

A Sustainable Energy Future: Leveraging the Potential of Smart Energy Systems

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Abstract. Due to climate change, the global focus is on generating energy from renewable sources. A significant challenge is ensuring sustainable energy development, given that climatic conditions directly influence renewable energy. A promising solution for sustainability is the implementation of smart energy systems. This study proposes an innovative approach to ensure a sustainable energy supply. The primary objective is to highlight the importance of smart energy system projects, analyse current technologies, and explore the transformation of traditional systems into smart systems to enhance their energy and environmental performance for sustainability. The study will also explain how these systems operate, their advantages, and their challenges. A smart energy system is fully renewable, cost-effective, and does not increase energy costs compared to traditional sources. These systems utilise clean, reliable, and affordable technologies and resources, which are evaluated based on their environmental performance in the selected regions in Nigeria.

Keywords: Climate Change; Renewable Energy; Sustainable Energy; Environmental Performance; Energy Technologies.

INTRODUCTION

A smart energy system is a cutting-edge solution that integrates renewable energy sources, infrastructure, and consumption, ensuring a cost-effective, sustainable, and secure energy supply. This is achieved through coordinating energy services, empowered consumers, and advanced technologies, creating a harmonised and efficient energy ecosystem" [1].

Energy is a fundamental driver of technological progress and is closely tied to the economic sustainability of all nations. Today, every process and technological device depends on energy, leading to a growing demand that necessitates increased production. Historically, non-renewable sources have been the primary energy providers, but the coming decade is seeing a shift towards renewable energy, with some countries aiming for 100% renewable energy production. This shift means that future energy needs must be met with sources that do not harm the environment.

Developing systems that can ensure sustainable and entirely renewable electricity production is crucial. These smart energy systems are not only cost-effective but also efficient and sustainable. They rely solely on renewable sources, maintaining or even reducing energy costs compared to traditional methods. These systems incorporate clean, reliable, affordable technologies and resources assessed based on environmental performance. For the successful implementation of smart energy systems, it is vital to evaluate current technologies, consider the transformation of traditional systems into smart ones, and enhance their energy and environmental performance. Our country possesses considerable potential for renewable energy, which should be harnessed smartly to ensure a sustainable energy supply.

By 2050, nations worldwide have committed to transitioning to renewable energy sources to safeguard the environment. However, achieving this goal will be challenging, particularly for developed countries, including ours, which must adopt innovative technologies, revised electricity market regulations, novel business models, and new taxation systems to support these initiatives. A successful strategy will involve combining flexible energy consumption in buildings, enhancing energy efficiency, integrating diverse energy infrastructures, and leveraging smart system operations. To ensure a sustainable and 100% re-

newable energy future, it's crucial to implement smart energy systems that are cost-effective, efficient, and environmentally friendly. This research will utilise data from stationary databases providing meteorological information across Europe to inform the development of these sustainable energy solutions. These systems are innovations in the energy sector; for that reason, the main focus will be to analyse the conditions and opportunities for implementing this model in our country [2].

The Smart Energy System Concept

The primary objective of renewable energy projects is to reduce dependence on fossil fuels and promote environmental sustainability. However, these eco-friendly resources must also demonstrate reliability and capacity to meet energy demands consistently. To ensure a steady and sustainable energy supply, renewable sources must be incorporated into a comprehensive system that harnesses energy from diverse sources. One approach to achieving this is integrating renewable energy sources, which leverage the power of solar radiation, wind energy, and biomass as a supplementary source, capitalising on their respective potentials to create a robust and diversified energy mix.

Biomass generally has the same characteristics as fossil fuels and will serve as a regulator of production to meet the needs for a stable energy supply [3]. These systems consist of new technologies with new forms of flexibility in the conversion stage of the energy system by combining electricity, thermal, and transport sectors.

Smart Electricity Grids. A smart electricity grid is an advanced and dynamic power network capable of intelligently integrating the activities of connected users, known as 'prosumers,' who can generate and consume electricity [4].

Smart Thermal Grids. Smart Thermal Grids create synergies between demand and supply to achieve maximum system efficiency. They encompass district heating and cooling, aiming to connect the electricity and heating sectors. Smart thermal grids can incorporate high-energy performance buildings, flexible, interactive networks, heat storage, integration of local renewable sources, and national energy policies [5, 6].

Smart gas grids connect the electricity, heating, and transport sectors. They can be presented as digitised gas networks supporting new features by integrating innovative and smart nanotechnological sensors. These solutions offer more accurate and sustainable monitoring and supply. They increase the percentage of green gas in the distribution network. They enable integration with electricity, heating, and other networks. They incorporate new technologies. They improve the energy efficiency of the gas grid [7].

A smart energy system integrates smart gas, electricity, and thermal technologies with storage solutions to identify synergies and achieve optimal performance for the entire energy network [2].

