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Smart energy systems for a sustainable future

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HIGHLIGHTS

- Smart energy systems are investigated to address major energy issues in a sustainable manner.
- Evaluation criteria are efficiencies, environmental performance, and energy and material sources.
- Energy sources are fossil fuels, renewables, biomass, and nuclear.

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ABSTRACT

In this study, smart energy systems are investigated and comparatively assessed to solve major global energy-related issues in a sustainable manner. In order to be considered as smart and sustainable, the energy systems should use technologies and resources that are adequate, affordable, clean, and reliable. Therefore, selected smart energy systems are evaluated based on their efficiencies, environmental performance, and energy and material sources. Our results show that increasing the number of products from the same energy source decreases emissions per unit product and increases efficiencies. Also, among the identified sources, geothermal has the most potential in terms of using cleaner technologies with energy conservation, renewability and the possibility of multiple desired products from the same source. Solar, hydro, and biomass are also beneficial. Even with carbon capture technologies, fossil fuels are not very desirable in smart energy systems because of their emissions and non-renewability.

1. Introduction

Energy is the key to tackling the most important issues of today and tomorrow such as climate change, sustainable development, health and environment, global energy and food security, and environmental protection. Nevertheless, traditional energy systems fail to accomplish meeting the multidimensional and multidisciplinary requirements of the 21st century.

During the transition from traditional to smart energy systems, it is primarily expected to design, analyze, develop and utilize transitional solutions to enhance their energetic, exergetic and environmental performance for better sustainability. In this regard, there is a strong need to greenize them in the best possible way by considering various criteria, such as environmental impact, resource utilization, efficiency, and cost effectiveness which will help achieve better sustainability ultimately.

For that reason, a substantial change in energy systems is needed to meet the increasing global energy demand in a sustainable fashion without hurting the environment, society, economy, and the well-being of the forthcoming populations. This study demonstrates that transition to smart energy systems is the most suitable approach to meet this need. Smart energy systems can possibly be beneficial when resolving many of the aforementioned requirements all together and provide multiple advantages at the same time. The successful functioning of smart energy systems necessitates strongminded, continuous, and direct action. There are substantial benefits of smart energy systems. However, in order to be considered as smart, an energy system should meet many expectations simultaneously. These expectations ultimately address the global energy challenges from various dimensions, including efficiency, effectiveness, cost, environment, resource use, sustainability, integrability, commercial viability, etc. The key expectations from smart energy systems are illustrated in Fig. 1 and described below:

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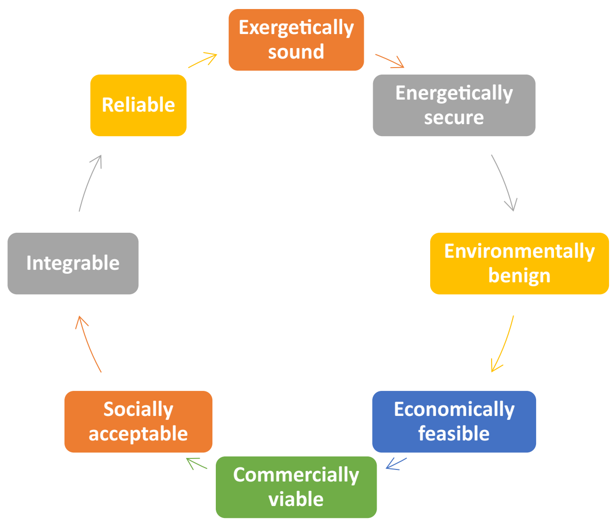

Fig. 1. Major expectations from smart energy systems.

