Distributed and Decentralised Energy Resources: Sources and Their levelized Costs

[1]Moses Jeremiah Barasa Kabeyi
[1]Department of Industrial Engineering Department, Durban University of Technology, Durban South Africa
https://orcid.org/0000-0003-1029-8632,
moseskabeyi@yahoo.com;
mkabeyi@uonbi.ac.ke

[2]Oludolapo .Akanni. Olanrewaju
[2]Industrial Engineering Department, Durban University of Technology, Durban South Africa
[2]https://orchid.org/0000-0002-3099-9295,
oludolapoo@dut.ac.za

Abstract
Distributed energy resources (DERs) like rooftop solar panels **and** battery banks**,** connected directly to the power grid offer significant economic benefits like lowering household energy bills**,** deferring costly utility infrastructure upgrades**,** and revenue generation. However, their integration creates financial challenges, ilike high upfront installation **costs** and the need to restructure how utilities bill users to maintain a fair, reliable grid. The integration of energy sources especially the decentralized and distributed energy resources (DERs) most of which are renewable and sustainable encounters various integration and utilization challenges. The DERs constitute technologies like diesel engines, micro turbines, fuel cells, photovoltaic, small wind turbines, among others using local energy resources, most of which are both sustainable and renewable. The main challenge with variable renewable energy sources is that they are associated with intermittence and are stochastic in nature, which requires optimal energy management strategies to attain a high level of system reliability and operational efficiency. The grid integration is a significant challenge associated with the global expansion of distributed energy systems that should be addressed. This study examines and synthesizes the various energy resources, conversion technologies, integration techniques, and scalability factors associated DER integration in smart grid and microgrids as well as the traditional grid. The integration of distributed and decentralized energy resources (DERs) in the grids is very important for the energy transition because it reduces greenhouse gas emissions and helps in mitigating global climate change while at the same time it advances critical components and deliverables of the sustainable development goals with additional socio-economic benefits derived from the renewable energy systems. Grids fueled by renewable energy sources and managed by smart grids offer higher reliability, cost effective and more efficient energy systems. The growing global concerns about greenhouse gas emissions and climate change as well as the resource depletion have led to increased interest in renewable energy alternatives and decentralization of generation to exploit the massive renewable sources which are sustainable, and environmentally sound, and offering a cost-efficient solution for electricity access.
Key words" Energy sources; energy resource price; levelized cost of energy; cost of energy

1. Introduction

The integration of distributed energy resources (DERs) into micro grids presents immense opportunities and challenges for the improvement of power system efficiency, reliability, and sustainability. The intermittence and variability, of variable renewable sources, is the main challenge to grid stability, while enhancing grid resilience, increased uptake of renewables and reduction of transmission and distribution losses, as well as creation of new business models are the opportunities presented by decentralized generation. These innovations are key if the world has to achieve a sustainable, low-carbon energy through pathways and technologies like green hydrogen and Power-to-X technologies while global energy interconnections will enhance energy security and grid stability on a global scale.

1.1. Problem Definition

The DERs constitute technologies like diesel engines, micro turbines, fuel cells, photovoltaic, small wind turbines, among others using local energy resources, most of which are both sustainable and renewable[1, 2]. The main challenge with variable renewable energy sources is that they are associated with intermittence and are stochastic in nature, which requires optimal energy management strategies to attain a high level of system reliability and operational efficiency. The grid integration is a significant

challenge associated with the global expansion of distributed energy systems that should be addressed. The integration is associated with multiple technical challenges in terms of grid stability, quality of power, and the need for robust control and communication system[3-5].

