Energy Efficiency in the Higher Education Institutions: A Review of Actions and Their Contribution to Sustainable Development

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Abstract. Universities are among the largest public sectors and energy consumers in many countries worldwide. They are considered crucial places to learn about opportunities to adopt sustainable and renewable energy to meet global greenhouse gas emission targets and incentivize economic growth. In this study, different energy efficiency strategies on university campuses were analyzed to investigate the level of engagement in practical actions at universities and the reduction of the environmental impacts of this sector. The results show that energy actions on university campuses are fewer and focused on plans for renewing energy systems and reducing energy consumption in buildings. Only a small portion of universities' energy consumption comes from renewable sources. There is a need for more empirical studies on the description of actions and their impacts on the sustainability of campuses, in addition to the need to better understand and study the connections between energy use and energy efficiency in university campuses. An integrated approach to different energy strategies, in parallel with the knowledge of available technologies and the commitment of university stakeholders, in partnership with government support and energy concessionaires, is essential to improve energy performance and reduce the energy footprint of the universities.

Keywords: Universities · Energy Efficiency · Energy Actions · Sustainable Campus

1 Introduction

Higher Education institutions (HEIs) should be at the forefront of research and development efforts on sustainable energy transition towards achieving the 2030 Sustainable Development Goals (SDGs). University campuses are like small-town ecosystems and thus constitute an important case study and a suitable field for urban experimentation [1]. Indeed, education is identified as the most effective means in the quest to achieve SDGs [2], and universities have a responsibility in promoting an energy transformation due to their leading role in training future leaders and decision-makers; ability to address environmental and socioeconomic problems; ability to induce collaboration between different stakeholders; and responsibility as social entities to meet emerging social needs [2, 3].

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The incorporation of approaches towards energy efficiency and renewable energy use at HEIs has been largely argued in literature. Universities use 3 to 5 more times energy than schools [4] and consume 60% more energy than commercial offices [5]. Universities use energy for various purposes and the pattern of energy use is defined by factors such as events and teaching schedules, occupancy, building size and type, and the equipment used. For that, there are differences concerning energy consumption on university campuses, mostly due to the influence of seasonal factors on heating (or cooling) the buildings.

Buildings account for a large amount of energy consumption and carbon emissions on university campuses. Worldwide, 30% of all primary energy is used in buildings, generating 8% of energy-related carbon dioxide emissions [6]. A building emits greenhouse gases (GHG) during different phases, but the largest portion of the GHG emissions is associated with the operational phase, about 75% of their entire lifecycle [7]. The World Green Building Council has issued a bold vision for buildings and infrastructure to reach 40% fewer carbon emissions by 2030 [7]. To achieve this goal, the HEI must take the responsibility to demonstrate an energy reduction commitment.

However, there is still no consolidation of strategies or difficulties faced in adopting energetic sustainable practices in universities. Senior university management does not have guidance on which energy management practices are most widespread and their effective results in reducing energy consumption in institutions. Sustainability international rankings, such as the Greenmetric ranking, also have no clear methodology to evaluate and compare university campuses concerning energy consumption and climate change criteria [8].

This study sought to identify the main sustainable energy management actions implemented in HEIs. Understanding the efforts that HEIs are adopting toward energy efficiency and renewable energy use can demonstrate research gaps and direct the action of universities, since this may lead to improvements not only concerning maximizing the use of their energy resources but also in terms of reducing the effects of climate change. In addition to the tangible and measurable impacts, these actions could allow the academic community to learn and explore innovative solutions and help society get involved in the incorporation of sustainability in all its dimensions.

2 Research Strategy

To answer what are the main sustainable energy management actions on university campuses, a bibliographic survey in the Web of Science database was carried out considering a set of search strings (Fig. 1) related to the terms universities, sustainability, and action, with a focus on energy management in HEIs. 46 articles were selected, categorized, and analyzed to obtain a holistic view of the main sustainable mechanisms for managing energy use in HEIs.

