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Review

Key Performance Indicators for Smart Energy Systems in Sustainable Universities

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Abstract: Sustainable campus management includes energy-saving measures and waste reduction and has become important to many universities, being part of the institution's societal responsibility. Smart energy systems (SESs), as part of campus energy management, can bring many benefits, including increased efficiency, reduced energy consumption, reduced emissions, increased reliability, and real-time control, and facilitate the integration of the renewable energy systems (RES). Despite the growing interest in energy efficiency and for the initiatives and projects to implement SESs, there are no universally accepted standards for assessing the performance of SESs, with most techniques being dedicated to subsystems. A KPI (key performance indicator) framework for evaluating the SESs' performance from university campuses is proposed, starting from the current findings and priorities from the scientific literature, energy standards, legislation, and university rankings. The framework can support the implementation, operation, and evaluation of the SESs from university campuses, based on SES requirements and the stakeholders' goals. Unlike previously developed solutions, the framework is focused not only on the technical side of SESs but also on the role that education, research, and innovation should have in sustainable development, making universities key contributors to achieving these goals.

Keywords: smart energy system (SES); key performance indicators (KPI); sustainable university

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1. Introduction

Modern society is facing increasing problems of climate change, caused mainly by excessive pollution. Industry [1], internal combustion engines [2], and even buildings, mainly from the perspective of high energy consumption [3], are responsible for the environmental degradation.

If traditional studies were focused on the problem of internal combustion engines, recent studies have begun to address the issue of buildings in terms of operation and energy consumption [3–5]. Whether we are talking about a residential building, an office building, or a university, the mode of operation and energy performance are the main elements that influence energy consumption and implicitly the pollution generated by its operation [3].

The issue of better energy use, translated into reduced costs and CO2 emissions, is increasingly emphasized in the building sector, which is responsible for around 40% of total energy consumption and 36% of total CO2 emissions in the European Union (EU) [6,7].

Connolly, Lund, and Mathiesen, (2016) showed that in order to achieve the EU's targets to reduce CO2 by 80% by 2050, compared to 1990 levels, the total annual cost of the energy system will be about 3% higher [8]. However, if the implementation of intelligent energy systems, based 100% on renewable energy, is moved forward, then the costs will be 12% higher compared to classic systems based on fossil fuels [8].

The recent COVID-19 pandemic and Russia's war on Ukraine caused drastic disruptions in energy supply chains, and hampered investments, with a long-term impact on pollution and low-carbon energy transitions [9].

There is an increasing number of studies in the last years discussing the transition to 100% renewable energy [10–13] within smart energy systems [14–17] that combine smart electricity, heating, and gas networks [14,18,19]. Lund et al. (2018) considered that the integration between energy sectors can lead to the use of more efficient and low-cost storage systems, to balance fluctuating renewable energy generation [20]. Some authors highlighted global energy challenges such as: costs, effectiveness, environment protection, efficiency, resource use, sustainability, etc. [21].

Lund (2014) defined the Smart Energy System (SES) as "an approach in which smart electricity, thermal and gas grids are combined with storage technologies and coordinated to identify synergies between them in order to achieve an optimal solution for each individual sector as well as for the overall energy system" [22].

The SES can bring many benefits, including increased efficiency, reduced energy consumption, reduced emissions, increased reliability, real-time control, and facilitating the integration of the renewable energy systems (RES) and thus reduced costs. Basically, an SES can help provide a more sustainable mode of operation [23].

In this context, many authors have focused on energy efficiency to reduce both carbon emissions and maintenance [7,24–26] and operation costs [27–30].

On the other hand, several studies have indicated the importance and influence of stakeholder behavior on the energy efficiency of the buildings [31–34]. The real consumption of a building could become two or even three times higher when compared to the projected consumption, as a result of the stakeholder's behavior [35,36]. This fact provides a perspective on the importance of user education and especially on the importance of a culture of sustainability among stakeholders.

Previous studies on sustainable universities were focused on energy efficiency in order to reduce both carbon emissions and maintenance and operating costs [27–30], and, on the other hand, on the introduction of sustainability in the curriculum to promote responsible behavior [37–41]. A number of universities have incorporated the SDGs (Sustainable Development Goals) into their institutional strategies [42].

Starting from such strategies, specific projects have been developed, for instance, the evaluation of the environmental impact of different hand-drying options in public restrooms from university campuses. Such a project can give consumers important information about which option is more eco-friendly and can be used to guide purchasing decisions and promote the use of more sustainable products [37].

Despite the growing interest in energy efficiency and for the initiatives and projects to implement SESs, there are no universally accepted KPIs for defining and measuring the performance of SESs, with most assessment techniques being dedicated to subsystems of SESs [43–45].

The main purpose of this paper is to define a KPI framework for evaluating SESs from university campuses, based on SES requirements and the stakeholders' goals, starting from the current findings and priorities from the scientific literature, energy standards, legislation, and university rankings. Unlike previously developed solutions, our framework is focused not only on the technical side of SESs, but also on the role that education, research, and innovation should have in sustainable development, making universities key contributors to achieving the goals. Universities should adopt policies for clean energy and on separating investments from carbon-intensive energy industries, and the progress toward this goal needs to be continuously evaluated based on relevant KPIs.

