and consumer waiting times by scheduling appliances effectively and incorporating renewable energy sources (RES). They divided appliances into shiftable and non-shiftable groups and proposed a hybrid algorithm (FLA) for optimal results. The findings indicated that this hybrid algorithm effectively decreased energy costs, and appliance scheduling significantly reduced consumer waiting times. Furthermore, the integration of RES provided significant benefits for end-users. However, the model was tested solely on a university campus load, suggesting a need for further testing. The impact of weather conditions on RES and the influence of user behavior on energy consumption were not considered. Future research should consider these factors and assess the model's applicability to different loads (Ullah et al., 2021).Shyr et al. (2017) developed an energy management system (EMS) for lighting control in a Taiwanese university campus using the Internet-of-Things (IoT). Figure 7 shows the web page for the energy system and lists the status of the wireless connections for each house on a university campus. The primary objective was to improve energy efficiency by controlling individual appliances based on user-specified rules. They designed a five-layer EMS, including a network layer, application layer, control layer, equipment layer, and a perception layer. Their results

**Figure 6:** IOT based model for college energy management system (Shyr et al., 2017)

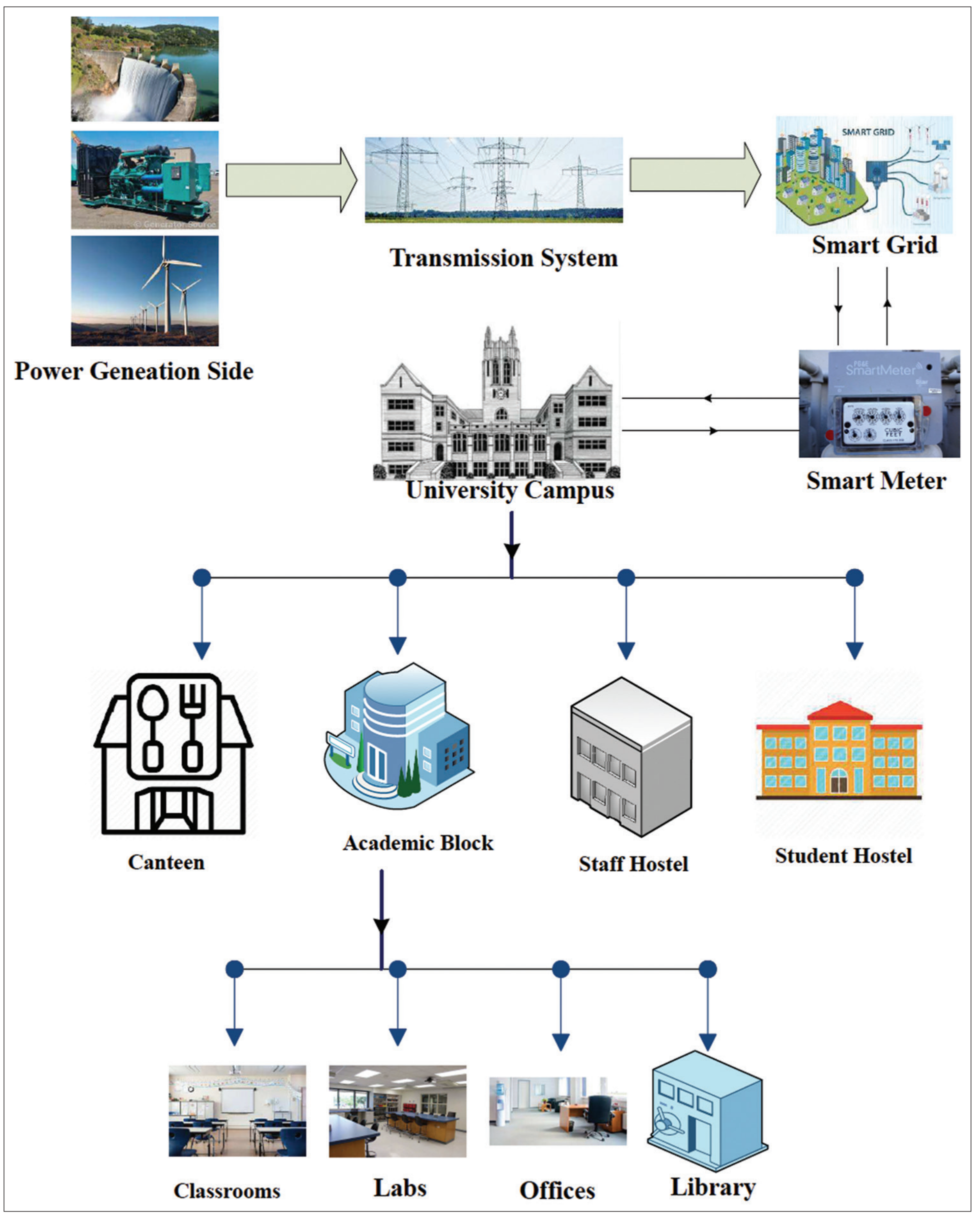
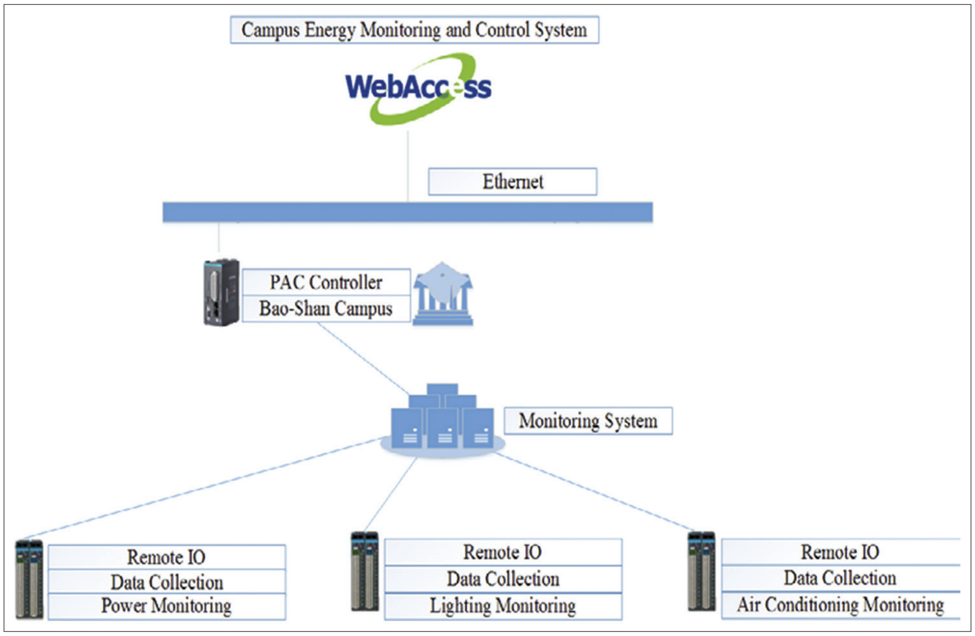