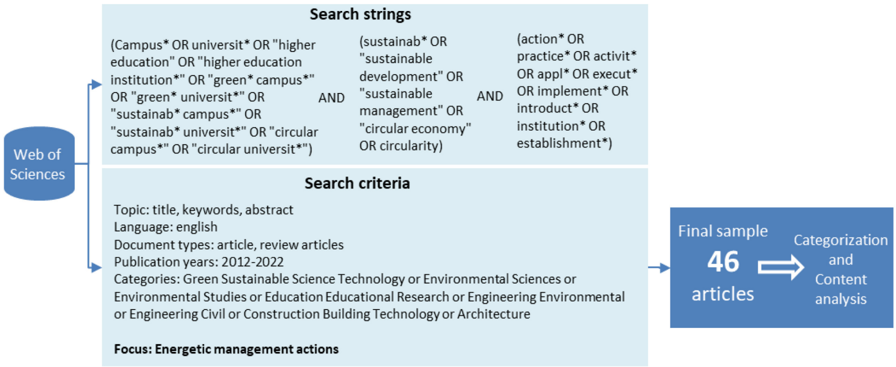

Fig. 1. Summary diagram of the research strategy adopted.

3 Results

The studies were categorized into two major groups: i) energy-saving actions and ii) energy-generation actions (Table 1). The energy-saving actions grouped actions related to energy efficiency practices in buildings management [9], consumption estimates at universities [8], the level of engagement in energy efficiency measures [1], critical analysis [10], and obstacles [11] in the energy actions of the campuses. Energy-generation actions grouped the actions related to the energy matrix of universities [12], the adoption of hybrid renewable energy systems [13], and alternative energy sources [14]. The main findings are described below.

3.1 Energy-Saving Actions

The main consumers of electricity in universities are lighting, ventilation, and cooling [1]. These systems are directly related to student activities and building type, factors that significantly contribute to the electricity consumption of a campus. Energy performance improvement and its monitoring are recognized as the first step for assessing and managing campus energy transitions [8].

Buildings that serve multiple functions consume more electricity as more types of appliances are used for different purposes [1]. The classification of buildings according to their energetic consumption is important to track, evaluate, and assist in readjustment and/or decision-making that best allocates resources to achieve low-impact infrastructure management in HEIs [4, 15]. Yoshida et al. [15] ranked energy consumption in buildings on a Japanese campus and guided actions that reduced 22% of campus energy use. In Category I, buildings with low energy density, the strategy was to adjust the energy system to people's daily routines; in Category II, buildings with high energy density, the strategy was energy conservation; in Category III, large-scale facilities such as hospital, the strategy was to outsource energy management.

Conducting energy audits is important to determine the university's energy profile, determine energy-saving options, and reflect the degree of compliance with energy efficiency standards [12, 16]. Shcherbak et al. [12] carried out a comparative analysis of

Table 1. Categorization of studies related to energy actions in universities.

Type	Papers		Focus	Papers	
	Number	%		Number	%
Energy-saving actions	28	61	Energy profiles	8	17.5
			Efficient electricity management	7	15.2
			Improving building envelope/Efficient HVAC systems	4	8.7
			Energy saving stimation	3	6.5
			Efficient appliances	2	4.3
			Efficient HVAC systems	2	4.3
			Environmental certification	1	2.2
			Passive design strategies	1	2.2
Energy-generation actions	18	39	Solar Photovoltaic (PV)	10	21.8
			Combined heat and power	4	8.7
			Biomass	2	4.3
			Renewable energy systems	2	4.3
	TOTAL			46	100.0

standards for certification of buildings by the level of energy efficiency on campus in Ukraine and found that all buildings in terms of energy consumption and energy efficiency belong to categories of low-level energy efficiency. Günkaya et al. [16] found that on a campus in Turkey, the building's annual heat requirement was considered higher than the heating requirement. To reduce heat losses, external insulation and double-glazing applications were considered as alternatives. However, these options would be greater resulting in environmental impacts. The energy audit should be used in combination with an ample approach such as Life Cycle Assessment.