2. Materials and Methods

A search strategy was defined, together with eligibility criteria, and a systematic review was performed based on the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) checklist. The results were further processed with the VOS Viewer software for the network and hierarchical clustering analysis.

The bibliographic data for this study were collected from the Scopus database in November 2022, within the indexed timespan from 1 January 2010 to 30 November 2022.

The initial search query for executing this systematic review was defined as the following combination of keywords: „smart energy" and „system" and „building" and „university" or „smart-university" or „E-university", and it returned 665 publications.

Figure 1 shows the study selection diagram.

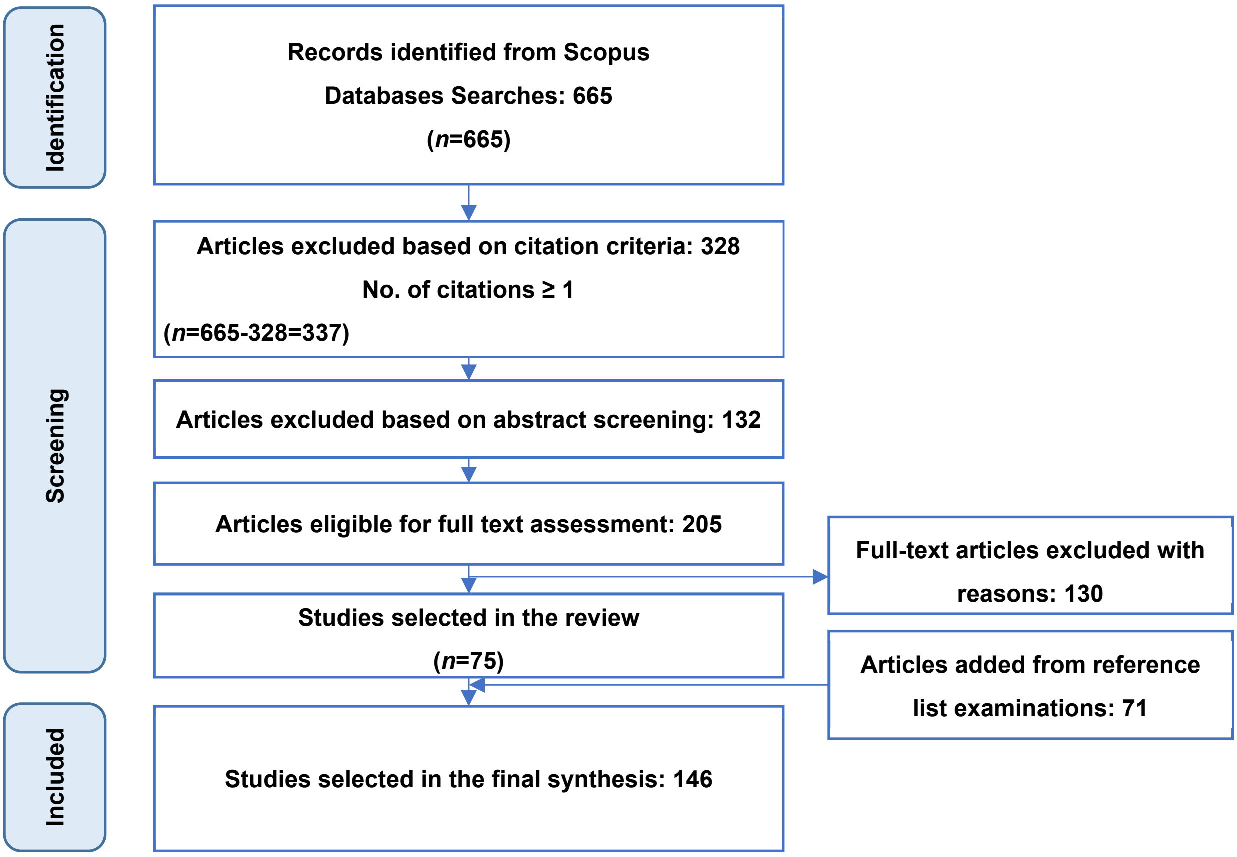

Figure 1. Study selection chart.

The citation criteria (at least 1 citation/article) removed 328 publications. Titles and abstracts that were not directly related to our research were also removed. Of the remaining 205 titles, 130 were removed after full-text screening, as we considered they were not directly related to our topic. When the 75 articles were reviewed, 71 further relevant titles (based on the established criteria) were identified in their reference lists, and included in our study. All these 146 articles were retained for the detailed review.

3. Results and Discussions

3.1. Results of the Bibliometric Analysis

Three main clusters can be observed in the VOS Viewer bibliometric mapping (Figure 2), with labels and circles representing the most frequently used keywords, the size of the label, and the circle being proportional to the number of occurrences for each keyword. The color of an item is determined by the group to which the item belongs. Lines between articles represent links. They appear between two circles, if the keywords associated with them appeared together, more than a predetermined number of times.

