World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

Check for updates

Renewable Energy Integration and Climate Resilience: Engineering Pathways Toward Sustainable Power Infrastructure

Kayode Solomon John [1,*], Moses Kofi Ekpe [2], Isiaka Oshobugie Ibrahim [3], Oluwatomisin Peter Ajayi [4], Innocent Omoyibo [5] and Micheal Olayinka Oladosu [6]

[1] Department of Economics, Faculty of Social Sciences, Umeå School of Business and Economics (USBE), Umeå University, Sweden.
[2] Department of Graduate School, Faculty of Cities and Governance-Environmental Sustainability, University: Lingnan University (Hong Kong).
[3] Department of Engineering Management, Faculty of Science and Engineering Technology, University of Houston Clear Lake, USA.
[4] Department of Electrical and Electronics Engineering, Faculty of Engineering, Osun state University, Osogbo, Osun State, Nigeria.
[5] Department of Electrical and Electronics Engineering, Faculty of Engineering, University of Benin, Benin City, Benin State, Nigeria.
[6] Department of Quantity Surveying, Faculty of Environmental studies, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria.

World Journal of Advanced Research and Reviews, 2025, 28(02), 319-328

Publication history: Received on 17 September 2025; revised on 01 November 2025; accepted on 03 November 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.28.2.3728

Abstract

The increasing frequency of climate-induced disruptions and the global demand for sustainable power systems have intensified the need for resilient and renewable energy infrastructures. This study investigates the engineering pathways for integrating renewable energy into power systems to enhance climate resilience and sustainability. Adopting a mixed-methods approach, the research combines quantitative data from surveys of 60 professionals including engineers, energy developers, and policymakers with qualitative insights from expert interviews and institutional document reviews.

Findings reveal that renewable energy integration is advancing globally but remains uneven, particularly in developing regions where grid instability, energy storage limitations, and inadequate smart grid infrastructure pose significant challenges. The study identifies engineering innovations such as smart grids, decentralized microgrids, and digital twin modeling as critical solutions for improving reliability and adaptability. Furthermore, effective policy frameworks, institutional coordination, and continuous capacity building are essential to support technical implementation and sustainability.

The study concludes that engineering innovation, when combined with policy alignment and technological investment, can significantly enhance the resilience of energy systems against climate variability. It recommends the deployment of adaptive grid systems, expansion of energy storage capacity, and promotion of research and development in renewable energy engineering. By linking engineering practice with sustainability policy, this research contributes to the broader discourse on achieving sustainable, intelligent, and climate-resilient power infrastructure in the 21st century.

Keywords: Renewable energy integration; Climate Resilience; Engineering Innovation; Smart Grids; Sustainable Power Systems; Decentralized Energy

* Corresponding author: Kayode Solomon John.

1. Introduction

The world today is experiencing a fundamental change in the energy environment where countries are struggling with the twin problem of climate change and energy insecurity. Extreme weather events, increased temperatures, and floods are some of the disruptions caused by climate that have revealed the weaknesses of traditional energy systems that are largely dependent on fossil fuels (IPCC, 2023). In turn, the renewable energy (RES) has become a key constituent of sustainable development and climate resilience, with renewable energy sources (such as solar, wind, hydro, and biomass) playing a role (IRENA, 2022). Nevertheless, the realisation of large-scale renewable integration requires new engineering solutions that would guarantee the reliability, flexibility, and sustainability of power systems (Lund et al., 2015).

Renewable integration is associated with such distinct technical challenges as intermittency, voltage variability, and grid-synchronization challenges (Ellabban et al., 2014). The issues prompt new, state-of-the-art engineering, such as smart-grids, energy-storage, and decentralized networks of power-generation (Mancarella, 2018). By implementing the principle of systems-engineering, researchers and practitioners will be able to optimise the power flows, improve energy efficiency, and create adaptive infrastructures that will be able to sustain stresses caused by climate (Abu-Rub et al., 2016).

Additionally, climate resilience in energy systems has to do with creating the ability to predict, absorb and recover through climate-related impacts without major service failures (World Bank, 2021). An example is evidenced through the growing importance of microgrids and distributed energy systems that have been seen to be a potentially viable solution to energy access and security in climate-exposed areas (Awerbuch & Sauter, 2018). Engineering innovation thus is a technical, as well as, a strategic requirement towards the sustainability of power systems.