**Figure 7:** IOT based model for college energy management system (Shyr et al., 2017)




demonstrated the successful implementation of the proposed system, which resulted in significant energy savings. This research offers practical implications for energy management on university campuses and serves as a reference for engineering and technology education. Future research could include an in-depth analysis of electricity usage information for equipment diagnostics and demand predictions, thereby further enhancing campus energy conservation (Shyr et al., 2017).

## 5. APPROACHES FOR SUSTAINABLE AND RENEWABLE ENERGY

Saidur et al. (2020) conducted a study focusing on the substantial energy consumption of electric motors in a public hospital in Malaysia. The research aimed to establish an energy consumption benchmark for public hospitals and identify energy-saving strategies for these motors. The team collected data on the hospital's energy consumption, energy intensity, potential energy savings, payback periods, and emission reductions. The findings showed the hospital used about 19,311 MW h of energy in 2008, and suggested that efficient motors could save significant energy annually. Furthermore, employing variable speed drives could lead to further reduction in energy consumption. The payback period for such changes was found to be less than a year, making it economically viable. This study, however, was limited to one Malaysian public hospital and did not consider the effect of weather conditions on energy consumption. The authors suggest that the findings could be applied to energy management on university campuses, calling for future research in this area (Saidur et al., 2010). Kudela et al. (2020) analyzed the effects of Daylight Saving Time (DST) on electricity consumption in Slovakia, seeking to evaluate the energy savings resulting from DST and its impact on the electricity demand curve. The research method employed a difference-in-differences approach using hourly data collected from 2010 to 2017. The findings showed a 1% annual reduction in electricity consumption due to DST and a smoothing of the demand curve. Despite these findings, the research had limitations, including unknown impacts of DST on emissions and lack of data on marginal technology. The study's findings could be used to inform efficient energy management policies in university campuses (Kudela et al., 2020).