Deployment of Decentralized Energy Systems (DES) signals a new frontier in power system design, and planning of local energy systems. As decentralization of power systems grows, cities and urban centers are transforming into venues, of both energy consumption and distribution, which calls for systemic and paradigmatic change in existing energy infrastructure[6]. For variable renewables, integration costs increase as the share increases in the mix. As an example, integration of large amounts of wind energy is technically and economically viable or feasible up to 30% of total generation, at integration costs generally being less than 10% of the cost per MWh of wind and often significantly less [7-9].As investments in electricity increase globally, there is need for grids to be robust and technologically sophisticated to cope with the growth. It is projected that Smart grids and digital infrastructure will get significant investment by 2030, based on the net-zero emissions by 2050 scenario. Growth of global electricity demand growth together with high need to identify sustainable energy sources, leading to a paradigm change in how power networks are planned and run. Decentralized and distributed energy resources (DERs) pose a significant threat to traditional centralized power generating and distribution models[10-12]. Global electricity demand increased by 3% year-on-year in 2025 after realizing 4.4% in 2024, on account of intense heat waves and strong industrial activity. The annual demand, annual demand growth over the next five years is projected to be 50% higher on average compared with the average across the previous decade[13, 14]. To meet this demand growth calls for strategies to exploits local energy resources most of which are renewable like wind, solar, and other environmental sources through energy harvesting technologies[15-17].

2. Energy Sources for Distributed/Decentralized Generation

Decentralized power can use different energy sources like biomass, geothermal power, solar power, hydro, photovoltaic (PV), solar thermal, wind energy, hydrogen [18] . These energy sources can be renewable or non-renewable. Fossil fuel sources like natural gas, coal and petroleum are the main non-renewable source. Heat and electricity can be produced in decentralized manner, but it is difficult to transport heat over long distances as compared to electricity [2, 19], hence the reason that heat generation and use has been traditionally done onsite, while power generation has traditionally been done in centralized power systems. For this reasons, decentralized power generation facilitate efficient use of combined heat and power resulting to higher system's efficiency with electricity and heat production [20, 21].

Decentralized energy resources are mainly renewable and sustainable energy sources, also known as green energy, which are derived from natural sources like wind, solar, water, geothermal, nuclear, or bio energy Green energy is also sometimes referred to as eco-friendly energy. Nuclear energy can be harnessed by nuclear fusion and fission. In nuclear fusion, separate atoms of chemical compounds fuse together and release energy, while nuclear fission, involves splitting of individual atoms of compounds in a process referred to as nuclear decay[2, 4].

Biomass or bioenergy is a form of energy harnessed as a direct alternative to carbon-based fossil fuels often through combustion. Bioenergy combustion does not generate greenhouse gases like the burning of carbon-based fossil fuels does[22, 23]. Hydropower is a common form of renewable energy used in the generation of hydropower. Solar and wind energy have a critical role as source of renewable energy that can be connected to the grid [24]

Decentralized generation can significantly reduce transmission and distribution losses with negligible footprints. This makes decentralized generation a preferred alternative as a sustainable solution to growing future energy needs. The decentralized energy systems can be solo operated but may be affected by variable resource availability. Different distributed energy resources can be used for electrification purposes as grid connected or standalone or hybrid systems [25, 26]. Decentralized energy systems have proved to be viable substitutes where generators are located closer to load centers to mitigate transmission and distribution losses[27]. There are diverse sources of energy that can be used in decentralized heat and power production by applying different conversion technologies as summarized in table 1 below

Table 1: Summary of energy options for the decentralized generation [8, 9, 28-35]