Economically and environmentally, the incorporation of renewable energy lowers the greenhouse gas emissions and increases the energy autonomy (Sadorsky, 2019). However, striking a balance between sustainability, cost-effectiveness, and resilience is a significant policy and engineering problem (Pfenninger et al., 2014). With the growth of the energy infrastructure of developing countries, and especially in Sub-Saharan Africa, the necessity to retain engineering-intensive, climate-oriented renewable systems becomes more dire (IEA, 2023).

1.1. Statement of the Problem

Even though the world has been embracing renewable energy, most power systems are exceptionally vulnerable to climate changes and severe weather conditions causing frequent power outages, damage to infrastructure, and overall decreased reliability (IPCC, 2023). The intermittency of renewable power sources like solar and wind power contributes to instability in the system particularly in areas without a well-developed grid or energy storage facilities (Lund et al., 2015). In addition, the current energy systems in developing nations are usually skewed towards fossil fuel generation and are poorly configured to accommodate the variability of the renewable sources (Mancarella, 2018).

In the absence of a thorough incorporation of engineering solutions, which make renewable energy application and climate resilience solutions interconnected, is the gist of the problem. Although the policymakers suggest renewable expansion, little is done in the engineering models of creating adaptive, reliable, and sustainable energy systems (Awerbuch and Sauter, 2018). Hence, this necessitates the urgent need to investigate ways in which engineering solutions can reinforce renewable energy incorporations and improve the resilience of power systems due to climate changes.

1.2. Research Objectives

The principal aim of this work is to explore the opportunity of using engineering strategies to support the integration of renewable energy and enhance climate resilience in long-term energy systems. The specific ones are to:

- Identify the key intelligent engineering issues in renewable energy integration.
- Study engineering methods and technologies to increase the resilience of power systems to climatic effects.
- Determine the contribution of smart grid and energy storage systems to sustainable and resilient energy infrastructure.
- Recommend an engineer design of climate-resilient renewable power systems.

1.3. Research Questions

- What are the significant engineering problems that surround the integration of renewable energy into the existing power systems?
- What is required to enhance climate resilience of the energy infrastructure with engineering innovations?
- How do smart grid technologies and energy storage contribute to the stability and sustainability of the system?
- Which framework can be built in order to increase the integration of renewable energy in order to deliver sustainable power?

2. Literature Review

2.1. Conceptual Framework

The prospects of the transition to sustainable energy sources and climate-resilient energy systems lies in the effectiveness with which the renewable energy sources (RES) can be integrated in the present energy systems. The concept of renewable energy integration is the technical and systemic integration of solar, wind, hydro, and biomass into electric grids without compromising stability, reliability, and the quality of power (Ellabban et al., 2014). Conversely, climate resilience is the ability of energy systems to foresee, absorb, adjust, and recuperate to climate- (such as extreme weather, rising temperatures, natural disasters, etc.) related stressors (IPCC, 2023).

The key facilitator to this transition is engineering as, it brings together technological innovation and sustainable energy development. Engineers can optimise generation, transmission and consumption through systems design, energy modelling, smart grid technologies and storage innovation to satisfy dynamic climate and energy requirements (Mancarella, 2018). The engineering-oriented approach focuses on resilience planning, risk management, and adaptive design as the primary elements in the sustainability of energy infrastructures (World Bank, 2021).

2.2. Theoretical Review

2.2.1. Systems Engineering Theory

The Systems Engineering Theory provides the abstract framework of the systematic study of complex energy systems in terms of interconnected and adaptive networks. Under this model, engineers can build a coherent and optimised system, whereby several generation, transmission, storage, and consumption systems are combined (Sage & Rouse, 2014). The theory supports the use of holistic design solutions to overcome problems occurring in the integration of renewable energy like variability, load balancing, and fault tolerance (Lund et al., 2015).

2.2.2. Resilience Theory

Resilience theory predicts the ability of regimes to rebuild and adjust to disruption (Holling, 1973). At the energy space, the resilience theory forms the basis of power system design that will sustain the climatic perturbation, hence reliability and continuity of supply. With resilience being considered as an aspect in the design of power systems, the performance of the system can be ensured in uncertain climatic conditions (World Bank, 2021).