The social factor must be considered to discover the behavioural responses of the occupants and their willingness to save energy [10]. For example, the energy demand during the academic calendar [17] and the vacation period are reduced and vary according to the different academic disciplines [1]. On Australian university campuses, there was a 5% reduction in campus energy consumption when changing from semester to trimester. This reduction occurred in teaching buildings while in buildings used for research, there was an increase in energy consumption. The results suggest that the standard of occupancy conditions should be adequately analyzed in the campus's energy management and carbon reduction policy [17].

By identifying a set of building energetic performances, decision-makers can estimate energy savings [17], control or manage building energy [18], adopt efficient appliances [19], adopt an energy-efficient measure [20], intervention planning [21], and change the user behaviour [22]. At the University of Zaragoza, Spain, an IoT ecosystem was implemented to monitor CO_2 and energy consumption in the classrooms and support research projects and institutional initiatives toward energy efficiency [23]. In Hong Kong, the average energy efficiency of educational buildings is 0.87, which means that 13% of the total energy consumption can be saved [18].

Fonseca et al. [21] designed a building renovation plan for a Portuguese university campus based on replacing the current lighting with LEDs and installing a photovoltaic system that achieved energy savings of 20%, with 27.5% of the consumed energy supplied by the photovoltaic system. The adoption of more efficient light bulbs; the replacement of ferromagnetic ballasts with electronic ones; and the installation of presence sensors in toilets would lead to a consumption reduction of about 26,123 kWh/year in the cost of electricity, avoiding the emission of 3,704 $kgCO_2$/year [24].

Efficient Heating, Ventilating, and Air Conditioning (HVAC) systems are mandatory to obtain high energy efficiency in buildings. In Brazilian public buildings is possible to reduce 30% to 50% of energy consumption by adopting low-cost technical and management measures [25]. When applying Data Envelopment Analysis (DEA) to evaluate and improve the energy efficiency of the internal spaces of buildings at a Brazilian University, considering lighting and air conditioning, it was observed that all classrooms were inefficient. The DEA model achieved a reduction of installed power of 43.5% and 22.7% (lighting and air conditioning systems) [25]. Liao & Liu [26] used the DEA model to investigate energy savings by recycling and reuse of rainwater in Taiwan, as a passive strategy. Recovering heat from wastewater discharged from showers was evaluated at a university sports facility in the United Kingdom [27]. Measurements of performance on different flow rates showed that over 50% of the heat in the wastewater could be recovered.

Improvement of the building envelope and efficient HVAC were important issues in renovation building plans [20, 28]. Proper retrofit actions can reduce buildings' energy demand for heating, cooling, and lighting by more than 60% at Balıkesir University (Turkey), with wall and roof insulation being the best passive retrofit actions in all buildings [20]. The main building envelope measures to improve the energy efficiency of the buildings were the application of an external thermal insulation layer on the walls of the classrooms, insulating the pipework and valves on heating systems, replacement of the existing windows by double glazing ones with thermal, correct use of shading in the classroom, airtightness, and replacement of fans and lamps [20, 24, 28]. In general, energy saving between 14 and 31% is possible with the addition of thermal insulation on external walls [20].

Sesana et al. [28] developed a Methodology for Energy Efficient Building Refurbishment to measure energy performance in historic buildings on Italy campus. The authors showed that energy use in existing buildings can be significantly reduced through a suitable retrofit. However, not all energy-retrofit actions are suitable and efficient. It is necessary to draw up a retrofit plan consisting of measures that provide relatively energy savings with low investment costs [20].

The investment required to implement energy efficiency measures can be three times less than capital inputs to increase the same amount of energy production [12]. Nunayon et al. [9] identified drivers of efficient electricity management, highlighting the vision and objective of an energy management program, knowledge and skills, risk identification, and effective communication between relevant stakeholders. In Madrid, the efficiency actions include the creation of the EcoCampus office, the introduction of environmental criteria in public tender procedures, the energy audits of buildings, the implementation of initiatives in lighting systems and information systems, the installation of thermostatic valves in radiators, and the increase of its renewable energy pool [29]. Lo [31] showed that China's HEIs have implemented non-technical and technical energy conservation measures. The non-technical initiatives were the institutionalization of energy conservation; energy conservation mechanisms; restriction of electricity use; extension of winter holidays; and awareness-raising measures. Technical initiatives are limited by a lack of funding and target LED and solar-powered lighting, compact fluorescent lighting, and infrared lighting controls. Murshed [31] reiterates that proper implementation of techniques for conserving electricity can reduce electricity bills by nearly a third and a 5% reduction in total on-campus electricity demand in Bangladesh.