	Energy resource	Characteristics features	Contribution to the transition and sustainability
1	Hydropower	Hydropower is the largest source of global renewable electricity. Its sustainability is significantly affected by weather.	Untapped hydropower potential is still huge, although mostly as small, micro and medium hydropower schemes that are ideal for decentralized generation.
2	Solar Energy	Solar is freely supplied by the sun as solar radiation and can be harnessed as solar thermal or directly using solar photovoltaic. It is a variable renewable affected by time of the day and weather conditions making it rather unpredictable and intermittent in in supply	Solar has a useful role in the transition, as a renewable energy resource but development in solar cells technology and smart grids will enhance their uptake contribution to grid electricity. The rate solar energy integration has been in two-digit growth rate over the last decade on year-to-year basis
3	Wind Energy	Wind energy is natural, renewable, and largely derived from differential heating of solar energy on the earth's surface. Wind power generation can be classified as onshore and offshore wind power stations.	Wind energy is renewable, but variable in supply due to intermittence nature of wind availability. Wind is an important energy resource for
4	Hydrogen	Hydrogen mainly made by steam reforming and by electrolysis.	Hydrogen will play an important role in the energy transition an energy source for fuel cells and direct combustion fuel for combustion engines
5	Biogas	Biogas is a product of anaerobic digestion of biomass in various forms like the crops, animal waste, plant waste and wastewater.	Biogas is a renewable energy resource with potential use as a substitute of fossil fuels. It can also be upgraded to biomethane, which is a direct substitute of natural gas natural gas in all possible applications.
6	Biomethane	Biomethane gas is a renewable energy resource produced by upgrading syngas and biogas	Can replace natural gas in almost all applications
7	Biodiesel	Biodiesel is derived from biomass and hence is a renewable energy resource, which biodegradable generally made from vegetable oils, recycled restaurant grease and animal fats	Biodiesel is a potential substitute of fossil fuels in transport and power generation.
8	Bagasse	Bagasse is a by-product of sugarcane milling with significant energy content used in steam and power production by sugar factories.	Bagasse is a source of law carbon energy and has an important role in decentralized generation by sugar factories. Bagasse can also be used to produce bioethanol which is an energy resource
9	Solid Biomass	Biomass can be obtained as waste products, forest products or energy crops	Solid biomass has applications like direct combustion, heating and green power generation
10	Geothermal Energy	Geothermal energy has significant potential for use in heat and power applications. It is however limited by	Geothermal power plants operate at high load factor and with no fuel cost making them ideal for base load application with

		long project delivery periods and high upfront costs and risks	the effect of reducing electricity price, reliability and reduce emissions.
11	Producer gas	The product is producer gas if the proportion of the non-combustible gases is high. Producer gas is produced by blowing through a carbonaceous material like coke or coal with and steam simultaneously. The calorific value of producer gas is low due to high nitrogen content. Improvements over producer gas; include water gas or synthesis gas	Producer gas is easy to deliver compared to solid fuel while the furnaces can be maintained at a constant temperature. It is possible to make producer gas even from the poorest quality of fuel. It is economically feasible to convert solid fuel into producer gas and avoid smoke nuisance in use of biomass.
12	Syngas (Synthesis gas)	Syngas or synthesis gas is a mixture of Carbon Monoxide and Hydrogen produced by steam or oxygen gasification of carbonaceous material i.e., biomass produced from different materials containing carbon like wood, plastics, municipal waste, coal, and similar materials during gasification of carbonaceous material subjected to high temperatures in the presence of limited oxygen but enough to sustain the reaction.	Syngas engines can be designed in cogeneration mode to maximize system efficiency. Syngas produced by the gasifier is considered as a renewable fuel and so is electricity generated by its combustion is renewable. For processes using waste stream, a combined benefit waste to useful products is realized. Benefits of using syngas include reduced energy, controlled generation, higher efficiency and ideal for 20-30 MW power plants, waste management and substitution of fossil fuels
13	Nuclear energy	Nuclear power is clean while uranium reserves are huge and have very high energy density guarantees a sustainable energy supply at high load and capacity factors. The conventional nuclear power plants are large in size, huge capital requirements, take long to deploy making them unsuitable for use in decentralized generation	Conventional nuclear power plants are huge in capacity and may not be ideal for decentralized generation., the small modular reactors (SMR) more ideal for low demand/capacity and hence good decentralized generation. The SMRs are more flexible, cost effective and smaller making them ideal for decentralized generation.
14	Ocean /marine energy	Marine energy is classified as renewable energy existing mainly as ocean thermal, osmotic, wave energy and tidal power. Renewable energy resource mainly in the form of tidal power, wave power, osmotic and ocean thermal.	Marine energy can play an important role in the energy transition by improving the harvesting technology to increase efficiency in extraction of energy like in the case of low thermal gradient in ocean thermal.
15	Natural gas	Natural gas is a fossil fuel regarded as the cleanest of all fossil fuels compared with coal and oil. It is currently the second largest source of source of global electricity.	Natural gas has an important role in the energy transition as the cleanest fossil fuel that can be used as a short and middle term substitute of coal and petroleum oil, which are heavier polluters. The main concern is delay in the transition and investment risk associated with earlier transition.
16	Coal	Coal is a non-renewable energy resource. It is the largest source of global	Coal is a source of dispatchable power but is a fossil fuel having the highest carbon

