Enhancing Energy Access in Africa Through Artificial Intelligence: Opportunities and Challenges

Ebikella Mienye, George Obaido, Priye Kenneth Ainah, Ikiomoye Douglas Emmanuel and Ibomoiye Domor Mienye

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Ebikella Mienye
Institute for Intelligent Systems
University of Johannesburg
Johannesburg 2006, South Africa
219105099@student.uj.ac.za

George Obaido
Center for Human-Compatible Artificial Intelligence (CHAI),
Berkeley Institute for Data Science (BIDS),
University of California, Berkeley,
California, 94720, USA
gobaido@berkeley.edu

Priye Kenneth Ainah
Dept. of Elect. & Elect. Engineering
Niger Delta University
Wilberforce Island, Nigeria
ainahpriye@ndu.edu.ng

Ikiomoye Douglas Emmanuel
School of Science, Engineering and Environment
University of Salford
Salford, United Kingdom
i.d.emmanuel@edu.salford.ac.uk

Ibomoiye Domor Mienye
Institute for Intelligent Systems
University of Johannesburg
Johannesburg 2006, South Africa
ibomoiyem@uj.ac.za

***Abstract*—Africa faces significant challenges in achieving universal energy access, a fundamental prerequisite for sustainable development. This paper explores the potential of artificial intelligence (AI) in bridging this gap by enhancing grid management, optimizing off-grid solutions, and improving energy efficiency across the continent. While AI offers significant potential, its implementation is hindered by several challenges, including infrastructural limitations, economic constraints, policy inconsistencies, and societal acceptance issues. This paper examines these challenges and proposes strategic solutions to overcome them. The paper also discusses the prospects of integrating AI into Africa's energy sector.**

***Index Terms*—Africa, artificial intelligence, electricity, energy, machine learning, SDG7, sustainable development**

I. Introduction

Energy is a critical driver of development, and its equitable access is central to achieving Sustainable Development Goal 7 (SDG7), which aims to ensure access to affordable, reliable, sustainable, and modern energy for all [1]. In Africa, the realization of SDG7 is met with significant challenges. Despite the continent's rich energy resources, including vast solar, wind, and hydro potentials, a substantial portion of the African population lacks access to electricity [2], [3]. According to the International Energy Agency (IEA), over 600 million people in Sub-Saharan Africa are living without access to electricity, which is about 48% of the region's population [4], [5].

This energy deficit is more acute in specific countries. For instance, in South Sudan, only about 7% of the population has access to electricity, one of the lowest rates globally [6]. Similarly, countries like Chad, Burundi, and Malawi face severe electricity access challenges, with less than 12% of their populations having access to power [7]. In larger economies like Nigeria, despite being Africa's largest oil producer, a significant portion of the population (about 43%) still lives without regular electricity [8].

The disparity in energy access between urban and rural areas further compounds these challenges. Rural areas, predominantly reliant on traditional biomass and off-grid solutions, are significantly underserved compared to urban areas, where access to electricity is considerably higher [9]. This urban-rural divide not only hinders equitable development but also contributes to other socio-economic issues. The lack of energy access impacts various aspects of life and development, including healthcare, education, and economic opportunities.

AI has become evident as a vital technology with the potential to address complex global challenges, including those in the energy sector. In Africa, AI presents a unique opportunity to improve traditional energy infrastructure development. AI can optimize renewable energy production, predict energy demand more accurately, and efficiently manage distributed energy resources. These capabilities are crucial for enhancing energy access, particularly in remote and off-grid areas. AI's role extends beyond mere technological advancement; it can also aid in better policy-making, demand forecasting, and consumer engagement, aligning energy production with usage patterns.

Therefore, this paper explores the multifaceted role of AI in bridging the energy access gap in Africa. We aim to provide an in-depth analysis of the current state of energy access in Africa, identify the challenges, and examine how AI can offer viable solutions. The paper will also review existing AI applications in energy systems, assess their impact, and discuss the challenges and opportunities associated with implementing AI-driven solutions.

The rest of the paper is structured as follows: Section II reviews related works. Section III provides background on the study, including an overview of AI and the state of energy access in Africa. Section IV highlights the challenges in achieving universal energy access in Africa. Section V discusses the application of AI in enhancing energy access.