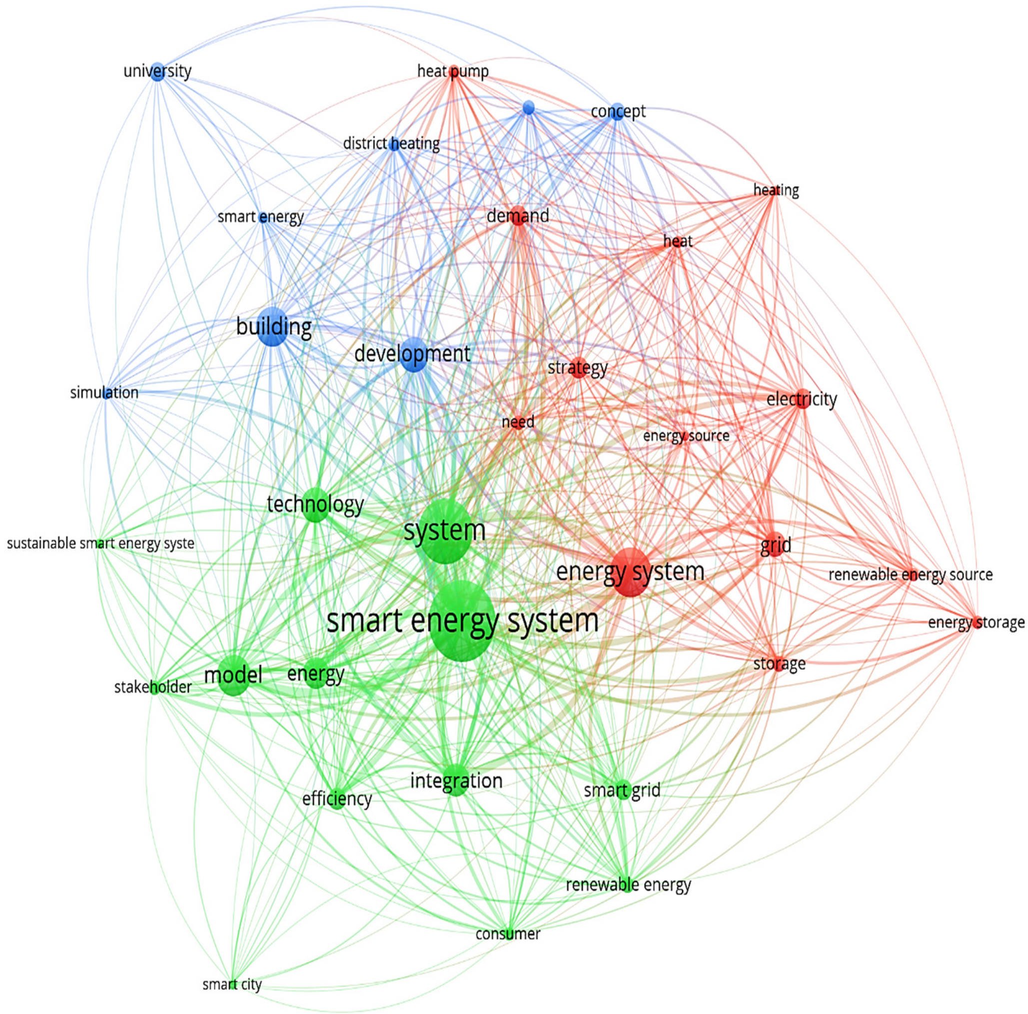

Figure 2. The VOS Viewer map of research trends in the selected papers from Scopus database.

We call the red cluster smart energy system and its components, because here we can find labels specific to energy resources, conversion, storage, and demand, that will be considered parts of the SES.

The blue cluster is directly related to the sustainable university: its buildings that are the main energy consumers [6,7], on the one hand, and, on the other hand, the know how generated by universities for developing and adopting new SES solutions.

The green cluster seems to be the most complex, with labels associated with energy, smart energy systems, and sustainable smart energy systems, but also labels related to performance, efficiency, and stakeholder. This suggests, in our interpretation, the orientation of the recent studies on SES performance and, on the other hand, on policies and evaluations that should be focused on stakeholders' needs.

It is not our intention to suggest a clear separation between the three clusters; it is merely a grouping of the topics of interest from specialized, recent literature, and also a structuration of our discussions to follow in the next chapter.

3.2. Smart Energy System and Its Components

Starting from the Lund's model [14], we will consider that an SES has four basic components:

- Resources—refer to all the resources that ensure the operation of the system, mainly RESs;

- Conversion—includes the technologies that provide the conversion of the RESs to such energy as electricity, fuel, or heat;
- Storage—refers to the storage of excess energy in various forms so that it can be consumed later;
- Demand—refers to the balance between demand, production, and storage [18].

3.2.1. Resources

Previous studies approaching SESs suggested that such systems should be based 100% on RESs: solar, wind, geothermal, biomass, hydro, hydrogen, waves, and tides [12,14,15].

However, of these types of energy, the solar energy [46–48] and wind energy [49–52] are mentioned most frequently in the category of the so-called fluctuating RESs.