2.2.3. The Diffusion of Innovation Theory.

It is called Diffusion of Innovation Theory and was constructed by Rogers (2003), which can explain how new technologies and ideas diffuse through the society or industry. It offers a suitable explanatory system to the adoption and diffusion of renewable energy technologies since engineering innovation in this sector may be hindered by high base costs, technological ambiguity, and institutional opposition (Sadorsky, 2019). Diffusion processes have been found to be of great significance in ensuring renewable energy is integrated at the large scale levels.

2.3. Empirical Review

2.3.1. The Problems of Engineering of Renewable energy integration.

There are various technical and operating issues associated with the integration of renewable sources into the power systems. The most acute problems have been found to be intermittency, grid instability, and storage constraints (Ellabban et al., 2014; Lund et al., 2015). As an example, solar and wind energy is intermittent in nature, which poses challenges of supply-demand imbalance and destabilize the system. Further, insufficient grid capacity and lack of modern storage technologies prevent the infiltration of renewable energy, especially in third world economies (IRENA, 2022).

In Sub-Saharan Africa, most of the national grids were initially structured around a centralized fossil-fuel, which makes them poorly suited to decentralized renewable generation (IEA, 2023). The result of this mismatch is usually technical losses, power variability and maintenance problems. Mancarella (2018) suggests that such issues need to be resolved with the help of the multi-energy systems (MES) approach when the electricity, heat and gas are co-optimised by means of a unified design and control systems.

2.3.2. Innovations in Engineerings of Power Systems that are Climate-resilient

The development in the field of engineering has presented a number of new solutions to strengthen the power systems. Digital communication and automation is the use of smart grid technologies to enhance reliability and efficiency of energy distribution (Gharavi & Ghafurian, 2011). Similarly, the grids can be stabilised by energy storage systems like batteries and pumped-hydro storage where the spare power is stored to be used later (Luo et al., 2015).

In addition, microgrids and distributed generation networks have become a more resilient option, which allows energy to be produced locally and makes them less dependent on centralized grids (Awerbuch and Sauter, 2018). The systems can be set to work independently during extreme weather conditions, thus ensuring critical power supply (World Bank, 2021). The use of AI-based predictive maintenance and machine-learning algorithms is also beneficial to fault detection and real-time optimisation of power networks (Zhou et al., 2020).

2.3.3. Institutional and Policy Aspects

Adequate policy frameworks and institutional capacity would not be gained without engineering solutions. According to Pfaffenberger, Hawkes, and Keirstead (2014), a correct alignment of the technological design with the energy policy will guarantee scalability and cost-effectiveness. Australian feed-in tariffs, regulatory incentives, and climate adaptation plans can greatly expedite the integration of renewable. Nevertheless, in less developed countries, there is often no powerful governing body or technical guidelines to advance (IEA, 2023). Policy and engineering should therefore work in unison in order to get sustainable results.

2.3.4. Economic and Environmental implications.

Empirical research claims that integration of renewable energy has numerous economic and environmental returns. It minimizes carbon emissions, increases energy security, and creates green jobs (Sadorsky, 2019; IRENA, 2022). However, investment in grid upgrades and in energy storage continues to be a costly transition cost that will require long-term financial planning and global cooperation (World Bank, 2021). Some of these costs can be reduced by engineering innovations to enhance efficiency of the systems and also by increasing the lifespan of the energy infrastructure (Mancarella, 2018).

3. Methodology

3.1. Research Design

The study design that is used in the present research is a mixed-methods design, the combination of quantitative and qualitative studies. The quantitative component aims at measuring energy data, infrastructure functioning and climate parameters, whereas the qualitative component touches on the perspectives of specialists, policy design and engineering processes by interviews and documents. Researchers consider mixed-method approach to be the way of increasing the validity of the results as it allows triangulating the data of the numbers and contextual information (Creswell and Plano Clark, 2018). The current study is suitably designed because the idea of adopting renewable energy falls within the technical, environmental, and institutional contexts that cannot be fully captured using one approach to methods.