Section VI presents the challenges hindering the introduction of AI solutions, and Section VII proposes strategies for overcoming these challenges. Section VIII concludes the study and provides future research directions.

II. Related Works

The integration of AI in energy systems has received extensive attention globally, establishing a robust foundation for understanding its technical capabilities and limitations. Research works by Hafeez et al. [10] and Pallonetto et al. [11] have explored machine learning algorithms for predicting energy demand and optimizing grid operations primarily in developed contexts. Similarly, Varganova et al. [12] have documented optimization techniques for grid operations that enhance the efficiency and reliability of energy distribution.

Meanwhile, the application of AI in rural and remote areas presents unique challenges and opportunities. Research by Chawla et al. [13] on managing renewable energy sources in rural India using AI provides valuable insights applicable to similar environments in Africa, suggesting scalable models that can be adapted to African off-grid systems. Additionally, Shafiullah et al. [14] highlight practical issues and scalability challenges in integrating AI into energy systems in Southeast Asia, drawing parallels that are crucial to the African energy access context.

Despite the wealth of global research, literature specific to Africa often focuses more on broad energy challenges rather than the complex application of AI. Studies like those by Tomala et al. [5] outline the infrastructural and economic barriers prevalent in sub-Saharan Africa but offer limited discussion on AI-driven solutions, indicating a significant gap in targeted research. Furthermore, Avila et al. [15] reviewed the energy challenge in sub-Saharan Africa and presented a guide for energy stakeholders, governments, and policymakers.

This paper builds upon and extends the existing body of knowledge by providing a comprehensive analysis specifically tailored to the unique challenges of energy access in Africa. It combines technical solutions with socio-economic and policy-related considerations, offering a holistic approach to leveraging AI to enhance Africa's energy sector. The research contributes to filling the identified gaps, particularly in understanding and implementing AI solutions that are culturally sensitive and technologically feasible across diverse African settings.

III. Background

A. Artificial Intelligence

Artificial Intelligence is a broad field of computer science focused on creating systems capable of performing tasks that typically require human intelligence [16], [17]. These tasks include problem-solving, decision-making, recognizing speech, and translating languages, among others. Unlike traditional programming, where tasks are explicitly defined, AI systems are designed to learn and make decisions based on data.

The foundation of AI is algorithms, which can be as simple as a set of instructions or as complex as neural networks mimicking the human brain. Machine learning (ML) is a subset of AI focused on building systems that learn from data. Instead of being explicitly programmed to perform a task, ML models adjust their parameters to optimize performance based on input data. A simple mathematical representation of an ML model can be expressed as:

$$y = f(x; \theta) \tag{1}$$

where y is the output, x is the input, θ represents the parameters of the model, and f denotes the function that the model uses to map inputs to outputs. Meanwhile, deep learning (DL), a subset of ML, involves models known as artificial neural networks with many layers of processing units, allowing them to learn complex patterns in large amounts of data [18]. AI, ML, and DL have a hierarchical relationship. AI is the broadest concept aimed at creating intelligent machines. ML is a way of achieving AI through systems that learn from data. DL is a specific ML approach that uses complex neural networks. The relationships among AI, ML, and DL can be visualized in Figure 1.

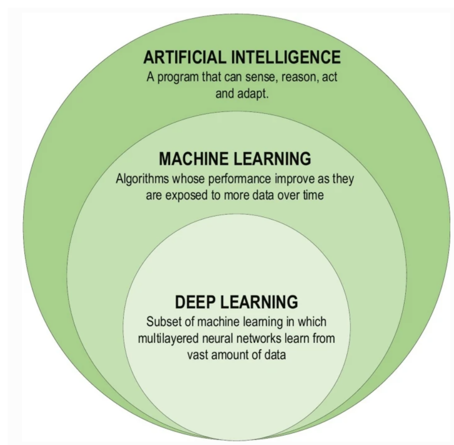

Fig. 1. AI, ML, and DL. [16]

B. Energy Access in Africa

The state of energy access in Africa is highly varied, reflecting the continent's diverse geographical, economic, and social landscapes. In North Africa, countries like Egypt and Tunisia have achieved almost universal access to electricity [19]. This success is attributed to sustained investment in energy infrastructure and a stable policy environment that supports energy development. In contrast, Sub-Saharan Africa faces more acute challenges. The region has the world's lowest rates of energy access, with disparities evident across countries and between urban and rural areas [5]. In East Africa, countries like Kenya and Ethiopia have made significant strides in improving access through renewable energy projects, yet challenges remain in reaching remote areas [20]. Central African countries, including the Democratic Republic of Congo and Cameroon, despite their significant hydroelectric potential, still struggle with low electrification rates due to political instability and infrastructural challenges.

