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SMART ENERGY SYSTEM FOR SUSTAINABLE UNIVERSITIES

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Abstract: *Sustainable universities have a major social responsibility by transferring knowledge and educating citizens, increasing their perception and involvement for the sustainable development of future society. However, universities must ensure that their environmental impact is minimized. In this regard, Smart Energy Systems (SES) could support universities by facilitating their sustainable operation. In this paper we are proposing a SES framework, where all energy grids are integrated, forming a synergy that leads to the increase of energy efficiency. Moreover, SESs are mostly based on energy produced by renewable energy resources. Therefore, the model proposed here represents a frame that can support universities in the implementation of SES.*

Key words: *smart energy systems, renewable energy sources, sustainable universities, smart energy in university campuses, smart energy model.*

1. INTRODUCTION

The challenges related to sustainability have become more and more evident in today's society, their effects being found in all areas and sectors of society, from transport, industry to the real estate sector. Major attention is paid within the European Union to the buildings sector because following the analyses it was found that they have a significant weight in the generation of greenhouse gases [1]. Thus, the reduction of CO_2, in the sector of institutional and residential buildings, has become a major objective of the European Union, regulated by standards and legislation [2, 3]. In the light of above, several authors have researched and demonstrated the importance of user behavior regarding the building's operation and the influence on their energy efficiency [4, 5, 6]. In this regard, some authors have studied the sustainability issues in universities, both from the perspective of the operation and from the perspective of the stakeholders' sustainability culture [7, 8]. Thus, some authors have focused on introducing sustainability into the curriculum to promote responsible behavior [9, 10], because universities are considered responsible for educating prominent members of society [8] (leaders, heads of institutions, political decision-makers) but also ordinary citizens and thus can be important catalysts in terms of the concept of sustainability in society. In a previous article, the authors showed that a sustainable university can be divided into 3 modules, respectively [11]:

- Building design and management (BDM);
- Environmental protection and quality of the indoor (EPQ);
- Human resources and other stakeholders (HRS).

Here it was shown that the classical energy management system has implications in at least two of these modules (BDM and EPQ). However, by involving stakeholders in the frame of SES, it can meet all three components, leading universities towards the path to sustainability.

In this regard, universities should become an example of good practices for the whole society. All the more so as universities can be considered micro-cities, having buildings, transport systems and even micro-industry. Thus, universities must provide a major signal of changes by rethinking the way they operate through increasing their energy efficiency and reducing energy waste. The integration of SES in energy management system could be the way for a more sustainable operation of cities, of the operation of buildings, of transportation or even industry. The key point of the SES concept is that low-cost operating solutions cannot be found within the areas of individual energy grids (electricity grid; thermal grid; gas grid) or separate activities sectors (industry; transportation; buildings). Consequently, through the strategic incorporation of these elements into the structure of a comprehensive energy system, it is possible to achieve optimal synergies among the distinct subsectors. This integrative approach facilitates the identification of the most viable alternatives for maximizing the efficiency of the entire system. This process underscores the importance of a holistic perspective in the management and utilization of energy resources [12]. The most comprehensive definition identified in the literature is given by Henrik Lund and collaborators in several articles from different years [13, 14, 15]: *"A Smart Energy System is defined 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."*

This paradigm distinctly diverges from the concept of a smart grid. SES adopt a comprehensive methodology that encompasses all components of the energy system [16]. The objective is to foster synergies and devise strategies that enhance operational efficiency. This holistic perspective underscores the uniqueness of the SES approach in contrast to the smart grid concept. The frame of SES proposes an integrated approach of the main types of energy grids: electricity grid, heating grid and gas grid, at the same time, in combination with the main activity sectors: industry, buildings and transport. Additionally, are added different energy storage options (hourly, daily, seasonal, biannual), with the aim of creating the necessary flexibility to increase the amount of Renewable Energy Sources (RES) as possible within the system, moving towards the percentage of 100% RES [12, 17]. Simultaneously, a primary challenge lies in maximizing the proportion of fluctuating RES within the SES, while concurrently diminishing the share of biomass to a level that aligns with sustainable practices [17]. As for the building sector, the main target is that by integrating several types of renewable energies together with a series of energy conversion and generation systems and devices, to create an integrated SES based 100% on RES. Thus, in this case, of all the types of energy, the emphasis falls most on the electric energy and especially on the methods of its production and storage.