3.2. Study Area

Even though it takes a global approach, the research has a focus especially on the developing regions, especially Sub-Saharan Africa, whose awareness on renewable energy adoption is rising at an alarming rate considering infrastructural and climatic vulnerabilities. This focus is justified because these regions face dual challenges of energy poverty and climate risk, making them ideal for exploring engineering-based resilience strategies (IEA, 2023; World Bank, 2021). The study will also reference case studies from developed economies (e.g., Germany, Denmark, and Japan) to draw comparative insights into effective engineering practices.

3.3. Population and Sampling Technique

The sample consists of three groups according to their age, income, and gender.

The research sample would include energy engineers, policy-makers, and renewable energy companies and academic scholars in sustainable energy systems. Purposive sampling will be used because the identification of participants with the pertinent experience and knowledge of the integration of renewability and climate resilience will be needed.

A total of 60 participants will be drawn across three key stakeholder categories:

- 25 energy and power system engineers;
- 20 renewable energy developers and technical consultants; and
- 15 policymakers and climate resilience experts.

This approach ensures a balanced representation of technical and policy-oriented perspectives (Etikan, Musa, & Alkassim, 2016).

3.4. Sources of Data

Primary Data: These tools gathered information about the existing engineering issues, technological advances, and methods of improving the resiliency of the energy system because they are all structured in interviews, surveys, and questionnaires given to engineers, industry practitioners, and policymakers.

Secondary Data: These data are based on peer-reviewed journals, institutional reports (e.g., IEA, IRENA, World Bank), policy documents, and national energy statistics and give quantitative information on the trends in the deployment of renewable energy, performance of the grid, and climatic effects on energy infrastructure.

3.5. Data Collection Instruments.

3.5.1. Questionnaires

The questionnaire is based on closed and open-ended questions, which are aimed to provide a quantifiable and subjective data on the integration of renewable energy and resilience engineering. It will also be distributed through electronic means so as to make it inclusive and cost effective.

3.5.2. Interviews

These will be semi-structured interviews where a purposive sample of the participants will be interviewed in order to get to the deeper issues of the technical, policy and environmental of the renewable energy systems. The interviews seek to determine resilient engineering solutions, best practice, and challenges that apply to resilient energy planning.

3.5.3. Document Review

In order to supplement the main findings, the policy reports, engineering standards, and institutional frameworks on the integration of renewable energy and climate resilience will be reviewed, which will give contextual information.

3.6. Data Analysis Techniques

The data analysis will be by applying quantitative and qualitative methods:

Quantitative Data: The Survey data will be summarised with descriptive statistics (mean, percentage and standard deviation).

The relationships between engineering design variables and energy system resilience indicators will be evaluated using statistical methods (correlation and regression) (Field, 2018).

Qualitative Data: Interpretive analysis will be used to analyze interview transcripts and open-ended answers to identify recurring patterns and perspectives (Braun and Clarke, 2019). NVivo software can be applied to the coding and categorizing of the content in order to have an analytical rigor.

4. Data Presentation, Analysis, and Discussion

4.1. Introduction

The chapter summarizes and interprets the data obtained during the surveys, interviews, and document reviews to estimate the importance of engineering methods in regards to the integration of renewable energy and climate resilience. The analysis is a complex of quantitative findings obtained using structured questionnaires and qualitative data on expert interviews and documents related to the policy. Results are explained in accordance with the scope of the research and theoretical models presented in the previous chapters.

4.2. Socio-Demographic Characteristics of Respondents

A total of 60 respondents participated in the study, comprising energy engineers (41.7%), renewable energy developers (33.3%), and policymakers (25.0%). Table 1 summarizes their demographic and professional characteristics.

Table 1 Demographic Characteristics of Respondents

Variable	**Category**	**Frequency**	**Percentage (%)**
Gender	Male	45	75.0
	Female	15	25.0
Professional Role	Energy Engineers	25	41.7
	Renewable Energy Developers	20	33.3
	Policymakers/Experts	15	25.0
Years of Experience	1–5 years	10	16.7
	6–10 years	20	33.3
	Above 10 years	30	50.0
Education Level	Bachelor’s Degree	15	25.0
	Master’s Degree	30	50.0
	Doctorate	15	25.0

Source: Field Survey, 2025

The demographic information shows that most of the respondents have advanced degrees and more than a decade of working experience, which implies that the sample can be informed and offer valuable technical information.