Southern Africa presents a mixed picture, with South Africa having relatively high electricity access rates while neighbouring countries like Mozambique and Zimbabwe struggle with frequent power outages and limited rural electrification [21]. In West Africa, Ghana stands out for its progress in expanding electricity access, but regions in countries like Niger and Sierra Leone remain largely underserved [21].

IV. Key Barriers to Achieving Universal Energy Access

A. Financial Constraints

One of the primary barriers to achieving universal energy access in Africa is financial constraints. The high costs associated with extending the electrical grid and investing in new energy technologies make it difficult to expand energy access across the continent [22]. These costs are not limited to the initial capital outlay for infrastructure development but also include ongoing expenses related to maintenance and operation. The situation is further complicated by the limited financial resources available at both the governmental and individual levels. Many African countries face economic challenges that restrict their ability to allocate sufficient funds to energy projects. At the individual level, the high cost of connecting to the grid or purchasing off-grid solutions puts these options out of reach for many households, particularly in rural and impoverished areas. Addressing these financial constraints requires innovative financing solutions, including public-private partnerships, international funding, and targeted subsidies to make energy access more affordable.

B. Political and Regulatory Challenges

The energy sector in Africa is also affected by political and regulatory challenges. Inconsistent policies and regulatory hurdles create an uncertain investment climate, deterring both domestic and international investors [23]. Political instability in some countries further worsens the issue, leading to delays or the abandonment of energy projects. For electrification efforts to be successful, it is essential to establish a stable political environment and clear, consistent regulatory frameworks that support the development and expansion of energy infrastructure. This includes policies that encourage investment in renewable energy sources, streamline the approval processes for new projects, and provide incentives for both providers and consumers of clean energy.

C. Geographical and Demographic Challenges

Africa's vast and varied geography poses significant logistical challenges in extending energy services, especially to remote and rural areas [24]. The continent's terrain, ranging from dense forests to arid deserts, complicates the construction and maintenance of energy infrastructure. Additionally, rapid urbanization in African cities strains existing energy infrastructures, leading to frequent power outages and unreliable service. Demographic challenges, such as population growth and migration patterns, further increase the demand for energy in both urban and rural settings. Addressing these geographical and demographic challenges requires a flexible approach to energy provision, including the deployment of off-grid and mini-grid solutions that can adapt to the diverse needs and conditions across the continent.

D. Reliance on Traditional Biomass

A significant portion of the rural population in Africa relies on traditional biomass for cooking and heating. This reliance not only contributes to environmental degradation due to deforestation but also poses serious health risks due to indoor air pollution. Traditional biomass is also an inefficient source of energy, requiring more resources to produce the same amount of energy as modern alternatives [25]. Transitioning away from traditional biomass requires the promotion of cleaner, more efficient energy sources such as liquefied petroleum gas (LPG), solar cookstoves, and biogas systems. This transition should be supported by awareness campaigns, subsidies, and infrastructure development to make clean energy accessible and affordable.

E. Technological Limitations

Finally, technological limitations hinder the transition to sustainable energy systems in many regions of Africa [26]. The lack of access to modern and efficient energy technologies, coupled with a shortage of skills and knowledge to operate and maintain these technologies, limits the potential for sustainable energy solutions. Bridging the technological gap requires investments in research and development, capacity building, and the transfer of technology from developed to developing countries. It is also essential to foster a culture of innovation within Africa, encouraging the development of local solutions to local energy challenges.

V. AI Applications in Enhancing Energy Access

AI has the potential to significantly impact the energy sector, especially in enhancing energy access across Africa. Figure 2 shows possible applications of AI in the global energy sector. By leveraging AI, African countries can optimize their existing energy infrastructure, integrate renewable energy sources more efficiently, and ensure energy is used in the most effective manner. This section explores several key areas where AI applications can be used to enhance energy access.