- *Exergetically sound:* Exergy is a critical indicator of the quality of energy. For a system to be considered as smart, it should be exergetically sound. This means the system should have minimum exergy destructions and maximum exergy efficiency possible. In that case, a system could not only conserve the quantity, but also the quality of its energy content.
- *Energetically secure:* This is basically about energy security. A smart energy system should be designed and implemented in a way by taking advantage of affordable, reliable, locally available, abundant and replenished sources. Such smart energy systems then become self-sufficient, safe, efficient and hence secure. With smart energy systems, end users have access to dependable, practical, safe, and efficient energy supply which eventually provides energy security.
- *Environmentally benign:* smart energy systems are clean at every stage from source to their end use with less emissions and efficient resource utilization. Smart energy systems also include waste and loss recovery for both energy and materials. Less waste and loss means more efficient systems, lower emissions, and better environment for future.
- *Economically feasible:* Smart energy systems are expected to use affordable, reliable, available, and abundant resources. In addition, smart energy systems minimize losses and waste and maximize system efficiencies and desired outputs. Together with dependable, affordable, and practical end use options, smart energy systems have significant economic benefits.
- *Commercially viable:* From their sources to end use, smart energy systems essentially take local and marked conditions into account. A smart energy system uses what already available or easily accessible resources and provides the goods and services that are desired and considered as commercially viable. This way they will have ability to compete effectively and economically to be profitable. For example, smart energy systems using renewables increase their commercial viability with the support of the government. Furthermore, multigeneration is an example of how a smart energy system could increase the number of outputs in order to provide more commercial products.
- *Socially acceptable:* A smart energy system are expected to be socially acceptable to the local and global communities as such systems can satisfy the social needs and harmonize the options. This is especially true when considering the end use aspect of smart energy systems. In order for a smart energy system to succeed, it should be accepted by the society so that it could become a part of their daily lives and replace the traditional systems.
- *Integrable:* Smart energy systems are expected to have the integrability feature which will have help achieve system integration for multigeneration purposes. It is also important to engineer energy systems in integrated fashion to be smart or even smarter. The literature has many examples of novel energy systems that require substantial change in existing energy systems. A smarter approach would be developing energy systems that can be integrated to the existing energy infrastructure. The process of Integration is defined as an ultimate operation where energy systems and sources are combined in a synergetic form to achieve better efficiency, cost effectiveness, resources use, and environment. The less modifications an energy system require, the more likely it would be accepted by the society and the industry.
- *Reliable:* The term energy system covers everything from the production, processing, and end use of energy. In every step, smart energy systems should be reliable such as using reliable and available/easily accessible resources, reliable energy processing/conversion systems, and providing reliable service for end use. Reliability also increases the possibility for social acceptability.

There are numerous studies present in the literature, focusing on many characteristics of smart energy systems. Dincer and Zamfirescu [1] have discussed smart energy systems in terms of enhancing the amount of useful products from the same renewable energy source. Getting a variety of desired products from the same energy source is definitely a promising way to increase energy conservation. Together with clean energy sources, such as renewables, multigeneration systems offer distinct advantages, such as reduced losses/wastes (and hence reduced environmental impact), increased system efficiencies (and hence increased cost effectiveness), and producing multi outputs simultaneously (e.g., power, heat, cooling, fuels, chemicals) in contrast to the traditional single generation systems (see further details elsewhere [2]).

In the literature, there are several approaches to evaluating the sustainability of traditional and novel energy systems. Several of these studies estimate the sustainability of a given energy system from a thermodynamic [1–3] or an environmental [4–7] point of view. Some of these studies use more thorough methodologies which take into account other characteristics of sustainability. These studies, in general, use ranking indicators with or without normalization by taking the quantitative and qualitative targets of sustainability into account. These studies are more appropriate for the comparative evaluation of traditional and novel energy systems. In addition, some other studies utilize quantitative sustainability evaluation means that tackle the technical, economic, social, and environmental requirements of sustainability [5].

Dincer and Zamfirescu [6] have introduced innovative prospective opportunities to greenize energy processing and end use. The authors' idea is based on the approach introduced by Dincer [7] as six core components to greenize energy systems. These components are better efficiency, better cost effectiveness, better resources use, better design and analysis, better energy security, and better environment. Dincer and Zamfirescu [6] have also proposed a novel greenization factor and demonstrated its use to evaluate the greenization capability of selected traditional and novel energy systems is for different case studies. Singh et al. [8] have conducted a review of sustainability assessment approaches and gathered the information about the sustainability indices formulation together with strategy, scaling, normalization, weighing, and aggregation procedures. Mainali and Silveira [9] have inspected various sustainability examination methodologies and demon-