The possibility of achieving a reliable SES based on 100% renewable energy (RE) has concerned numerous authors in the specialized literature, creating a whole debate on this topic. Thus, in certain studies, authors highlighted that it is extremely expensive and quite complicated if not even impossible to achieve a total transition of SES to 100% RE [18, 19]. On the other hand, more and more studies conclude that the transition to 100% RE can be economically and technically feasible [17, 20]. At the same time, a comprehensive study [21] that analyzed 180 publications, concluded that most of papers highlight the technical feasibility but also the economic viability of the transition to 100% RE.

However, some papers conclude that in 100% RE scenarios, especially if an electricity-only approach is adopted, the cost of the infrastructure, especially storage, can significantly overcome the cost of the classical systems [22]. Other significant concerns of the authors identified related to SES were:

- Integration all sectors [23, 24];
- Flexible system 100% RE with high share of fluctuating RES [14,15];
- Nearly Zero Energy Building (nZEB) [25];
- Electrification of all sectors [24, 26];
- Energy management system [12, 25];
- Stakeholders [21, 25].

As for the building sector, the main target is that by integrating several types of RE together with a series of energy conversion and generation systems and devices, to create an integrated SES based 100% on renewable energy. And in this case, of all the types of energy, the emphasis falls most on the electric energy and especially on the methods of its production and storage.

Although in the literature it was not possible to identify a concrete model of SES implemented, some authors have developed theoretical models with a series of stages that compose a smart energy system such as those presented in Table 1.

Table 1

The main components and stages of SES designed identified in the literature

	Basic model	Ref.
I.	Resources → Conversion + Storage → Demand	[15, 17,23]
II.	Resources + Conversion → Distribution + Storage → Demand	[27];

Thus, considering the above (Table 1), it can be said that the main stages that are considered by most of the authors when designing a SES model are:

- Resources;
- Conversion;
- Storage;
- Demand.

Energy resources have an essential role within smart energy systems, being emphasized by many authors. Thus, it was found that the authors who addressed the topic of SES, state very often the need for a system based 100% on renewable energy sources [12, 15, 21]

The most known and relevant types of renewable energies resources (RES) that we could identified are: [28]: solar energy; wind energy; geothermal; aerothermal energy [29]; biomass and waste energy; hydro energy of river; hydrogen; waves energy; tides energy, and so on. Regarding fluctuating RES, the authors put the greatest emphasis only on solar [30] and wind energy [31, 32].

Viewed from a different angle, certain scholars [20] underscore the significance of power-to-gas technologies in the quest to curtail the utilization of biomass to sustainable thresholds. This discourse has led to the coinage of the term ‘electrofuels’ [33, 34]. The name electrofuels comes from a type of fuel produced with help of electricity based on water and carbon or nitrogen, presumed to be a good opportunity to replace fossil fuels [35].

Energy conversion represents a very important stage within SES because is responsible for useful energy needed for daily activities by usage a series of devices and installations that convert the RES. However, some authors consider that SES flexibility depends primarily on the conversion stage which together with storage capacity can lead to a resilient SES [15].

The most frequently addressed conversion systems by the authors are: photovoltaic [36, 37]; solar panels [38, 39]; solar plants [40]; wind turbine [41, 42]; combined heat and power (CHP) [43]; heat pumps [44]; boilers[45]; power plants [46], etc.

However, most authors have focused on conversion systems for fluctuating energy such as solar and wind, which is why almost every SES model involves conversion devices for these types of energy resources [38, 47]. Although less popular than photovoltaic, in Nordic countries such as Denmark, wind turbines are preferred due to its specific climate.

On the other hand, in the literature it talks more and more about heat pumps and cogeneration systems. As articulated by Lund et al. (2012), it is imperative to incorporate thermal infrastructure, such as heat pumps and heat storage facilities, into SESs. This integration, in conjunction with cogeneration plants, facilitates the efficient assimilation of renewable energy sources into the system. This approach enables the assimilation of up to 40% of fluctuating RES into the electricity supply, without compromising the overall system efficiency. [48].

Some studies have tried to identify and understand which is the optimal balance between energy saving and production measures [49, 50]. Several authors state that heat pumps could be the key conversion that makes the connection between the electrical and thermal sectors [51].