A. AI in Grid Management

AI technologies offer robust solutions for grid management, including demand forecasting, real-time energy distribution optimization, and fault detection [28]. ML algorithms can analyze patterns of energy use, predict peak times, and help in balancing the load to prevent outages [29]. For example, predictive models can forecast energy demand with high accuracy, allowing utilities to adjust their operations accordingly. This reduces waste, improves reliability, and ensures a steady energy supply, even in remote areas. In Africa, where grid infrastructure can be unstable, these technologies are particularly valuable.

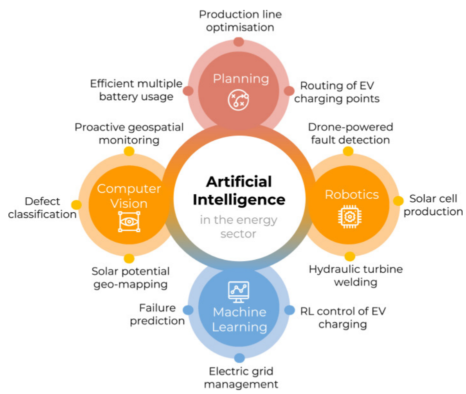

Fig. 2. AI applications in the Energy Sector [27]

B. AI in Off-Grid Solutions

AI can significantly enhance the management of off-grid energy systems in Africa's remote and rural areas, where traditional grid expansion is often unfeasible. By utilizing predictive algorithms, AI can forecast solar and wind energy production, optimizing the output of renewable sources. Additionally, AI can efficiently manage battery storage systems, extending their lifespan and reliability by optimizing charge and discharge cycles based on predicted energy generation and usage patterns.

Furthermore, AI can be used to balance supply and demand within off-grid systems. It achieves this by analyzing consumption patterns to predict future energy needs, thus enabling precise adjustments in energy distribution. This not only ensures that essential services have reliable energy access but also maximizes overall system efficiency, reducing waste and supporting sustainable development. Such applications of AI not only bridge the energy access gap but also facilitate broader economic and social advancements in underserved communities.

C. AI in Energy Efficiency

AI's role in enhancing energy efficiency is vital, particularly in African regions where energy resources are often scarce. Predictive analytics enabled by AI can optimize energy usage in buildings and industrial processes by adapting to usage patterns and environmental conditions in real-time. For instance, AI-integrated systems in smart buildings can autonomously manage heating, cooling, and lighting based on occupancy and ambient conditions, thereby reducing unnecessary energy consumption. The United Nations Environment Programme (UNEP) has noted that such technologies have the potential to reduce building energy consumption by up to 30% [30], demonstrating a significant impact on energy conservation and operational efficiency.

D. AI in Predictive Maintenance

Predictive maintenance facilitated by AI can transform the maintenance of energy infrastructures, significantly enhancing operational reliability. AI algorithms can predict failures before they occur by identifying unusual patterns and predicting potential breakdowns. This allows for timely maintenance actions and avoids the higher costs associated with unscheduled downtimes and extensive repairs. Studies have shown that such AI-driven maintenance strategies can extend equipment lifespan and reduce overall maintenance costs, thereby ensuring a more reliable energy supply and supporting continuous access to energy in unstable regions [31].

The integration of AI into the energy sector presents a promising avenue for addressing the challenges of energy access in Africa. By optimizing grid operations, enhancing off-grid solutions, improving energy efficiency, and employing predictive maintenance, AI can contribute significantly to making sustainable, reliable, and affordable energy a reality for all. The continued development and deployment of AI technologies, coupled with supportive policies and investments, are critical for harnessing these benefits and achieving universal energy access in Africa.

VI. Challenges in Implementing AI Solutions

The deployment of AI solutions in the energy sector, particularly in regions with limited infrastructure like Africa, faces several significant challenges. These include technical and infrastructural hurdles, economic and policy-related challenges, and societal implications and acceptance. Each of these areas requires careful consideration and strategic planning to successfully implement AI technologies. They are described as follows:

A. Technical and Infrastructural Hurdles

One of the primary challenges in implementing AI solutions in Africa's energy sector is the lack of necessary technical infrastructure [32], [33]. Many areas, especially rural and remote regions, lack the connectivity and data infrastructure required for AI technologies. Additionally, the absence of standardized data collection and processing frameworks makes it difficult to leverage AI fully. There is also a significant skills gap, with a shortage of local expertise in AI and data science, which hinders the development and maintenance of AI systems.