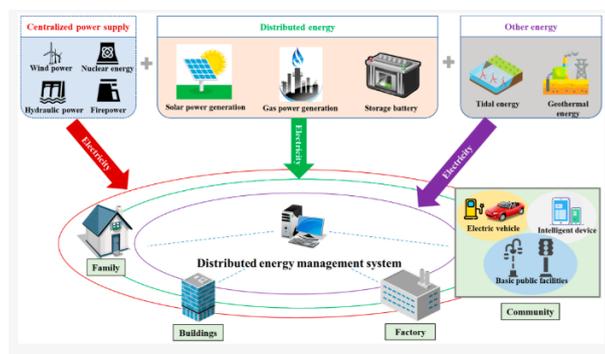


Figure 1 – Smart Energy System Structure

Figure 1 illustrates the overall structure of a smart energy system for achieving 100% clean energy. According to IDA Energy Vision, a system operating entirely on renewable energy is technically and economically viable for Denmark and compares favourably to fossil fuel systems. Their scenario for achieving a 100% renewable energy system by 2050 involves replacing non-renewable sources with clean energy, increasing investments in wind and solar energy, and using biomass energy as an alternative and stabilising source [3].

The plan is to ensure that by 2050, all primary energy will be derived from renewable sources, managed by smart energy systems that balance consumption and production. [3] Assessing the economic parameters when planning these systems is crucial to ensuring they are feasible and justifiable for investment. Smart energy systems must meet several criteria and expectations detailed in Figure 2 to justify the investment and achieve their goals.

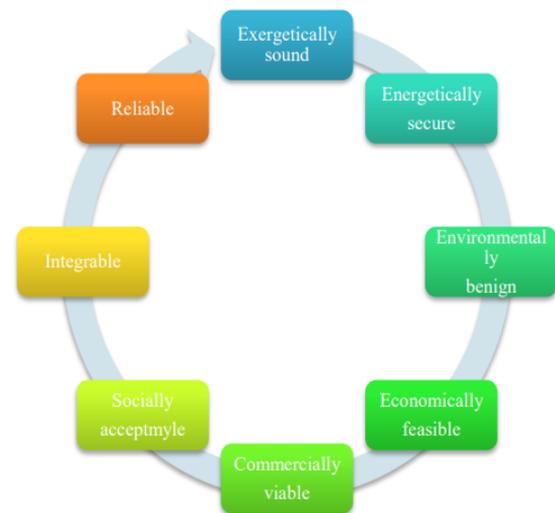


Figure 2 – Expectations from smart energy systems [8]

A smart energy system must prioritise exergy, a key indicator of energy quality, to ensure the conservation of its energy content and minimise exergy destruction. Such a system should embody the following characteristics [8]: 1) Energetically sound: Optimise energy quality and minimise waste; 2) Energetically secure: Foster sustainable energy development and security; 3) Environmentally benign: Leverage renewable energy sources, such as biogas from biomass, to reduce emissions; 4) Economically feasible: Benefit from reduced costs due to technological advancements; 5) Commercially viable: Encourage competition and investment through government support and tariffs; 6) Socially acceptable: Gain societal acceptance by offering advantages in social, economic, and environmental aspects; 7) Integrable: Seamlessly integrate with existing energy infrastructure, with a focus on smart energy networks for future implementations; 8) Reliable: Ensure dependable energy production, processing, and end-use to facilitate widespread adoption.

The evolution of modern electricity, heating, and gas systems into smart energy networks necessitates the integration of cutting-edge Information and Communication Technology (ICT) innovations. Grids must be interconnected through advanced storage, generation, conversion, and demand management technologies to achieve this. ICT will be instrumental in optimising energy planning and management within these systems. Its presence should be ubiquitous throughout the

network to facilitate seamless coordination of operations and management. Moreover, ensuring the confidentiality, availability, and integrity of smart energy systems is crucial to guarantee secure operation and protect user data from unauthorised disclosure [9]

Optimal energy management in renewable energy systems requires special consideration for seniors, who will be integral to these systems. Sensor data and other relevant information must be meticulously processed to make informed decisions. Data fusion algorithms may sometimes be necessary to combine data from various sensors, providing a more accurate picture of system operations. During the planning and design phase, it's crucial to analyse wind and solar sensor data to predict energy output from these sources and determine the required biomass energy contribution, ensuring a sustainable energy supply. This careful data analysis will enable effective system management and informed decision-making.

RESULTS AND DISCUSSION

Smart energy systems are an innovative approach for some regions in Nigeria. Climatic conditions influence solar and wind energy and are not always available. As a result, renewable energy sources can sometimes need more stability for consistent supply. Smart energy systems address this issue by integrating biomass energy to stabilise production and consumption and ensure sustainability. When solar and wind resources are available, these systems will generate energy from these sources. Conversely, when solar and wind resources are insufficient due to weather conditions, biomass will be used to produce energy, whether as thermal energy, biogas, or electricity.