Particular attention is given to the use of hydrogen [21,53–55], the integration of geothermal energy [56], or hybrid systems that use solar and geothermal energy [11,57].

Other studies suggested the need for power-to-gas to reduce the use of biomass to a sustainable level, using electrofuels [58–61]. Electrofuels are defined as fuels produced from electricity, water, and carbon or nitrogen, and are considered a useful option in all energy sectors to replace fossil fuels [16,62]. In 2014, Lund et al. described the process of obtaining electrofuels starting from the conversion of electricity through electrolysis into hydrogen. Subsequently, the produced hydrogen is used in two possible ways [13]:

- in a process called hydrogenation which represents the stimulation of gasified or fermented biomass;
- merged with CO2 emissions from such sources as energy or industrial facilities.

Depending on the chosen method of obtaining electrofuels, they are called bio-electrofuels or CO2-electrofuels [13].

3.2.2. Conversion

The flexibility of the SESs depends primarily on the conversion system, thus making the transition from simple approaches used today in energy systems, to interconnected approaches [8,14].

The main conversion systems found in the literature are as follows: photovoltaics [14,63–65]; solar panels [14,66–68]; solar plants [66,69]; wind turbine [70–72]; combined heat and power (CHP) [22,73–75]; heat pumps [66,76–78]; boilers [66,79,80]; and power plants [67].

There is a focus of the authors on fluctuating energy conversion systems, and almost every design of a SES involves photovoltaics [14,66] and wind turbines [64,81,82]. Less popular than photovoltaics, wind turbines are preferred in Nordic European countries such as Denmark (the leader in the implementation of these conversion systems). In 2020, wind turbines in Denmark supplied 50% of the final demand for electricity [83].

Lund et al. (2012) considered that heat pumps as well as additional heat storage capacities should be combined in SES together with cogeneration plants and operated in such a way that RES can be efficiently integrated, without losing the overall efficiency of the system [18].

Several studies showed that heat pumps represent the key conversion solution, connecting electrical and thermal sectors [14,84,85]. Buffa et al. (2018) considered that heat pumps should be integrated in low-temperature excess heat recovery installations [86]. Dincer and Acarac, (2017) emphasized that increasing the number of products from the same energy source will lead to a decrease in emissions per product unit and an increase in efficiency, referring to multigeneration systems such as the following [11]: cogeneration—heat and electricity production (CHP); trigeneration—heat, cooling, and electricity production (CCHP); and quadgeneration—heat, cooling, hydrogen, and electricity production (CCHP-H2).

3.2.3. Storage

Energy storage is another important element in assuring the flexibility of the SESs [12,87] permitting to integrate a higher share of fluctuating RES [12,18,19], and it facilitates the transition to 100% RES [14]. Several authors emphasized the need to use storage solutions for system reliability and flexibility [88,89]. Three main types of storage in the SES framework can be identified in the literature: electricity [21,52,66], thermal [10,72], and fuel [10,64,72].

Regarding electricity storage, the main storage systems identified in the literature are as follows: batteries [14,63,66,72] and electric vehicles (Evs) [4,79,90]. Some studies have shown that the electricity surplus should not be directly stored in the battery (off grid) [91], with other solutions being recommended: thermal storage by transforming electrical energy into thermal energy, storage in the heating networks, or chemical storage (hydrogen and methane) [92].

Electric energy storage systems are very expensive, especially because fluctuating RES require numerous conversion systems. The losses are very high, for example, electrical energy storage is approximately 100 times more expensive than thermal storage [14]. Thus, except for powering heat pumps, electric storage is not feasible to meet the flexible demands of consumers. Electricity storage systems should facilitate power saving or securing grid stability [76]. However, some authors indicated that electric vehicles offer the possibility of sources of electrical energy that can be programmed on demand, but also of storing the electrical energy itself that can later be reintroduced into the grid [93,94]. The solution of electric energy storage through EVs due to the flexibility advantages of the system they offer has become a topic increasingly researched by authors in recent years, and integrated in their models and scenarios [95–98].

Thermal storage is a much more efficient method of storage that involves lower costs compared to electrical storage [14,92]. The main thermal energy storage systems identified in the literature are as follows: water tank [21,64,67,90] and pit thermal energy storage [99–101].

3.2.4. Demand

In the case of a city, or, at a smaller scale, a university campus, there are three main types of useful energy demand [14,102]: electricity, thermal (heating and cooling), and fuel.

Lund et al. (2014) considered that the energy supply can be facilitated by using systems such as heat pumps and electric boilers [76]. Some authors believed that due to their high consumption and thermal inertia, buildings can ensure flexible demand [103].

Bačeković and Østergaard proposed a balance between demand, production, and storage [64], that should be updated, in our opinion, including the energy losses.