B. Economic and Policy-Related Challenges

Economic constraints play a crucial role in the limited adoption of AI solutions in Africa. High initial investment costs for AI infrastructure and ongoing expenses for operation and maintenance are significant barriers for many African countries [33]. Furthermore, the absence of clear regulatory frameworks and policies supporting AI integration into the energy sector can deter investment and innovation. Policy ambiguity and bureaucratic hurdles often slow down the implementation of AI projects.

C. Societal Implications and Acceptance

Societal acceptance of AI technologies is another critical challenge in Africa [34]. Misunderstandings and mistrust regarding AI can lead to resistance among the population. Concerns about job displacement and privacy, along with cultural attitudes towards technology, can hinder the adoption of

AI solutions. Ensuring that AI implementations are inclusive, ethical, and transparent is vital for gaining public trust and acceptance [35], [36].

VII. Strategies for Overcoming Challenges

Addressing the challenges associated with deploying AI solutions in Africa's energy sector demands a comprehensive strategy that encompasses technical, economic, policy-related, and societal dimensions.

A. Building Technical Capacity and Infrastructure

Developing the necessary technical infrastructure is crucial for the successful application of AI technologies. This strategy involves enhancing connectivity and data processing capabilities across the region. Additionally, substantial investments in education and training programs are required to cultivate local expertise in AI and data science [32]. Establishing partnerships with international tech companies and academic institutions can expedite this development, fostering a robust technological ecosystem conducive to advanced AI research and applications.

B. Economic Incentives and Policy Reform

To stimulate investments in AI technologies, creating economic incentives is essential. These incentives might include tax breaks, grants, and subsidies specifically targeted at AI projects [33]. Simultaneously, it is crucial for governments to develop clear, supportive policies and regulatory frameworks that promote AI investments and innovation. Simplifying the approval process for new technologies and ensuring that policies evolve in tandem with technological advances will create a nurturing environment for AI integration.

C. Fostering Societal Acceptance

Engaging with communities and stakeholders from the initial stages is vital to addressing societal concerns regarding AI. Educational campaigns can effectively communicate the benefits of AI for enhancing energy access and promoting sustainability, thereby helping to alleviate apprehensions and build community support. Moreover, involving local communities in the development and implementation of AI solutions ensures that these technologies are tailored to meet local needs and are sensitive to cultural contexts, which can greatly improve their acceptance and adoption [36].

D. Leveraging International Cooperation

International cooperation is crucial in addressing the myriad challenges of implementing AI in Africa's energy sector. Collaborative efforts with global organizations, foreign governments, and non-governmental organizations can provide essential financial, technical, and educational support. Sharing knowledge, best practices and technologies across international borders can significantly expedite the adoption of AI solutions and play a decisive role in achieving universal energy access.

These strategies outline a pathway towards mitigating the challenges facing AI deployment in Africa's energy sector, highlighting the need for an integrated approach that combines local initiatives with global partnerships.

VIII. Conclusion and Future Directions

The integration of AI technologies offers huge potential for bridging the energy access gap in Africa. In this paper, we explored the various applications of AI in enhancing grid management, off-grid solutions, and energy efficiency. The paper also addressed the significant challenges—ranging from technical and infrastructural hurdles to economic, policy-related, and societal issues—impeding the widespread adoption of AI in the energy sector. Additionally, strategies to overcome these obstacles have been proposed, emphasizing the need for capacity building, policy reform, economic incentives, and fostering societal acceptance.

Future research should focus on developing innovative AI applications that are adaptable to Africa's unique challenges. There is a particular need for studies that evaluate the impact of AI on energy access in remote and underserved areas, offering insights into scalability and sustainability. Additionally, exploring the intersection of AI with renewable energy sources could provide pathways to enhancing energy access and promoting environmental sustainability.