Aponte and McConky (2022) introduced a new approach allowing electricity users to implement demand response measures, with the goal of reducing demand charges and user inconvenience. The method involved the use of several arithmetic and tree-based machine learning models to establish an efficient electricity demand threshold value. Their empirical results suggested that the regression random decision forest-based model performed the best in setting the threshold value for different types of consumers. Despite the promising results, the study had limitations including a limited consumer sample size and lack of consideration for weather forecasts and consumer behavior. The results, however, could potentially be applied to university campuses to decrease demand charges and user inconvenience, leading to considerable cost savings (Aponte and McConky, 2022).

Zhou et al. (2022) aimed to identify buildings with excessive electricity consumption and high energy-saving potential using data mining methods. The study aimed to help government management interpret large volumes of data collected from buildings for more efficient energy conservation and fund allocation. Despite its success in identifying buildings with high energy-saving potential, the study was limited by the lack of detailed energy use information for each building. Future research could look at acquiring more detailed energy use information, such as energy system types and occupancy rates. The findings could be applied to energy conservation in public buildings, including university campuses (Zhou et al., 2022). Bjerregaard and Møller (2022) investigated the response of industrial sectors to increases in electricity prices in Denmark. Using time-series data, they examined whether price increases led to reductions in electricity use per unit of output. The study revealed that a segment of the industries did conserve electricity per output unit when electricity prices increased. Despite its valuable insights, the study's findings are specific to Denmark and short-term effects, limiting its broader applicability. Further research is suggested to study the long-term impact of price fluctuations and the influence of other policy interventions. The findings may help policymakers and industries identify opportunities for energy efficiency and cost reduction (Bjerregaard and Møller, 2022).

Guibentif et al. (2021) focused on how energy efficiency programs could be monitored within small to medium-sized businesses and communal spaces in buildings. They proposed a method to compare energy savings before and after implementation of these programs and highlighted the limitations of these preliminary estimates. The method used centered on the distribution of energy savings shortfalls, that is, the relative difference between predicted and actual savings. When applied to a dataset about lighting renovations, this approach proved effective in checking calculated savings against utility meter data. Interestingly, the research uncovered an average energy savings shortfall of 39% in small to medium-sized businesses and 28% in communal areas within buildings. Calculation errors and rebound effects were noted as the main reasons for this overestimation. The research suggests that factors such as time-of-use and the type of replaced technology can increase the precision of energy savings predictions. However, it should be noted that the study was limited to one specific region and to lighting renovation measures, thus potentially limiting its generalizability (Guibentif et al., 2021). Obiora et al. (2017) conducted a study to identify cost-effective and socially responsible energy-saving techniques for a university setting through paperless initiatives. The team specifically investigated the benefits and challenges of transitioning to a paperless environment at a university in Cyprus. The methodology involved a SWOT analysis, online surveys, and one-on-one interviews to gather stakeholder insights. Findings suggested that going paperless could enhance the university's reputation, improve productivity, reduce costs, and contribute to environmental sustainability, possibly leading to increased student enrolment. However, the researchers caution that their findings might not be applicable in all contexts as the study was conducted within a specific setting (Obiora et al., 2017). Shafiullah et al. (2020) presented a research focused on optimizing energy management for clusters of buildings equipped with local distributed energy resources (DERs). They developed a stochastic mixed-integer linear programming (MILP) model to manage a local energy community's energy needs. The model worked by predicting the electricity and gas purchasing costs, $CO_2$ emissions costs, and the operational cost of local DERs a day in advance. This method was validated using a real-world case study in Amsterdam and proved to be superior in cost and $CO_2$ emissions reductions compared to deterministic models (Shafiullah et al., 2020).