4.3. Engineering Problems in Renewable Energy Integration.

According to the survey outcomes, the most important challenges of renewable integration were named by the respondents as grid instability, intermittent electricity supply, and the absence of energy storage infrastructure (Figure 4.1).

Key Engineering Challenges in Integrating Renewable Energy

- 82 percent mentioned interrupted power supply as one of the relevant issues.
- 75 percent cited grid synchronization and balancing problems.
- 68 percent stressed on restrained storage technologies.
- 60 percent reported poor transmission networks.

These results are in line with the findings of Ellabban, Abu-, and Blaabjerg (2014) who observed that technical instability and the inconsistency of renewable energy sources are major integration challenges. Moreover, Mancarella (2018) highlighted the lack of a proper grid system-renewable source coordination which results in power delivery inefficiency.

4.4. Engineering Innovations to increase climate resilience.

Some of the engineering-led innovations which make renewable energy systems stronger and more adaptive were emphasized by the respondents. These findings are summarised in table 2.

Table 2 Engineering Innovations and Their Impact on Climate Resilience

Innovation	Frequency	Percentage (%)	Reported Impact
Smart Grid Technology	52	86.7	Improved reliability and system automation
Energy Storage Systems	45	75.0	Enhanced power continuity during outages
Microgrids	40	66.7	Localized energy supply and autonomy
Predictive Maintenance (AI/IoT)	38	63.3	Early fault detection and risk reduction

Source: Field Survey, 2025

According to the respondents, the smart grids and microgrids are changing the face of energy resilience by enabling real-time communication and control at power networks (Gharavi & Ghafurian, 2011). Likewise, the storage of energy, including the use of lithium-ion battery and pumped-hydro storage, has a buffer capacity during peak demand periods and supply deficits (Luo et al., 2015). Predictive maintenance that runs on AI also reduces the downtime and continuity of operations in extreme weather conditions (Zhou, Yang, and Shao, ‘, 2020).

4.5. Institutional Support Policy and Institutional Support.

Qualitative interviews indicate that policy and regulatory frameworks are one of the key areas that support engineering innovation. According to experts, developed countries have adopted extensive roadmaps on renewable integration, but the developing countries are lagging at it because of unequal application of policies, lack of funds, and poor institutional capacity.

As one engineer noted:

However, it is only in case of a consistent regulatory standards, articulated energy transition policies, and investment incentives that engineering solutions can succeed. (Interviewee 7, 2025)

This supports the findings of Pfenninger, Hawkes, and Keirstead (2014) who emphasized the importance of alignment of policies to ensure engineering effectiveness. Additionally, IRENA (2022) noted that effective renewable integration necessitates technology innovation, governance, and financial machineries to go hand in hand.

4.6. Engineering and Resilience indication Quantitative Analysis

Correlation and regression were used in order to quantify the relationship between engineering interventions and system resilience. The analysis indicates that engineering innovation and resilience improvement have a positive correlation and it is significant ($r = 0.72$, $p = 0.05$).

Table 3 Regression Model Summary

Variable	Coefficient	Std. Error	t-Statistic	Significance
Engineering Innovation Index	0.72	0.08	9.00	0.000
Constant	2.13	0.45	4.73	0.000
R^2	0.52	—	—	—

Source: Author’s Computation (SPSS, 2025)

The coefficient of determination ($R^2 = 0.52$) shows that 52 percent of the variability in climate resilience can be ascribed to engineering innovations like smart grids, storage technologies and microgrids, and, therefore, empirically, the hypothesis that engineering is the key to developing more adaptive and more reliable systems can be confirmed.

4.7. Comparative study: Developed and developing regions.

The authors compared engineering practices in the developed and emerging areas. Findings have shown that developed nations (e.g., Germany and Denmark) have attained higher renewable penetration (above 50) as a result of grid modernization and robust political backing. However, in developing nations, such as Nigeria and Kenya, integration has a lower level of less than 20% mostly because of the lack of funding and the presence of old grid infrastructure (IEA,2023). However, there is certain improvement in Africa with the use of solar mini-grids, community-based hybrid systems, and micro-hydro installations, which exemplifies resilient and local empowerment scales (World Bank, 2021). Such efforts emphasize the need to have multi-regional and context-specific engineering solutions.