Regarding energy consumption in the building sector, one of the main concerns was related to the energy performance difference between the designed energy consumption of buildings and their actual operation consumption [25,27,28,104]. This difference is influenced by three factors: the performance of energy systems, the user behavior, and the insulation performance, especially in the case of buildings [105,106]. Numerous studies conducted in recent years have shown that one of the most influential factors affecting the energy consumption of buildings is the behavior of the occupants [31,107]. The difference between the estimated consumption when designing the building and the actual final consumption can be 200% higher [35], or even 300% higher [36], depending on user behavior. Electricity demand should be the main concern for energy conservation in universities, according to some authors who considered that the key factor involved in energy consumption is the cooling system [108]. Other authors emphasized the consumption of electricity for lighting; in this case, the estimated percentage of energy consumption varies between 20% [109] and 45% [110] of the building's total energy consumption. In what concerns the educational institutions, classrooms are the biggest consumers of energy in terms of lighting, reaching up to 50% of the total building's energy consumption [111].

3.3. SESs and Sustainable Universities

Sustainable campus management includes energy-saving measures, resource efficiency, and waste reduction, and has become important to many universities, and considered part of the institution's societal responsibility [112].

The role of higher education in sustainable development has not always been very clear, because many institutions have not realized that integrating the Sustainable Development Goals (SDGs) [42] in their teaching and research programs could provide the opportunity to expand education for sustainable development [113], and, at the same time, it could serve as an important catalyst for student involvement [114].

Velazquez, Munguia, Platt, and Taddei (2006) proposed a model to assist universities to improve the effectiveness of their potential or current sustainability initiatives through the identification of strategies and opportunities for sustainability within universities. The model is based on four strategies delivered through a set of tailored initiatives: developing a sustainability vision for the university; the mission; a sustainability committee creating policies, targets, and objectives; and sustainability strategies [115].

Grecu (2012) showed also that a sustainable university should be based on six fundamental principles: leadership and vision, social network, participation, education and learning, research integration, and performance management [116].

Universities need to more closely assess the operation and management of the campus as well as the energy performance of buildings and their systems and facilities [117].

A university campus is very similar to a city, facing similar problems in general [118], from the problem of parking spaces to the energetics' administrative problems such as electricity, hot water, or the gas grid. Most studies have focused on the concept of a smart city and less on smart universities [118]. However, both problems and solutions can be similar. Thus, thorough research should consider the SES whether it is a university building, an office building, or even a smart city.

3.4. KPI Framework for SESs in Sustainable Universities

Although many universities adopted sustainability-oriented policies and implemented SESs, there is a little evidence on how such systems are assessed for their performance and the results of these assessments.

Efkarpidis, et al. (2022) proposed a generic KPI framework for the evaluation of SESs installed in application areas of different scales. The framework is based on four main layers, which are required for the definition of the application area, the involved stakeholders, the SES requirements, and the stakeholders' objectives, and the application area of each SES deployment is determined based on four levels of spatial aggregation varying from single buildings to communities, cities, or regions [45].

The only framework we could identify for university campuses was proposed by Saleh et al. (2015) for Malaysian universities to ensure sustainability, and consists of five clusters: top management support, comprehensive energy management team, stakeholders' involvement, awareness, and risk management [119]. The framework is based on the Talloires Declaration ten-point action plan for incorporating sustainability and environmental literacy in teaching, research, operations, and outreach at colleges and universities [120].

The most relevant assessments of universities from the sustainability point of view come from ranking institutions who created in the last years specific indexes (for instance, QS World University Rankings: Sustainability, Times Higher Education—Impact Ranking), to show how universities are developing towards the UN Sustainable Development Goals [121], or how universities are taking actions to tackle the world's most pressing environmental and social issues [122]. There are also rankings (Green Metrics, for instance) providing an overview of the sustainability policies [123], assessing the universities based on the environmental protection and ethical issues (People & Planet University League)

[124], or highlighting the schools that have launched the most important initiatives to reduce campus waste and energy consumption, promote alternative modes of transport, fund environmentally friendly proposals from students and faculties, and take other measures for the benefit of the environment (Best Colleges) [125].

The KPI framework proposed in our study (Figure 3) is developed starting from the current findings and priorities from the scientific literature, energy standards, legislation, university rankings, and specialized websites.

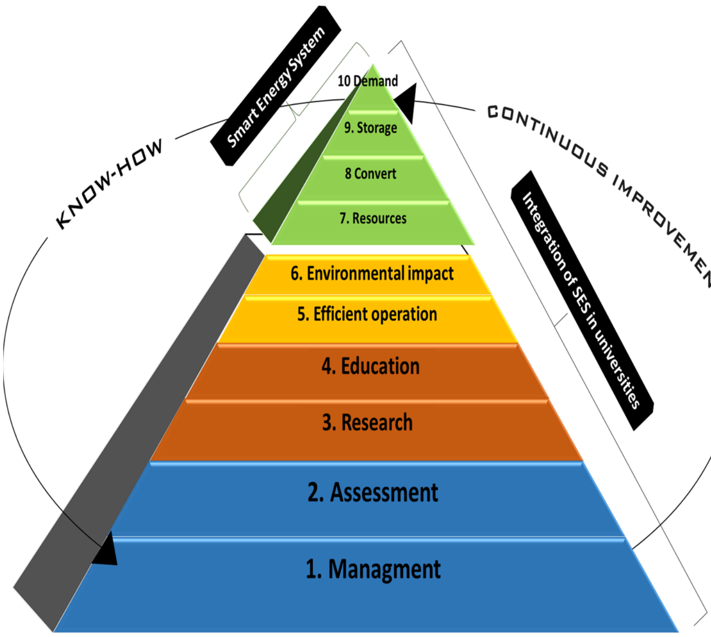

Figure 3. KPI framework for SESs in sustainable universities.