Valsan and Kanakasabapathy (2017) conducted a study on the design and execution of an affordable Smart Energy Management System (SEMS) for an isolated micro-hydro system in a remote tribal village. The research showed that implementing the SEMS could enhance the quality of life for the villagers by using surplus energy, which would otherwise be wasted, to provide hot water. Despite being developed in a lab, the prototype has potential for application in university campuses, highlighting the need for further research into cost-effective SEMS for various types of renewable energy systems (Valsan and Kanakasabapathy, 2017).

## 6. CARBON FOOTPRINT REDUCTION TECHNIQUES

The research of Zhao et al. (2015) has explored the greenhouse gas (GHG) emissions associated with room air conditioner (RAC) refrigerants. Through the life cycle carbon footprint (CFP) methodology, they computed the emissions from the production, filling, service, and disposal stages of RAC refrigerants, using a "cradle to cradle" system boundary. The study determined that high global warming potential (GWP) refrigerants had larger life cycle CFPs than those with middle and low GWPs. In order to reduce these emissions, the authors suggested increasing refrigerant recycling rates and switching high GWP refrigerants with alternatives of middle and low GWP. There were, however, certain limitations to the study such as assumptions regarding RAC service life and usage rate, and the lack of consideration for indoor air quality, human health impacts, and energy required for RAC production and disposal (Zhao et al., 2015). In a distinct study, Li et al. (2023) conducted a bibliometric analysis of the evolution and domains of carbon-electricity markets. The authors analyzed 54,739 articles using CiteSpace visual software and identified various research directions for electricity-carbon market interactions. They found interactions related to price, mechanism correlations, transaction information, and transaction behavior that significantly influence low-carbon investment decisions, power structure optimization, and carbon emission reduction. The study suggests future research to focus on these interactions from medium and microscopic perspectives, considering the development of the markets under new circumstances and how to optimize their coupling relationship (Li et al., 2023).

**Figure 8:** Clemson University's carbon footprint by source (Clabeaux et al., 2020)

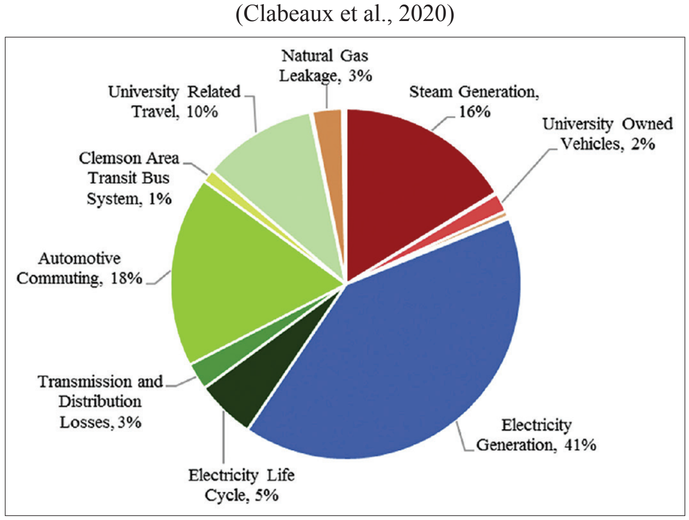
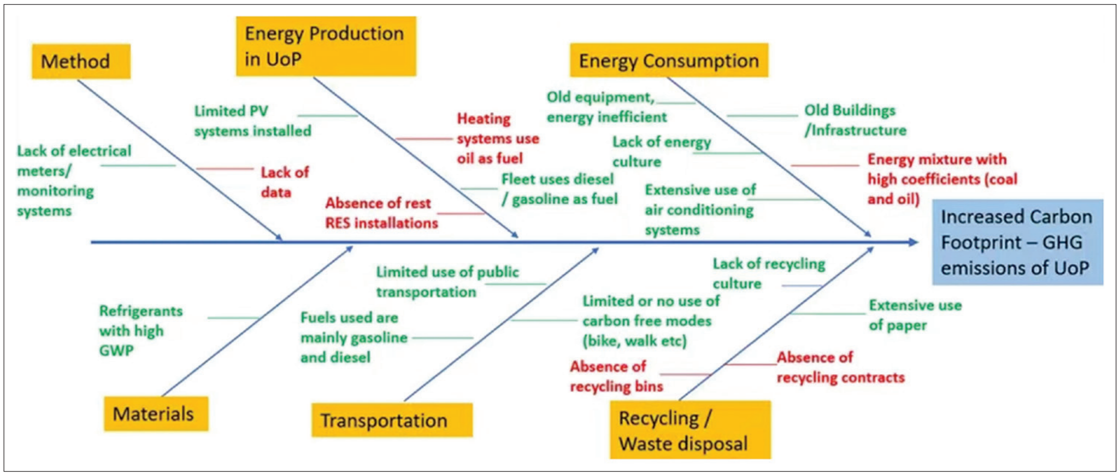