		electricity generation. Several countries have huge coal reserves, which complicates the energy transition.	values. The conniptions of should be reduced gradually through substitution with renewable and sustainable sources of energy.
17	Fossil Oil	Oil produces high carbon emissions together and pollutants like nitrous oxides (NO_X) and (Sulphur dioxide) SO_2 and particulates. High reserves in some countries hence slow transition	Oil can continue to place an important role as a dispatchable source of energy for energy systems stability and peak power applications by application of efficiency measures like cogeneration and use of more efficient conversion

It is demonstrated in table 3, that both renewable and nonrenewable energy sources have an important role in decentralized generation and in the energy sustainability e.g., although oil and coal are nonrenewable fossil fuels, they are dispatchable, cheaper and easily accessible sources of energy for power generation. Sustainable and renewable energy sources like wind and solar and hydro have the greatest potential but are significantly affected by reliability of supply due to intermittence and variability in resource supply. The main solution to these challenges is investment in storage, smart grids and micro grid technology infrastructure, which effectively increases the cost of investment [30, 36].

The unpredictable and unreliable nature of supply for variable renewables is a significant risk to energy security and the grid stability hence power/energy system, reliability for the traditional grid. This, which increases the demand for smarter and resilient grids for decentralized generation [37, 38]. The use of smart grids increases the ability to absorb small producers and variable supplies especially for wind and solar and small hydro sources and which have a significant role in the global energy transition[38, 39].

3. Energy Resource Price

The price of energy is an important factor in sustainability as it affects the price of electricity and the demand. Various factors affect the price including availability and taxes imposed by the state e.g., carbon tax. The price of an energy resource is what is paid for acquisition and is usually based on prevailing market price.

Table 2: Energy resource price

	Energy resource	Market Price Range (USD)	Average
1	Hydropower	0	0
2	Solar Energy	0	0
3	Wind Energy	0	0
4	Hydrogen	0.5-8.5/kg	4.5/kg
5	Biogas	2-20 2/MBtu	11/ MBtu
6	Solid biomass	44-85/tone	64.5/tone
6	Biomethane	0.45—0.75/LGE	0.6/LGE
7	Biodiesel	50-69/litre	54.5/litre
8	Bagasse	9-22	10.5/MT
10	Producer gas	*6.5 per mmBtu*	*6.5 per mmBtu*
11	Uranium	120-130 /kg	225/kg
12	Wave energy	N/a	
13	Tidal power	N/a	

15	Natural gas	*2.63- 2.78/MMBtu*	*2.705 MMBtu*
16	Coal	130-137.14 /kg	133.6/kg
17	Heavy Fuel Oil	0.6-0.644 /kg	0.622/kg
18	Diesel	1.20-1.25/litre	1.225/liter
19	Petrol	1.25-1.30/liter	1.275/liter

From Table, it is noted that the price of energy resources varies with type of energy, while factors like quality and other costs like freight affect the price of the same energy resource.

Table 19.6. Levelized cost of Energy

	Energy resource	**Levelized cost of energy (USD)/MWh**	**Average USD/MWh**
1	Hydropower	50-70	60
2	Solar PV-Utility scale	49-185	117
	Solar PV-Roof top	117-282	199.5
3	Wind Energy-Onshore	33-35	34
4	Wind power-Offshore	79 - 81	80
5	Nuclear	141- 221	181.5
6	Coal	68-166	117
7	Combined cycle natural gas turbines	39-101	70
8	Bagasse	9-22	15.5
9	Hydrogen fuel cells	278 - 322	300
10	Battery energy storage	270-442	356
11	Biogas systems	50-190	120
12	Solid biomass	*40.5 -46.3$*	43.4
13	Biomethane	80-200	140
14	Magnetohydrodynamic generation	*212.2 - 218.9*	215.6
15	Geotherma lenergy	*40-140*	90
16	Diesel power plants	*300-500*	400