Dincer and Acarac (2017) underscore the notion that augmenting the diversity of products derived from a singular energy source (cogeneration; trigeneration; quadgeneration) will decrease the emissions per product unit and will increase energy efficiency [24].

Energy storage is a very important component of SES, especially when we talk about integration in the system a high share of fluctuating energies and also an operation with 100% green energy from RES. For example, having a storage energy capacity within the energy system it can lead to the 100% green energy transition [52] by integrating a larger amount of fluctuating RES [48, 53] helping in this way the system to become much more flexible [21, 54]. Within the academic discourse, one can discern the existence of three distinct categories of storage capacities, each corresponding to a specific type of useful energy demand of system, such us: electricity storage [38]; thermal storage [55]; and fuel storage [56].

In particularly, for the electricity storage, the literature often addresses storage methods such as: batteries [55] and electric vehicles (EVs) [57].

Lund et al. (2016) posit that electricity storage is more susceptible to significant losses compared to other forms of energy storage [52]. For instance, while gas caverns and oil reservoirs exhibit no losses, thermal storage incurs approximately 5% losses, contingent on the size and duration of retention.

Literature indicates that the costliness of electrical energy storage systems is notably exacerbated by the variable nature of Renewable Energy Sources (RES). This variability necessitates numerous ancillary conversion systems, which contribute to the overall expense. Furthermore, it is observed that the efficiency losses in such storage systems are substantial. Comparative analyses suggest that the cost of electrical energy storage could be an order of magnitude higher potentially up to a hundredfold (100%) when contrasted with thermal energy storage solutions [15]. Nevertheless, electricity storage systems have an important role in energetics security, facilitating grid stability in blackouts cases [44].

Conversely, electric vehicles (EVs) have garnered significant focus within scholarly discourse, with certain researchers positing that they offer a viable avenue for the interim storage of electrical energy, which may subsequently be re-injected into the power grid [58]. Thus, more and more researchers have considered the idea of electric energy storage through EVs due to flexibility that this method could offer [59].

However, regarding thermal storage, the authors state that it is a method much more efficient for storage energy because involves much lower costs compared to electricity storage [60]. Thermal storage systems enhance the adaptability of coupling between the electrical and thermal sectors [61]. In the literature, thermal energy storage methods based on different types of water tanks can be identified [62] such us puffers and pit thermal energy storage [63].

Also, regarding fuel storage, the main storage forms identified in literature were fuel tanks, gas caverns and oil tanks, etc. [15, 57].

Energy demand is so important stage of SES because depending on how the energy demand is managed, the system can be 100% operational with renewable energy, being also resilient or it can have numerous problems and blackouts.

In order to have an effective energy management, it is very important to know in detail everything related to the energy demand of the system, whether it's about a building, a university or a city [64]. Energy demand could be divided into three sectors [65]: electricity demand; heat/cooling demand; and gas demand.

Many authors emphasize the importance of energy demand flexibilization [66]. This concept means according to Alliance to Save Energy *"Demand flexibility is the use of communication and control technologies to change electricity consumption during the day while maintaining the quality and value of end services: air conditioning; water heating; and electric vehicle charging"* [67].

Some authors state that buildings can facilitate a flexible energy demand due to their thermal inertia [68].

Another important aspect regarding energy demand, highlighted by the authors who addressed this topic, was the creation of a balance between demand and supply [44, 69].

Bačeković & Østergaard proposed an equilibrium equation between demand, production and storage [57]:

$$\sum_{h=1}^{8784} Demand_{h,t} + Production_{h,t} + Storage\ flow_{h,t} = 0 \quad (1)$$

Where h is the indicates hours;

t - types of demand and production.

In our opinion, the formula should be updated to consider the energy losses within the system [70], from storage to transport losses [69].

In the construction industry, numerous scholars highlight the discrepancy between the anticipated energy usage of edifices and their real consumption [71]. Thus, it was concluded that this gap may have the following causes: the energy efficiency of infrastructure, including the efficacy of electrical apparatus and the insulative properties of edifices, as well as the conduct of stakeholders (users) [72].

In this regard, many authors have concerned about the behavior of users and shown that this is the most important factor with a major influence on the final energy consumption [4].