Sustainable international rankings and environmental certificates do not guide or guarantee the energy efficiency of buildings [8, 32]. Chen et al. [32] compared the energy performance of Ohio State University buildings and showed that one of the LEED buildings consumed twice the predicted energy use while causing occupant dissatisfaction. Sonetti & Cottafava [8] compared the consumption profile of a Japanese and Italian university and although the universities have different features, functions, and occupancy patterns, in 2015 were situated in the same density area of values for the Energy and Climate Change category of Greenmetric ranking.

The adoption of energy-efficient buildings can be hampered by the lack of legal requirements, lack of qualified professionals, lack of customer demand, inadequate heat metering reform, underperformance of energy service companies, inadequate knowledge and information, investment by schools, lack of government funding, quality problems in energy conservation products, and low availability of green products in the market [11, 30].

3.2 Energy-Generation Actions

The implementation of photovoltaic (PV) solar energy systems is the main research topic of the studies (21.8% of the articles), the most implanted renewable energy system in the world [11] and in universities [1]. Most studies sought to evaluate the economic viability of this system in generating energy and reducing GHG emissions from universities [33, 34].

Mohammadalizadehkorde & Weaver [34] showed that 13 buildings at Texas State University (USA) could achieve annual electricity savings of 15.39 GWh - representing 17% of their annual energy costs by implementing energy efficiency projects. The investments in the projects will cost nearly $12 million, with the most expressive investment on solar panel installation and a payback return of 18 years. In addition, on energy savings, CO_2 emissions will be reduced by 12,561 metric tons annually, with a rate of savings of about 0.82 $kgCO_2/kWh$.

Karanam & Chang [33] analyzed the economic feasibility of solar PV systems on rooftops of the University of New Haven's Celentano. The study shows that the Net Present Value (NPV) is $121,134 and the payback period is 10.5 years. The energy generation for 2019 was 73,273 kWh and one panel among 226 panels generates approximately 324 kWh/year. Also recycling the PV panel at the end of its life could obtain an additional benefit of 4.3% of the total expected revenue.

Hasapis et al. [35] analyzed that the deployment of PV energy on a Greece campus could provide around 1,899 MWh of electricity annually, which represents around 47% of the campus's annual electricity consumption and reduce 1,234 tones of CO_2 that would be emitted by the diesel thermoelectric plant to generate the corresponding amount of energy. At a Spain university, the optimal PV power would maximize emissions savings, guarantee the best economic return, and coincide with the maximum solar potential of the Campus (around 3.3 MW). Approximately 77% of PV electricity production would be consumed locally, which would represent coverage of around 40% of electricity consumption and reduce between 619 and 1400 tCO_2e, equivalent to a 13–30% reduction over 2016 campus emissions [2].

The possibilities of integrating solar energy with fossil fuel-based energy were analyzed as a backup for periods of insufficient and unreliable supply from autonomous renewable energy system technologies [13, 36]. Ajiboye et al. [13] showed that the option of a hybrid renewable energy system based on a PV-Diesel-Grid-battery energy storage system is the best configuration to meet Covenant University's load demands in terms of reducing the cost of electricity. At Silliman University, Philippines, the components of an ideal solar-diesel grid system, with a renewable energy fraction of 15%, the most profitable system consists of 500 kW photovoltaic solar energy, three diesel generators, and a connection to the grid. This has an initial capital cost of $1,222,222; the Cost of energy is also $0.227/kWh, and the NPC is $11,237,959 [36].