**Figure 9:** Fishbone diagram for cause and effect analysis in university campus (Vrachni et al., 2022)




Zhang et al. (2021) introduced an optimal clean heating model for an integrated electricity and heat energy system (IEHES), considering the comprehensive energy-carbon price. The study found that the high back-pressure turbine heating mode (HBPeCHP) is most effective when the heat load growth rate is below 14%. However, the model loses flexibility when the rate exceeds 8%. To solve this issue, a combined heating mode was proposed, which enhanced the system's flexibility and had the best coal-saving effect. Limitations of the study included assumptions about a set carbon tax rate and stable coal and gas prices, which may not be accurate in real-world situations (Zhang et al., 2021). Clabeaux et al. (2020) focused on a comparative analysis of carbon footprints (CFs) among higher education institutions (HEIs) in the United States. The study, using the Greenhouse Gas Protocol and the Carnegie Mellon Economic Input-Output Life Cycle Assessment (EIO-LCA) tool, identified several factors such as population size, methodology, and GHG emission sources that significantly varied the CFs among the HEIs. The study emphasized the need for accurate GHG emission calculations and suggested future research to establish baselines for CF improvements and consider the effects of electricity usage and solid waste disposal. The source wise carbon footprint of the Clemson University is shown in Figure 8 (Clabeaux et al., 2020).

Vrachni et al. (2022) investigated the carbon footprint of the University of Patras in Greece, aiming to formulate a better carbon and energy management plan. The research identified student commuting activities and purchased electricity as the major contributors to the university's greenhouse gas emissions. The study proposed a series of goals for 2030 that align with Greece's National Plan for Energy and Climate, focusing on managing carbon and energy and strengthening the environmental culture within the community. Despite some limitations such as financial constraints and uncertainties around future gas supplies, the study provided important insights into GHG emission management on university campuses. Authors did a cause-and-effect analysis to identify and address issues as shown in Figure 9 fishbone diagram (Vrachni et al., 2022).

## 7. CONCLUSION

This comprehensive review has synthesized diverse studies focusing on energy management strategies and carbon footprint reduction techniques in various contexts, with an emphasis on university and institutional settings. The assessment of energy-saving initiatives, as discussed by Obiora et al. (2017), underscores the potential of paperless policies to enhance reputation, productivity, and environmental stewardship, despite their context-specific applicability. The utilization of distributed energy resources in building clusters, as illuminated by Shafiullah et al. (2020), offers opportunities for energy cost reduction and $CO_2$ emissions mitigation through stochastic predictive models. Meanwhile, the study by Valsan and Kanakasabapathy (2017) has demonstrated how affordable Smart Energy Management Systems could improve quality of life in remote regions and have potential broader applications.

Carbon footprint reduction was examined in various contexts as well. Zhao et al. (2015) revealed that substituting high GWP refrigerants with lower GWP alternatives and increasing recycling rates could potentially mitigate the environmental impact of room air conditioners. Li et al. (2023) provided insight into the dynamics of electricity-carbon markets, suggesting future research avenues that could optimize market coupling. Clabeaux et al. (2020) highlighted the importance of accurate greenhouse gas emission calculations within higher education institutions, while Zhang et al. (2021) proposed an optimal clean heating model for integrated energy systems. Finally, the study of Vrachni et al. (2022) offered specific carbon and energy management strategies tailored to the context of the University of Patras.

Across all these studies, it's clear that effective energy management and carbon footprint reduction are both feasible and beneficial. However, each study also highlights a need for further research, with specific limitations and assumptions in each context that warrant a more holistic approach to environmental sustainability. This includes considerations not only of financial and energy efficiency but also of broader ecological impacts, stakeholder perceptions, and long-term sustainability. Thus, while the advancements highlighted in this review are promising, continued explorations into energy management and carbon footprint reduction are needed to navigate the complexities of environmental stewardship in the twenty-first century.

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