Taking into account the aforementioned factors, the objective of this study is to construct a graphical conceptual framework for a SES. The general objectives are to detailing the stages that could lead to its integration into the university framework, along with a performance assessment system based on KPI. In this way, would be facilitated for universities the path towards sustainable operation.

2. METHODOLOGY

For this paper, the authors have conducted qualitative research on Scopus database. Researches were performed by using a series of key word combinations such as "smart energy systems"; "smart energy" and "university" etc. In the following, 205 papers were identified and selected based on certain criteria such as: number of citations: minimum one citation; research area: energy; engineering environmental efficiency, etc.; year of publication: >2009; type of paper: articles; review, conference paper.

In the following, VOSviewer software was used to process the 205 identified papers and transform them into a bibliometric map based on the number of co-occurrences of the most relevant keywords.

In the next stage, the identified papers were opened in order to select only those articles that that best fit on the research topic. Therefore, 130 works were considered irrelevant for this research, leaving 75 eligible articles. Of these, approximately 55 had as topic SES or their components such as smart grids. Additionally, 19 relevant papers and sources identified along the way were added. Thus, 74 relevant papers were selected for research, and 5 of them were from Romania. However, very few of these papers addressed the concept of SES in the frame of universities and none have made a clear connection, as it could be seen in figure 1.

Based on the qualitative research, the IDEF methodology was used for creating the graphical conceptual model. For the design of the model, it was used the Microsoft Excel.

3. RESULTS

Based on the 205 selected articles in the first stage, a bibliometric map was made using the VOS Viewer software, presented in figure 1. Here It can be seen that within the map three different colored groups have formed with a series of keywords in circular labels. Thus, each keyword belongs to a group and depending on the occurrence number of the word within the 205 articles used, its label is smaller or larger. The bigger the circular label, the more important the topic is, being more intensively debated by the authors of these articles. Also, each keyword forms a network with other keywords depending on how much they were addressed together.

Thus, we see that the most prominent label is "smart energy systems" being closely linked to other labels such as "system" or "energy system". This fact confirms that the topic is relevant. At the same time, it can be seen that the label "university" is on the periphery of the map in a distinct group compared to the one with "smart energy system", which suggests that these two topics were not addressed enough together to create links strong and so that is a research niche. Following the literature review, we were able to delineated the principal components of SES concept. In this way it was possible to develop a conceptual graphic model of a SES adapted to the university framework.

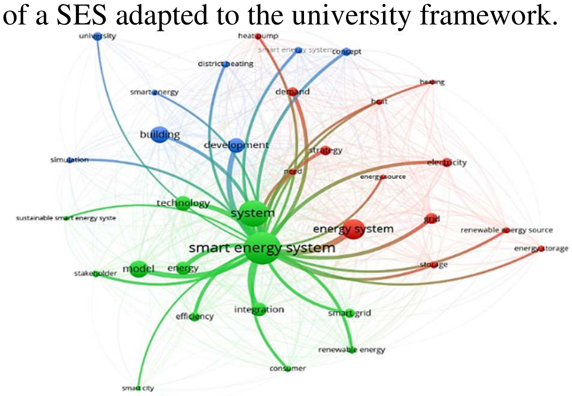

Fig. 1. Bibliometric map with VOSviewer

Thus, for the graphical model of the concept IDEF methodology was used. IDEF diagrams are used for modeling data flows in processes logic. Thus, for a process to be functional, it needs four essential elements: inputs, outputs, resources and constraints. For creating an IDEF diagram there are many programs that can be used, but most of them are for fee, the most known being iGrafx. However, in this paper where we used Microsoft Excel, being a much more accessible program. Thus, in the figure 1 it can be seeing a general graphical conceptual model of the energy-smart university can be seen. In other words, it is about a concept of a SES adapted to the university framework as part as energy management system, as support for a much more sustainable operation of universities. Thus, in this context, the concept of SES was developed from a process's perspective into the university framework, taking into account the following component elements, presented in figure 2.

Inputs – in this case, represent requirements, internal and external, that must be met according to the conditions imposed by the restrictions;

Restrictions – impose the manner and conditions according which the requirements will be achieved. Most of the restrictions considered are legislative: directives, national or local legislation, university internal legislation or even standards and university rankings. However, a particularly important restriction is ensuring of the energy demand of university, around which the whole process will be oriented.