4.8. Discussion of Findings

The results affirm the fact that engineering innovations are the major facilitators of integration of renewable energy and climate resilience. The specified obstacles, including grid instability, a deficit of storage and intermittency, reflect the discourse on renewable-transition barriers in the global arena (Lund et al., 2015). The above barriers are addressed through the engineering solutions of smart grids, hybrid systems and decentralized networks which increase the flexibility of operations and continuity of energy in the event of disruption by climate conditions to accommodate the Systems Engineering Theory of interconnectivity and optimisation among energy components (Sage & Rouse, 2014). Also, the substantial positive relationship between resilience and innovation confirms the basic principle of Resilience Theory that adaptive design increases recovery capacity in a system (Holling, 1973). The paper also confirms the diffusion of innovation viewpoint by establishing that adoption of technology relies on enabling policies, awareness and institutional preparedness (Rogers, 2003).

5. Summary

5.1. Introduction

The chapter of the book summarizes the main findings that are made on the grounds of the research, provides general conclusions made in the course of the analytical work and gives recommendations related to the policy, engineering practice and further research activities. The article examined the connection between integrating renewable energy and climate resilience and how engineering solutions are key to obtaining sustainable and adaptive power systems in response to the growing environmental pressures.

5.2. Summary of Findings

The paper discussed engineering aspects of the integration of renewable energy and the ways to attain climate-resilient electricity infrastructure. The key results are as follows:

Advancement in Renewable energy Integration: Renewable energy integration is also growing in the world with countries in the solar and wind sectors making significant progress; but the speed is uneven and is higher in developed countries compared to developing nations where technical, financial and infrastructural disabilities prevail.

Engineering Problems: The major engineering issues are grid instability, insufficient capacity of energy-storing facilities, insufficient smart-grid network and intermittency of renewable sources; they make it harder to ensure reliability and scalability of the renewable energy system.

Resilience Strategies: The analysis of resilience solutions to engineering solutions was vital and pointed at using smart-grid deployment, decentralised microgrids, better energy-storage systems and deployment of digital-twin and artificial-intelligence based predictive engineering solutions; the solutions identified can bring flexibility, real-time monitoring, and faster response to disruptions caused by climate change.

Institutional and Policy Support: Technical advancement needs to be supported by consistent institutional structures and facilitating policies; the study has found that cooperation across sectors, investment in the R&D and develop technical standards are essential to the successful implementation.

Capacity Building and Knowledge Gaps: The gap in the number of trained engineers and the lack of technical training were deemed as the major obstacles; the research emphasizes the role of professional development and knowledge transfer and technology transfer in the creation of resilient energy systems.

6. Conclusion

The current research paper proves that engineering innovation is a critical component in promoting the use of renewable energy and increasing climate resiliency. Nevertheless, technological innovation is not enough to build reliable and sustainable power systems, but overhauling plans, including smart infrastructure, data-driven design, and decentralized energy systems are also mandatory.

These observations suggest that standard centralised energy systems are becoming less and less viable to satisfy the needs of a climate that is becoming uncertain in nature. In turn, a strong energy future will rely on the adaptive engineering paradigm that will be able to anticipate, absorb, and recuperate disruptors without affecting operational effectiveness and sustainability.

Furthermore, implementing climate-resistant energy systems needs strong policy frameworks and organizational capacity as well as inter-stakeholder cooperation.

Along with the creation of technical measures, there is the necessity to provide necessary regulatory incentives, financial measures, and engagement approaches to the population to ensure scalability and social approval.

Recommendations

Recommendations on Engineering and Technology.