Collecting data on solar radiation and wind speed for a specific location is essential to predict the output of solar and wind energy sources accurately. For this purpose, we have selected some locations in Nigeria and utilised the Photovoltaic Geographical Information System (PVGIS) to generate data on solar radiation for 2016, broken down into monthly values. The location's coordinates (9.0579° N, 7.4951° E) were used to obtain this data, which will be crucial in designing a future energy system. Additionally, we will create a Typical Meteorological Year (TMY) dataset to further inform our energy system design. The

solar radiation data for this location is presented in Table 1.

Table 1 – Solar radiation for a specified location in Nigeria

Location	Geopolitical Zone	Latitude (°N)	Longitude (°E)	Elevation (m)
Abuja	Federal Capital Territory	9.24	7.15	244
Akwa-Ibom	South – South	4.93	7.87	43
Ikeja	South – West	6.75	3.20	40
Ilorin	North – Central	8.26	4.30	308
Onitsha	South – East	6.16	6.78	55
Sokoto	North – West	12.55	5.12	351

Also, a TMY can be generated for this location to get the data for the typical meteorological year from measurement 2007-2016 for 12 typical months. "A typical meteorological year (TMY) is a set of meteorological data with data values for every hour in a year for a given geographical location. The data are selected from hourly data in a more extended period (usually ten years or more). The TMY is generated in PVGIS following the procedure described in ISO 15927-4.[11].

Table 2 presents the generated data from TMY for a specified location in Nigeria. These data are generated using the PVGIS databases (Sarah, Cosmo, Era) and can be used for designing energetic systems with software like Energy PLAN2. It has been essential to have accurate data for solar and wind speed for the past ten years to build a model that can be used to design systems based on previous measurements and new predictions for the future. Knowing the solar and wind speed data makes it easier to project a system and plan additional resources like biomass for energy production.

Table 2 – TMY For Specified Location

Location	MPE (%)				
	Mean Temperature	GSR	Wind Speed	RHM	DPT
Abuja	-0.075	0.06	0.131	0.119	0.038
Akwa-Ibom	-0.0076	-0.043	-3.67	-0.152	0.257
Ikeja	-0.011	0.037	-0.0029	-0.036	1.480
Ilorin	-0.025	-0.034	-0.747	0.177	0.221
Onitsha	0.0284	0.074	-0.433	0.183	0.190
Sokoto	-0.147	0.068	0.495	0.430	0.156

With data on solar radiation and wind speed, we can design a triple-source renewable energy system. When wind and solar energy are sufficient to meet grid capacity, biomass energy won't be needed. However, biomass will ensure a stable supply during periods without solar and wind energy. Since wind and solar resources vary across Macedonia, rural areas have more potential than urban areas. The Smart Energy System enables municipalities to transition from carbon neutrality to 100% renewable energy. This is achieved by leveraging local intermittent renewable sources to power heating, transportation, and other consumption needs [12].

Depending on climatic conditions and location, these systems may encounter changes in implementation and results. Different locations will probably need a specific approach when designing these systems. From the preliminary analysis, we can see that the solar radiation data differ from location to location, as well as wind potential data. Depending on the data generated by the stationary measurement bases for the potential of renewable energy sources, smart energy systems will be designed concerning those data.[8] The whole idea is to offer a system that will provide clean and stable energy in the future. Based on the system [3] to provide sustainable energy from renewable sources in Denmark until 2050, a similar approach can be analysed in some regions in Nigeria. Given that climatic conditions are variable and biomass energy resources are not the same, a smart energy system will have to be designed based on sun, wind, and water energy in Nigeria. As additional energy to balance the

ratio of consumption/production will be biomass.

CONCLUSIONS

This paper offers a theoretical framework for implementing smart energy systems to create a cost-effective, sustainable, secure energy network. The advancement of sustainable energy is closely linked to technological progress and the integration of renewable sources. As fossil fuels become obsolete, designing smart systems that can reliably and cleanly generate power from renewable sources is crucial to ensure a sustainable energy future.

The selected location can address regional energy needs through innovative smart energy systems, harnessing solar, wind, and water power and balancing production with biomass when necessary. The initial concept involves gathering data on solar radiation and wind potential to design a system tailored to these resources, analysing biomass's role in meeting energy demands. This idea requires further analysis and design to create a functional prototype. Additionally, integrating various models can enhance data processing, enabling weather prediction algorithms. Future research should focus on processing stationary database data to predict future trends, facilitating system design based on generated data. Ultimately, smart energy systems offer a promising, clean, sustainable energy solution, ensuring a stable supply while reducing emissions and protecting the environment.

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