Resources – constitute all the elements (informational, human, material, financial, etc.) through which the whole process will take place in the optimal conditions;

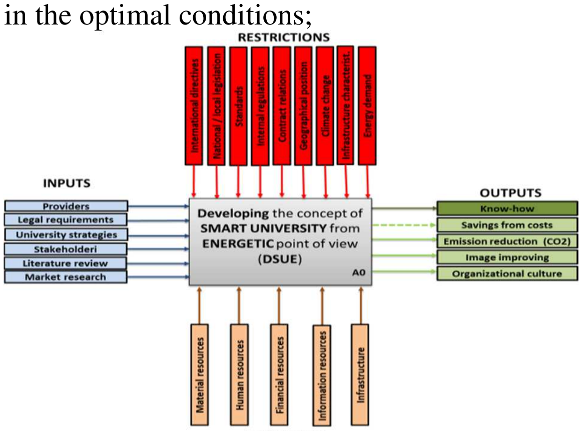

Fig. 2. The general graphical conceptual model

Outputs – these represent the direct or indirect results of the process that running under optimal conditions. The outputs of the global system integrated in the university environment are: know-how; savings from costs; CO2 emissions reducing; image leveraging, organizational culture.

However, regarding to the outputs from this conceptual model of SES (figure 2), it can be of two types, tangible (ex: savings from costs, emission minimization) or intangible (ex: know-how, organizational culture) being described in more detail in the following.

Know-how – represents an accumulation of knowledge, acquired following the implementation of some processes and sub-processes. In this case, know-how supports continuous improvement.

Savings from costs – the potential savings resulting from cost reductions are intermittent, not continuous, because it represents a consequence of a previous investment that will amortize over time. At the same time, these savings can vary depending on the year periods and can be reinvested later in the infrastructure.

Emissions minimization – represents the difference between the emissions generated by the conventional operation and the renewable energy-based operation.

Image leverage – a substantial improvement in the image is an implicit consequence of the transition from conventional energy to green energy.

Organizational culture – it is a long-term outcome of implementing a stakeholder engagement strategy to support the system and make it sustainable.

In the following, the general model was developed into an extended model of SES. Here it can be observed all four main stages identified in the literature as part of smart energy systems.

The extended model represents a more detailed breakdown of the logic on the basis of which the general model was developed and at the same time a vision of how the stages should be organized. Therefore, it will be delineated in a comprehensive manner, aims to highlight the intricate interconnections among the four fundamental constituents that underpin the smart energy system: resources, conversion, storage, and demand. This detailed exposition will provide a deeper understanding of the synergies and interactions within this complex system. The objective is to elucidate how these components interact and influence each other, thereby contributing to the overall efficiency and effectiveness of the smart energy system.

Resources - for this model have been carefully chosen to ensure the complete energy demand of a university. In this regard, first type of resource is national/local grid that is intended to be used until the moment when the system becomes functional, and also at the moments when the energy production in situ from renewable resources does not meet the demand**.** From the grid it can be purchased both gas and electricity. In case of electricity, it can be opted electricity from renewable energy sources by buying green certificates. The other types of energy resources proposed for the production of useful energy were: solar energy; wind energy; geothermal/aerothermal energy and biomass.

Conversion - represents the process that integrates all the technical systems that transform the primary energy of the renewable sources into useful energy, such us: electricity, thermal energy and fuel. Thus, for each type of energy resource, conversion systems were identified in the literature review, among which the most representatives and optimal systems for the university frame was selected, as follows: solar: solar and photovoltaic panels; wind: wind turbines; geothermal/aerothermal: heat pumps, geothermal central; biomass: pelletizing machines, biogas/biodiesel plants, etc.

It was also proposed to integrate a cogeneration plant (CHP) in the conceptual model of SES. CHP plants have been the concern of many authors who have addressed these systems in their papers [73]. The integration of a CHP within this concept presents many benefits, one of which is that a cogeneration plant can integrate all the energy sources presented above, being able to operate with bi-fuels (pellets, biogas) and also to use a small amount of electricity that can be produced by photovoltaic panels and wind turbines.