References

[1] M. Jayachandran, R. K. Gatla, K. P. Rao, G. S. Rao, S. Mohammed, A. H. Milyani, A. A. Azhari, C. Kalaiarasy, and S. Geetha, "Challenges in achieving sustainable development goal 7: Affordable and clean energy in light of nascent technologies," *Sustainable Energy Technologies and Assessments*, vol. 53, p. 102692, 2022.

[2] B. Aboagye, S. Gyamfi, E. A. Ofosu, and S. Djordjevic, "Status of renewable energy resources for electricity supply in ghana," *Scientific African*, vol. 11, p. e00660, 2021.

[3] H. Othieno and J. Awange, "Energy resources in africa," *Springer Int Publ Switz*, vol. 2016, pp. 193–205, 2016.

[4] P. Valickova and N. Elms, "The costs of providing access to electricity in selected countries in sub-saharan africa and policy implications," *Energy Policy*, vol. 148, p. 111935, 2021.

[5] J. Tomala, M. Mierzejewski, M. Urbaniec, and S. Martinez, "Towards sustainable energy development in sub-saharan africa: Challenges and opportunities," *Energies*, vol. 14, no. 19, p. 6037, 2021.

[6] R. Ranganathan and C. Briceño-Garmendia, "South sudan's infrastructure: a continental perspective," *World Bank Policy Research Working Paper*, no. 5814, 2011.

[7] K. Bos, D. Chaplin, and A. Mamun, "Benefits and challenges of expanding grid electricity in africa: A review of rigorous evidence on household impacts in developing countries," *Energy for sustainable development*, vol. 44, pp. 64–77, 2018.

[8] "Key findings – africa energy outlook 2022 – analysis." https://www.iea.org/reports/africa-energy-outlook-2022/key-findings. Accessed: 2024-5-15.

[9] I. Bisaga, "Innovation for off-grid solar rural electrification," in *Affordable and Clean Energy*, pp. 783–793, Springer, 2021.

[10] G. Hafeez, K. S. Alimgeer, and I. Khan, "Electric load forecasting based on deep learning and optimized by heuristic algorithm in smart grid," *Applied Energy*, vol. 269, p. 114915, 2020.

[11] F. Pallonetto, M. De Rosa, F. Milano, and D. P. Finn, "Demand response algorithms for smart-grid ready residential buildings using machine learning models," *Applied energy*, vol. 239, pp. 1265–1282, 2019.

[12] A. V. Varganova, V. R. Khramshin, and A. A. Radionov, "Improving efficiency of electric energy system and grid operating modes: Review of optimization techniques," *Energies*, vol. 15, no. 19, p. 7177, 2022.

[13] Y. Chawla, F. Shimpo, and M. M. Sokołowski, "Artificial intelligence and information management in the energy transition of india: lessons from the global IT heart," *Digit. Pol. Regul. Gov.*, vol. 24, pp. 17–29, Feb. 2022.

[14] M. Shafiullah, S. Rahman, B. Imteyaz, M. K. Aroua, M. I. Hossain, and S. M. Rahman, "Review of smart city energy modeling in southeast asia," *Smart Cities*, vol. 6, no. 1, pp. 72–99, 2023.

[15] N. Avila, J. P. Carvallo, B. Shaw, and D. M. Kammen, "The energy challenge in sub-saharan africa: A guide for advocates and policy makers," *Generating Energy for Sustainable and Equitable Development, Part*, vol. 1, pp. 1–79, 2017.

[16] H. H. Al-Baity, "The artificial intelligence revolution in digital finance in saudi arabia: A comprehensive review and proposed framework," *Sustainability*, vol. 15, no. 18, 2023.

[17] N. Kagiyama, S. Shrestha, P. D. Farjo, and P. P. Sengupta, "Artificial intelligence: practical primer for clinical research in cardiovascular disease," *Journal of the American Heart Association*, vol. 8, no. 17, p. e012788, 2019.

[18] I. D. Mienye and Y. Sun, "A deep learning ensemble with data resampling for credit card fraud detection," *IEEE Access*, vol. 11, pp. 30628–30638, 2023.

[19] S. Griffiths, "A review and assessment of energy policy in the middle east and north africa region," *Energy Policy*, vol. 102, pp. 249–269, 2017.