Perea-Moreno et al. [14] analyzed the use of loquat seed as biofuel for the heated swimming pool at a university in Spain, achieving a reduction of 147, 973.8 kg of CO_2 in emissions and savings of 72.78% compared to the previous fuel oil installation. Tian et al. [37] developed an energy system carbon-neutral optimization model considering earth source heat, lake source cooling, on-site renewable electricity generation, and sustainable peak heating systems to minimize the annual total cost of the main campus of Cornell University (USA). Based on the current electrical energy mix, GHG emissions are substantially reduced to 8% to 17% of the 2020 value.

Most studies that report failures in the adoption of renewable energy sources in universities are related to the implementation of PV systems [10]. The biggest obstacles identified were the lack of support and involvement from the university administration [11] and the lack of financial resources [5]. Geh et al. [11] showed five barriers critical related to cost and funding: lack of financial resources, high upfront cost, long payback period, and scarcity of power purchase agreement or lease acquisition options. Regarding institution-related barriers, there was a lack of green building targets, a lack of policy direction, and a lack of reporting sustainability performance. The government-related barriers were the lack of incentives, lack of demand from project financiers, and inadequate infrastructure funding.

4 Discussion

Energy efficiency measures in buildings were the focus of the studies and should be a priority strategy in campus decarbonization. Measures to improve building envelopes, HVAC systems, and the adoption of efficient appliances aim to save energy in universities. However, they are intrinsically linked to the thermal comfort of users and will probably become more frequent with climate change. In this way, the balance between energy efficiency, thermal comfort, and budget management should guide new discussion scenarios at universities and promote the creation of sustainable solutions and environmental education.

However, there has been no research on strategies for raising user awareness and promoting engagement in energy-saving long-term measures in university buildings. User behaviour directly affects energy consumption and drives the implementation of sustainable measures in universities. HEIs should closely monitor the user's behaviours and the performance of their buildings and refine their policies, and procedures to address energetic problems. The best way to improve the performance of existing buildings towards zero energy is an integrated approach of different energy strategies, working in parallel, that addresses behaviour, equipment efficiency, on-site renewable energy generation, and storage power [21].

Renewable energy provides around 15.5% of the energy used in the world's buildings [7]. In universities, they represent minimal shares in energy generation and are little explored [1]. Among renewable alternatives, solar energy predominates but is still in the design and economic viability prospecting phase. Biomass, wind, and geothermal are alternatives seen as secondary sources and, although renewable energy can represent 100% of energy generation, no study presents this as a hypothesis.

Energy efficiency is more common than investing in renewable energy, probably because it encompasses a larger investment and technological changes. Regarding challenges to the implementation of renewable energy, lack of funding was the most predominant. Globally, only a few overarching targets exist for the use of renewables in buildings, and/or for renewables to supply a rising share of heating and cooling needs [7]. Universities must create committees for existing administrative procedures in implementing funds for energy efficiency management. The full support of top management is essential for the continuous improvement of energy efficiency programs. The need for government support is essential to increase the picture of these energies in universities. Goals need to be defined, especially considering that universities are public institutions and need to lead society in global climate objectives.

5 Conclusions

Universities are complex, polycentric, and multistakeholder organizations, for which energy management can represent an opportunity to promote new institutional governance mechanisms. However, the reviewed literature shows that energetic management actions are emergent and focused on some energetic efficiency buildings measures. The energy-efficiency agenda is not part of the top management's policies and there is a lack of leadership that coherently guides the internal decision-making processes, the allocation of resources, and the system of incentives for teaching and research under the aspects of sustainable development. Funding is a big barrier. However, there will only be resources when senior management is aware of the importance of sustainability practices in the growth of university campuses.

HEIs will need to transition from the current partial and piecemeal tactic, taking a proactive approach, reviewing their current operating models, and increasing their levels of ambition to bring about the change needed for society to achieve carbon-neutral goals. These institutional changes will need political support at the government level, as HEIs are intrinsically linked and influenced by external factors. Only through a joint and coordinated approach will HEIs be able to successfully expand the lessons learned to society through the dissemination of their energetic results and the management of university campuses.

More empirical literature is needed, as the disproportion between the information on the description of actions and their impacts is notorious. There is also a need to better understand and study the connections between energy use and energy efficiency in universities, as this can maximize the use of their energy resources and reduce the carbon footprint.

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