The framework is based on a bottom-up approach and can support the implementation, operation, and evaluation of the SESs from university campuses, based on SES requirements and the stakeholders' goals. Unlike previously developed solutions, our framework is focused not only on the technical side of SESs but also on the role that education, research, and innovation should have in sustainable development, making universities key contributors to achieving the goals. Universities should adopt policies for clean energy and on separating investments from carbon-intensive energy industries, and the progress toward this goal needs to be continuously evaluated based on relevant KPIs.

The KPIs were organized in 4 clusters (management and assessment, research and education, environmental impact and efficient operation, and SES components) and 10 categories, suggesting that the evaluation of the SES performance should be part of a holistic approach. The scoring for each indicator was adapted from the UI Green Metric and THE—impact ranking [121,123], and this can be adjusted based on the results of the evaluations and, respectively, on the new rankings (QS, for instance). The KPIs are discussed and presented below in Tables 1–4.

3.4.1. KPIs for Management and Assessment of the SESs

University policies should be adopted, ensuring that all renovations or new buildings are following energy efficiency standards and that the green building elements are implemented in the new projects [123,126]. The existing buildings need to be upgraded to higher energy efficiency and plan for carbon management and reducing the carbon dioxide emissions adopted. Universities should have an energy efficiency plan in place to reduce overall energy consumption, and a policy for clean energy and on divesting investments from carbon-intensive energy industries, notably coal and oil [121]. Once the SESs are implemented, they need to be continuously evaluated to ensure their conformance with standards (ISO 5001, for instance) [127] and the continuous improvement of the system. Table 1 shows the most relevant KPIs identified for this cluster.

Table 1. KPIs for management and assessment of the SESs.

Cluster	Category	KPI	Measurement Unit/Criteria	Scoring (Based on: [121,123])
1. MANAGEMENT AND ASSESSMENT (10p)	1.1. Management	Have a policy for ensuring that all renovations or new buildings are following energy efficiency standards [121]	Policy/institution Yes/No	Yes: 1 No: 0
		Implementing the green building elements in construction and renovation policies For example [126]: energy efficiency and renewable energy; water efficiency; waste reduction; indoor air quality; smart growth, etc. [123]	Negbi (Number of elements of green building implementation)/institution	None: 0 1 element: 0.25 2 elements: 0.5 3 elements: 0.75 >3 elements: 1
		Have a plan to upgrade existing buildings to higher energy efficiency [121]	Plan/institution Yes/No	Yes: 1 No: 0
		Have a process for carbon management and reducing carbon dioxide emissions [121]	Process/institution Yes/No	Yes: 1 No: 0
		Have an energy efficiency plan in place to reduce overall energy consumption [121]	Plan/institution Yes/No	Yes: 1 No: 0
		Have a policy for clean energy and on divesting investments from carbon-intensive energy industries, notably coal and oil [121]	Policy/institution Yes/No	Yes: 1 No: 0
		Have a policy development for clean energy [121]	Policy/institution Yes/No	Yes: 1 No: 0
	1.2 Assessment	Has an internal energy assessment been organized in the last five years?	Internal assessments/last 5 years Yes/No	Yes: 1 No: 0
		Have a certified energy management system (EMS) ISO 50001, for instance	EMS certificate/institution Yes/No	Yes: 1 No: 0
		Audits of the EMS organized in the last five years, other than certification audits [124]	EMS audit/institution Yes/No	Yes: 1 No: 0

3.4.2. KPIs for Research and Education in the Field of SESs

Education, research, and innovation are essential in sustainable development, making universities key contributors to achieving the goals [114]. The KPIs from this cluster (Table 2) are specific to universities and allow us to assess how devoted the universities are to effectively implement the green policies, and how the research and education processes are stimulated in this endeavor.

Table 2. KPIs for research and education in the field of SESs.

Cluster	Category	KPI	Measurement Unit/Criteria	Scoring (Based on: [121,123])
2. RESEARCH AND EDUCATION	2.1 Research	Funding research on energy sustainability [123]	Energy sustainability research funding/total research funding	⩽1%: 0 >1-8%: 0.25 >8-20%: 0.5 >20-40%: 0.75 >40%: 1
	2.2 Education	- Energy sustainability educational program for staff and students [121,128] - Increased environmental/sustainability education [22,107,129] - Involving the stakeholders [107,130]	Educational program/institution Yes/No	Yes: 1 No: 0
		- A program for local community about the importance of energy efficiency and clean energy [121] - Increased environmental/sustainability education [22,107,129]	Local community program/institution Yes/No	Yes: 1 No: 0
		Promote a public pledge toward 100% renewable energy beyond the university [121]	Public pledge/institution Yes/No	Yes: 1 No: 0

3.4.3. KPIs for Infrastructure Assessment from the Environmental Impact Point of View

The KPIs from this category are dedicating to assessing areas with higher energy losses and also the usage of the equipment belonging to different energy efficiency categories. The total carbon footprint per total population of the institution is calculated, and greenhouse gas emission reduction programs are also evaluated. Table 3 shows the most relevant KPIs identified for this cluster.