[20] J. Mugisha, M. A. Ratemo, B. C. B. Keza, and H. Kahveci, "Assessing the opportunities and challenges facing the development of off-grid solar systems in eastern africa: The cases of kenya, ethiopia, and rwanda," *Energy Policy*, vol. 150, p. 112131, 2021.

[21] M. P. Blimpo and M. Cosgrove-Davies, *Electricity access in Sub-Saharan Africa: Uptake, reliability, and complementary factors for economic impact*. World Bank Publications, 2019.

[22] O. Johnson, C. Muhoza, P. Osano, J. Senyagwa, and S. Kartha, *Catalysing investment in sustainable energy infrastructure in Africa: Overcoming financial and non-financial constraints*. JSTOR, 2017.

[23] J. Gregory and B. K. Sovacool, "Rethinking the governance of energy poverty in sub-saharan africa: Reviewing three academic perspectives on electricity infrastructure investment," *Renewable and Sustainable Energy Reviews*, vol. 111, pp. 344–354, 2019.

[24] K. Ulsrud, T. Winther, D. Palit, and H. Rohracher, "Village-level solar power in africa: Accelerating access to electricity services through a socio-technical design in kenya," *Energy Research & Social Science*, vol. 5, pp. 34–44, 2015.

[25] S. Karekezi, K. Lata, and S. T. Coelho, "Traditional biomass energy: Improving its use and moving to modern energy use," in *Renewable energy*, pp. 258–289, Routledge, 2012.

[26] M. Agoundedemba, C. K. Kim, and H.-G. Kim, "Energy status in africa: Challenges, progress and sustainable pathways," *Energies*, vol. 16, no. 23, p. 7708, 2023.

[27] H. Quest, M. Cauz, F. Heymann, C. Rod, L. Perret, C. Ballif, A. Virtuani, and N. Wyrsch, "A 3d indicator for guiding ai applications in the energy sector," *Energy and AI*, vol. 9, p. 100167, 2022.

[28] S. S. Ali and B. J. Choi, "State-of-the-art artificial intelligence techniques for distributed smart grids: A review," *Electronics*, vol. 9, no. 6, p. 1030, 2020.

[29] M. S. Ibrahim, W. Dong, and Q. Yang, "Machine learning driven smart electric power systems: Current trends and new perspectives," *Applied Energy*, vol. 272, p. 115237, 2020.

[30] R. Alawneh, F. E. M. Ghazali, H. Ali, and M. Asif, "Assessing the contribution of water and energy efficiency in green buildings to achieve united nations sustainable development goals in jordan," *Building and Environment*, vol. 146, pp. 119–132, 2018.

[31] J.-R. Ruiz-Sarmiento, J. Monroy, F.-A. Moreno, C. Galindo, J.-M. Bonelo, and J. Gonzalez-Jimenez, "A predictive model for the maintenance of industrial machinery in the context of industry 4.0," *Engineering Applications of Artificial Intelligence*, vol. 87, p. 103289, 2020.

[32] M. Amir and S. Z. Khan, "Assessment of renewable energy: Status, challenges, covid-19 impacts, opportunities, and sustainable energy solutions in africa," *Energy and Built Environment*, vol. 3, no. 3, pp. 348–362, 2022.

[33] D. Mhlanga, "Artificial intelligence in the industry 4.0, and its impact on poverty, innovation, infrastructure development, and the sustainable development goals: Lessons from emerging economies?," *Sustainability*, vol. 13, no. 11, p. 5788, 2021.

[34] A. Ade-Ibijola and C. Okonkwo, "Artificial intelligence in africa: Emerging challenges," in *Responsible AI in Africa: Challenges and Opportunities*, pp. 101–117, Springer International Publishing Cham, 2023.

[35] H. Felzmann, E. Fosch-Villaronga, C. Lutz, and A. Tamò-Larrieux, "Towards transparency by design for artificial intelligence," *Science and engineering ethics*, vol. 26, no. 6, pp. 3333–3361, 2020.

[36] K. Kieslich, B. Keller, and C. Starke, "Artificial intelligence ethics by design. evaluating public perception on the importance of ethical design principles of artificial intelligence," *Big Data & Society*, vol. 9, no. 1, p. 20539517221092956, 2022.