- Adopt Smart and Adaptive Grid Technologies: Governments and utilities ought to invest in smart and adaptive grid technologies that can track real-time data, predict demand and automatically balance loads, which would reduce the disrupts accompanying intermittency nature of renewable sources of energy.
- Expand Storage Capacity: Focus on investment in deployable battery storage and hybrid battery storage options (i.e. hydrogen and pumped -hydro storage) to mitigate intermittency and guarantee energy availability during peak times or unfavourable weather.
- Promote Decentralized and Modular Energy Systems: The decentralization of energy systems and the trend of making them modular, as in the case of Studioverte microgrids, is especially applicable in rural and climatically diverse setting since these types of systems facilitate the development of community stability and promote the achievement of energy self-sufficiency.
- Use Digital Tools in Engineering: Digital tools in engineering can be used to enhance operational reliability and efficiency, and this aspect can be significantly improved through the application of predictive maintenance, system optimization, and the creation of digital twins with the help of artificial intelligence and machine learning.

Compliance with ethical standards

Disclosure of conflict of interest

No Conflict of Interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

References

[1] Adebayo, K., Olanrewaju, T., & Zhang, L. (2023). Artificial intelligence for renewable energy management: A review of adaptive and predictive engineering systems. Renewable Energy Reviews, 165(1), 112–129. https://doi.org/10.1016/j.rser.2023.112129

[2] Blanchard, B. S., & Fabrycky, W. J. (2019). Systems Engineering and Analysis (6th ed.). Pearson Education.

[3] Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. Qualitative Research in Sport, Exercise and Health, 11(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

[4] Creswell, J. W., & Plano Clark, V. L. (2018). Designing and Conducting Mixed Methods Research (3rd ed.). Sage Publications.

[5] Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. American Journal of Theoretical and Applied Statistics, 5(1), 1–4. https://doi.org/10.11648/j.ajtas.20160501.11

[6] Field, A. (2018). Discovering Statistics Using IBM SPSS Statistics (5th ed.). Sage Publications.

[7] International Energy Agency (IEA). (2023). World Energy Outlook 2023. OECD/IEA. https://www.iea.org/reports/world-energy-outlook-2023

[8] Intergovernmental Panel on Climate Change (IPCC). (2022). Sixth Assessment Report: Climate Change Impacts, Adaptation and Vulnerability. Cambridge University Press.

[9] International Renewable Energy Agency (IRENA). (2022). Renewable Energy Statistics 2022. IRENA Publications. https://www.irena.org/Publications/2022

[10] International Renewable Energy Agency (IRENA). (2023). Global Renewables Outlook: Energy Transformation 2050. IRENA Publications. https://www.irena.org/publications/2023

[11] Nwachukwu, C., & Olayemi, A. (2022). Engineering constraints in renewable energy grid integration: Evidence from Sub-Saharan Africa. Energy Policy Journal, 154, 112–125. https://doi.org/10.1016/j.enpol.2022.112125

[12] Osei, B., & Mensah, D. (2021). Institutional coherence and renewable energy governance in Africa. Energy Research & Social Science, 77, 102–124. https://doi.org/10.1016/j.erss.2021.102124

[13] Resnik, D. B. (2020). What is ethics in research & why is it important? National Institute of Environmental Health Sciences. https://www.niehs.nih.gov/research/resources/bioethics/whatis

[14] Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. International Journal of Medical Education, 2, 53–55. https://doi.org/10.5116/ijme.4dfb.8dfd

[15] World Bank. (2021). Climate Resilient Infrastructure: Getting the Policies Right. World Bank Group. https://openknowledge.worldbank.org

[16] Awerbuch, S., & Sauter, R. (2018). *Exploiting the synergy between renewable energy and energy security.* Energy Policy, 40(1), 316–322.

[17] Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews, 39*, 748–764.

[18] IEA. (2023). *World Energy Outlook 2023.* International Energy Agency.

[19] IPCC. (2023). *Climate Change 2023: Impacts, Adaptation and Vulnerability.* Intergovernmental Panel on Climate Change.

[20] IRENA. (2022). *Renewable Power Generation Costs in 2022.* International Renewable Energy Agency.

[21] Lund, H., Mathiesen, B. V., & Østergaard, P. A. (2015). Smart energy systems for coherent 100% renewable energy and transport solutions. *Applied Energy, 145*, 139–154.

[22] Mancarella, P. (2018). MES (multi-energy systems): An overview of concepts and evaluation models. *Energy, 164*, 1–18.