Table 3. KPIs for infrastructure assessment from the environmental impact point of view.

Cluster	Cate-	KPI	Measurement Unit/Criteria	Scoring (Based on: [121,123])
3. EFFICIENT INFRASTRUCTURE AND ENVIRONMENTAL IMPACT	3.1 Efficient operation	Energy report to assess areas with higher energy losses and optimal improvement measures [121]	Energy report/institution Yes/No	Yes: 1 No: 0
		- Renovation of the areas with significant energy losses [128,131] - Reduce heat demand (by 50%) [14,132]	Renovation areas/significant energy losses area identified	<1%: 0 1-25%: 0.25 >25-50%: 0.5 >50-75%: 0.75 >75%: 1
		Type I * energy efficient equipment ** [123,128]	Ne_I/N_I Ne_I = Number of type I energy efficient equipment N_I = Number of all type I equipment	<1%: 0 1-25%: 0.25 >25-50%: 0.5 >50-75%: 0.75 >75%: 1
		Type II *** energy efficient equipment ** [123,128]	Ne_I/N_{II}	<1%: 0 1-25%: 0.25 >25-50%: 0.5 >50-75%: 0.75

Cluster	Category	KPI	Measurement Unit/Criteria	Scoring (Based on: [121,123])
			Ne_{II} = Number of type II energy efficient equipment N_{II} = Number of all type II equipment	>75%: 1
		Equipment automation Smart energy solutions' implementation (automations) to reduce energy losses [123,128]	Tae/Te Tae = Total automated equipment Te = Total electrical equipment.	<1%: 0 1-25%: 0.25 >25-50%: 0.5 >50-75%: 0.75 >75%: 1
		Ensuring thermal comfort for users in all classrooms and laboratories of a university [17,123,129,133]	Mtu = 23 ± 3 °C Mtu = The average temperature in all university spaces (classrooms, laboratories, etc.) [134]	Yes: 1 No: 0
	3.2 Environmental	- Greenhouse gas emission reduction program [123]; - Reducing the CO2 emissions [12,86,129,135]	Program/institution Yes/No	Yes: 1 No: 0
		Total carbon footprint per total population of the institution (metric ton–mt) [53,92,123,129]	TCf/Tp TCf = Total carbon footprint Tp = Total campus population	⩾2.05 mt: 0 <2.05-1.11 mt: 0.25 <1.11-0.42 mt: 0.5 <0.42-0.10 mt: 0.75 <0.10 mt: 1

* For instance: washing machines; electronic displays; refrigerators; heaters; light sources; air conditioners and fans, etc. [136,137]. ** energy efficient equipment means: only A Class of energy efficiency for each specific equipment or appliance according to the EU energy efficient products [136]. *** For instance: pumps; transformers and converters; computers and servers; electric engines; welding equipment, etc. [136,137].

3.4.4. KPIs for SES Components

The KPIs for SES components propose measures for evaluating each of the SES components: resources used, energy conversion and storage, and energy demand. Table 4 shows the most relevant KPIs identified for this category.

Table 4. KPIs for the SESs' components.

Cluster	Category	KPI	Measurement Unit/Criteria	Scoring (Based on: [121,123])
4. SMART ENERGY SYSTEM	4.1 Resources	Total of renewable energy purchased from grid (for example: electricity from RES with green tariffs and gas) [124,128];	Tep/Tec Tep = Total energy produced Tec = Total energy consumed	>45%: 0 45-35%: 0.25 <35-25%: 0.5 <25-15%: 0.75 <15%: 1
		The number of renewable energy sources in the institution (for example: solar; wind; geothermal; biomass, etc.) [121,128,138,139]	nRES/institution nRES = The number of renewable energy sources used	None: 0 1 RES: 0.25 2 RES: 0.5 3 RES: 0.75 > 3 RES: 1