The levelised cost of the various energy and power sources presented in table 2 can be diaagramatically presented in figure 1 below

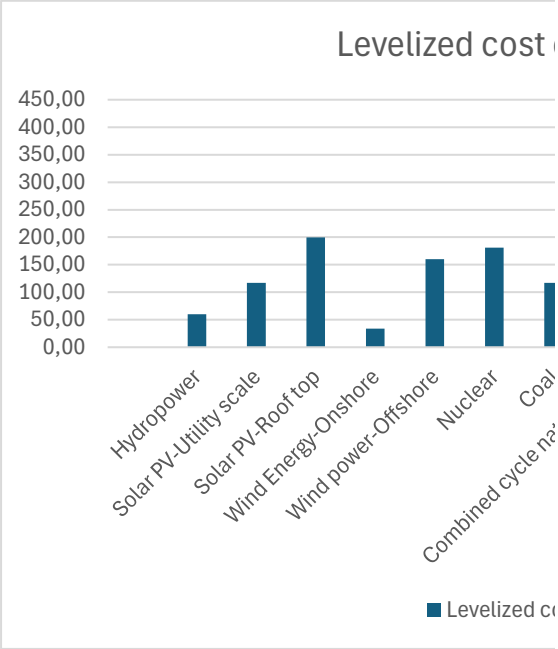

Figure 1: Levelised cost of energy from different sources

From figure 1 and table 2, it is observed that diesel power generation, battery energy storage and hydrogen fuel cells have the highest values of levelized cost, while bagasse, offshore wind and solid biomass have the lower levelized cost of energy.

4. SUMMARY, DISCUSSION AND RECOMMNDATIONS

Grid integration of DERs requires a coordinated operation and control and use of controllable loads and storage devices, like batteries, flywheels, and capacitors being central to the concept of micro grid among other strategic, design and operational measures. The flexibility of local energy generation and energy use has increasingly become relevant for planning energy systems having high share of renewables, vehicle electrification, and decentralization

5. CONCLUSIONS

Grid integration of DERs requires a coordinated operation and control and use of controllable loads and storage devices, like batteries, flywheels, and capacitors being central to the concept of micro grid among other strategic, design and operational measures. The flexibility of local energy generation and energy use has increasingly become relevant for planning energy systems having high share of renewables, vehicle electrification, and decentralization

6. DISCLOSURES

6.1. Funding

This research did not receive any external funding.

6.2. Availability of data

The authors will be available to provide any requested data by making written request to the corresponding author.

6.3. Authors contribution

The first author (MJBK) developed the manuscript draft under with the e second author (OAO) providing administrative and technical support and guidance and review. The authors jointly agreed on content and submission of manuscript for peer review and publication.

6.4. Declaration of competing interest

The authors declare that there are no known competing interests or personal relationships that could have appeared to influence the contents of this manuscript.

6.5. Acknowledgement

The authors acknowledge the support offered by Durban University of Technology by providing a conducive research environment and infrastructure for research.

References

[1] Erdiwansyah, Mahidin, H. Husin, Nasaruddin, M. Zaki, and Muhibbuddin, "A critical review of the integration of renewable energy sources with various technologies," *Protection and Control of Modern Power Systems,* vol. 6, no. 1, p. 3, 2021/02/23 2021, doi: https://doi.org/10.1186/s41601-021-00181-3.

[2] M. J. B. Kabeyi and A. O. Olanrewaju, "Decentralized and Distributed Power Generation," presented at the 4th Asia Pacific International Conference on Industrial Engineering and Operations

Management, Vietnam, September 12–14, 2023, 2023. [Online]. Available: https://ieomsociety.org/proceedings/2023vietnam/268.pdf.

[3] K. C. Nwala, M. J. B. Kabeyi, and O. A. Olanrewaju, "A Visual and Strategic Framework for Integrated Renewable Energy Systems: Bridging Technological, Economic, Environmental, Social, and Regulatory Dimensions," *Energies,* vol. 18, no. 20, p. 5468, 2025, doi: https://doi.org/10.3390/en18205468.