Storage - is a critical component in improving the reliability, flexibility, resilience, and safety of energy systems. It has the potential to facilitate the realization of Sustainable Energy Systems (SES) that are entirely powered by renewable energy sources. In the framework of the conceptual model, the storage of useful energies (electricity, thermal energy and fuel) was proposed, but the emphasis being on the storage of electricity. Thus, for each type of useful energy, the optimal storage methods identified in the literature were selected: for electricity: battery, electric vehicles, national grid; for thermal energy: thermal tank storage, puffer; for fuels: fuel tanks; pellets storage.

Demand - this stage refers to ensuring the energy needs of university (electricity, thermal energy and fuel). Within the universities, energy demand is influenced by a multitude of factors, from infrastructure to user behavior and organizational culture. Practically, in this stage a balance between first three stages and actual energy consumption must be achieve, taking also into account the energy losses.

As was highlight above, all these components interact with each other and influence each other through their outputs. So, it is important to highlight that an output of a process can be an input, a resource or a restriction or even all of these together for other processes within the system. For example, the resource ensuring process directly and indirectly influences all other processes.

At the same time, it should be noted that although in the extended model the processes will be much more detailed, the inputs, outputs, resources and restrictions will be the same. It is very important to emphasize that they are of two types, on the one hand the outputs of the global system (indirect outputs), presented above, and on the other, the outputs specific to each process (direct outputs), being presented below:

- For resources: grid energy; renewable energy sources RES; parameter of RES.
- For conversion: energy (by converting RES); parameters of energy.
- For storage: stored energy and parameters;
- For demand: responsible consumption of resources to ensure balance between production and demand.

An additional crucial point to underscore in this context pertains to the interplay and mutual influence of the processes within the SES. This highlights the interconnected nature of the system, where each process does not operate in isolation but is part of a complex network of interactions that collectively contribute to the functioning of the SES. This perspective is essential for a comprehensive understanding of the dynamics and efficiency of the system. For example, the main outputs of the resources process are, on the one hand, the energy from grid (electricity and gas) that flows directly to ensuring the demand of the university and when is need to supports the conversion, and on the other hand, RES and their parameters that flow to the conversion process. The outputs of the conversion process are RES converted into useful energy (electricity, thermal energy and fuels) and its parameters which flow to demand, the surplus going to storage. Storage process has as output the stored energy (electricity, thermal energy and fuels) and its parameters that flow when needed to demand or to conversion.

4. CONCLUSIONS

Unlike other previous works, this research makes a clear connection between the concept of SES and the university environment, presenting a concrete graphic model that would support the effective implementation.

Consequently, the graphical conceptual model delineated within this manuscript serves as an exemplary paradigm for academic institutions aspiring to adopt smart energy systems, thereby expediting their progression towards sustainable functioning. At the same time, this graphic model could offer a deeper understanding of the energy flow form an university frame, from production to consumption, by providing a vision of how the main the processes in this flow influence each other. Although this is a static model, by providing concrete data regarding energy production, consumption, losses, etc., it could be transformed into a dynamic model based on a series of specific KPIs [74]. Moreover, the developed graphic model m4y be suitable for, with some modifications, to any educational institution or public building such as high schools, hospitals or town halls.

In the perspective of the authors, the process of dependable and efficacious enactment of SES is considerably comprehensive, delineating four principal phases [74]: management; education; infrastructure; and the effective implementation of SES components.

Further research should be focused on the preparation of a strategy that identifies the most relevant stakeholders to involve through various methods to support the optimal operation of the SES in the university environment.

5. ACKNOWLEDGEMENT

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Sisteme energetice inteligente pentru universități sustenabile

Universitățile sustenabile au o responsabilitate socială majoră prin transferul de cunoștințe și educarea cetățenilor, sporind percepția și implicarea acestora pentru dezvoltarea durabilă a societății viitoare. Cu toate acestea, universitățile trebuie să se asigure că impactul lor asupra mediului este minimizat. În acest sens, Sistemele Energetice Inteligente (SES) ar putea sprijini universitățile prin facilitarea funcționării lor durabile. În această lucrare, propunem un cadru SES, în care toate rețelele energetice sunt integrate, formând astfel o sinergie care ar putea conduce către o creșterea eficienței energetice globale, a întregului sistem. Mai mult decât atât, SES-urile se bazează în mare parte pe energia produsă din resurse de energie regenerabilă, având un aport consistent la reducerea impactului semnificativ asupra mediului. Prin urmare, modelul propus aici reprezintă un cadru care poate sprijini universitățile în implementarea SES.

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