Cluster	**Category**	**KPI**	**Measurement Unit/Criteria**	**Scoring (Based on: [121,123])**
		The share of fluctuating RES (*for example: solar, wind, wave, etc.)* [14,17,20,53]	efRES/teRES efRES= Electricity from fluctuating renewable energy sources teRES = Total electricity renewable energy sources	< 1%: 0 1-25%: 0.25 >25-50%: 0.5 >50-75%: 0.75 >75%: 1
	4.2 Conversion	The share of renewable energy generated on site of the total energy used [123,138,139]	Teg/Tec Teg = Total energy generated on site Tec = Total energy consumed	<1%: 0 1-25%: 0.25 >25-50%: 0.5 >50-75%: 0.75 >75%: 1
		Report for assessing and reducing energy conversion losses [88,89,135]	Report/institution Yes/No	Yes: 1 No: 0
	4.3 Storage	Storage off grid for security: - The storage capacity of each type of energy must ensure the energy demand of the system in emergency situations *(for example: breakdowns, blackout, etc.)* [88,135,140,141] - Short differences between demand and production during certain hourly intervals (demand peak) [22,45,92,129] - Mitigation of maximum hourly surplus-deficit [129] - Secure and maintain voltage and frequency in the electricity supply [17,45,92,129]	Esong/Hd Esong = Energy stored on grid Hd= Hourly demand.	< 12 h: 0 12–24 h: 0.25 > 24–48 h: 0.5 >48–72 h: 0.75 >72 h: 1
		Storage on grid for flexibility: - Ensuring system flexibility by storing the surplus energy production for times when demand is higher than production [11–13,64] - Balance between supply and demand [22,53,107] - Reducing the system average interruption frequency and duration [129]	Ei/Ep Ei = Electricity injected on grid Ep = Electricity purchased from grid *(Target: 100% energy from RES)*	<1%: 0 1-25%: 0.25 >25-50%: 0.5 >50-75%: 0.75 >75%: 1
		Report for assessing and reduction storage losses of the energy system [88,89,135]	Report/institution Yes/No	Yes: 1 No: 0

Cluster	Category	KPI	Measurement Unit/Criteria	Scoring (Based on: [121,123])
	4.4 Demand	Specific requirements for universities: - Site energy use per unit of floor area; - The total electricity usage divided by total campus population (kWh/person); - Energy used/floor space; - Heating energy efficiency; - Cooling energy efficiency [121,123,128]	Criteria: (a) Energy consumption for class A 150 kWh/m^2/year (100%) [14]; (b) Primary energy for Nzeb (target for 2021) 92 kWh/m^2/year [142]; (c) Primary energy for Nzeb (target for 2050) 47.05 kWh/m^2/year [143]; (d) Passive building total energy 60–30 kWh/m^2/year (total) [144]	>150 (kWh/m^2/year): 0 150-100 (kWh/m^2/year): 0.25 <100-75 (kWh/m^2/year):0.5 <75-50 (kWh/m^2/year): 0.75 <50 (kWh/m^2/year): 1
		General legal requirements: - Reduce energy consumption [145,146]; - Increase the energy efficiency [14,131,142,147,]	Fulfilment criteria from the total criteria [14] as follows: • $\leqslant$70 kWh/m^2/year (heating); • $\leqslant$40 kWh/m^2/year (lighting); • $\leqslant$15 kWh/m^2/year (warm water); • $\leqslant$20 kWh/m^2/year (cooling); • $\leqslant$5 kWh/m^2/year (mechanical ventilation)	None: 0 1 fulfilled criterion: 0.25 2 fulfilled criteria: 0.5 3 fulfilled criteria: 0.75 >3 fulfilled criteria: 1
		Proportion of energy from RES per total energy demand for system operation Reduced/replaced fossil fuel consumption [14,19,53,129];	Annual proportion of energy from RES used/total annual energy demand	<25%: 0 25-50%: 0.25 >50-75%: 0.5 >75-99%: 0.75 >99%: 1

4. Conclusions

The SESs, as part of the EMSs, support the organizations to better manage energy use, by implementing new energy efficient technologies, reducing energy waste, and improving current processes to cut energy costs. This will be done by developing and implementing energy policies, setting achievable targets for energy use, and designing action plans to reach them and measure progress.

The development and implementation of SESs is a difficult task, especially if the goal is to achieve the goal of 100% use of energy from renewable sources [12,16]. These systems can be applied from the macro level (cities or neighborhoods) to the micro level (institutional buildings or homes) [4]. However, most of the reviewed studies are still in the research and testing stage, and only very few intelligent systems have been concretely applied.

Based on the bibliometric analysis, the relevant keywords most frequently used in the literature in the field of SESs were organized in three clusters in our study, specific to SES and its components, sustainable university, and the performance of the SES. Special attention was given to the last cluster, as the literature review also revealed that the assessment of the SESs for university campuses is an insufficiently approached subject [45].

In order to ensure a good implementation, operation, and assessment of the SESs in the institutional buildings, such as universities, KPIs need to be developed [45,129] and used as required by the energy management standards (ISO 50001, for instance), internal, and external assessment frameworks. Such indicators can help a university to prepare for evaluations in international rankings.

The study proposed a framework for evaluating SESs from university campuses, based not only on the technical side of SESs, but also on the role education, research, and innovation should have in sustainable development, making universities key contributors to achieving the goals.

The KPIs from this framework are structured in four clusters: management, education and research, infrastructure evaluation, and SES elements, and are dedicated to universities adopting policies for clean energy and interested in evaluating the progress toward this goal.

Future studies will aim to test the framework, analyzing how the KPI fits different types of universities, and how the KPI framework will support the university toward a green future. Testing the KPIs for different scenarios will allow an optimization of the KPI score, and also an estimation of the importance of each indicator relative to the other indicators.

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