[4] M. J. B. Kabeyi and A. O. Olanrewaju, "Economic evaluation of decentralised energy sources for power generation," *Energy Strategy Reviews,* vol. 60, no. July 2025, p. 101774, 2025, doi: https://doi.org/10.1016/j.esr.2025.101774.

[5] M. J. B. Kabeyi, K. Nwala, and A. O. Olanrewaju, "Economic sustainability assessment of energy sources for decentralized generation," presented at the 34th Southern African Institute for Industrial Engineering Conference 2024 (SAIIE34), Vanderbijl Park, South Africa., 14–16 October 2024, 2024, 226. [Online]. Available: https://www.proceedings.com/078172-0090.html.

[6] A. M. Adil and Y. Ko, "Socio-technical evolution of Decentralized Energy Systems: A critical review and implications for urban planning and policy," *Renewable and Sustainable Energy Reviews,* vol. 57, pp. 1025–1037, 2016/05/01/ 2016, doi: https://doi.org/10.1016/j.rser.2015.12.079.

[7] J. Weiss and B. Tsuchida, "Integrating Renewable Energy into the Electricity Grid," Advanced Energy Economy Institute, USA, June 2015 2015. [Online]. Available: https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/aeei-renewables-grid-integration-case-studies.pdf

[8] M. J. B. Kabeyi and A. O. Olanrewaju, "Solar Energy as a Sustainable Energy For Power Generation " presented at the 2nd Australian International Conference on Industrial Engineering and Operations Management, Melbourne, Australia, November 14–16, 2023 2024, 244. [Online]. Available: https://index.ieomsociety.org/index.cfm/article/view/ID/13876.

[9] M. J. B. Kabeyi and A. O. Olanrewaju, "Wind Energy in Sustainable Power Generation and Supply," presented at the 2nd Australian International Conference on Industrial Engineering and Operations Management, Melbourne, Australia, November 14–16, 2023 2024, Wind Energy in Sustainable Power Generation and Supply, 246. [Online]. Available: https://index.ieomsociety.org/index.cfm/article/view/ID/13878.

[10] S. Dawn *et al.*, "Integration of Renewable Energy in Microgrids and Smart Grids in Deregulated Power Systems: A Comparative Exploration," *Advanced Energy and Sustainability Research,* vol. 5, no. 10, p. 2400088, 2024/10/01 2024, doi: https://doi.org/10.1002/aesr.202400088.

[11] G. E. Ouma, M. J. Kabeyi, and O. A. Olanrewaju, "Performance Analysis of Solar Photovoltaic Integration in Liquid Carton Packaging Manufacturing," *Energies*, vol. 19, no. 10, p. 2448doi: https://doi.org/10.3390/en19102448.

[12] M. N. Letiyan, M. B. Kabeyi, and O. Olanrewaju, "Modelling the Impact of Solar Power Expansion on Generation Costs in Kenya," *Energies,* vol. 19, no. 2, p. 296, 2026, doi: https://doi.org/10.3390/en19020296.

[13] M. J. B. Kabeyi, "Sustainable energy transition and optimization of grid electricity generation and supply," Doctor of Engineering, Industrial Engineering, Durban University of Technology, Durban, South Africa, 2024. [Online]. Available: https://doi.org/10.51415/10321/5485

[14] M. J. B. Kabeyi and O. A. Olanrewaju, "Sustainable energy transition for renewable and low carbon grid electricity generation and supply," (in English), *Frontiers in Energy Research,* Review vol. 9, no. 743114, pp. 1–45, 2022–March–24 2022, doi: https://doi.org.10.3389/fenrg.2021.743114.

[15] M. J. B. Kabeyi and A. O. Olanrewaju, "Social Value of Energy Sources for Decentralized Generation," presented at the 2025 13th International Conference on

Smart Grid (icSmartGrid), 27–29 May 2025 2025. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/11071840.

[16] M. J. B. Kabeyi and A. O. Olanrewaju, "Energy sources for harvesting, availability and application," presented at the 2025 13th International Conference on Smart Grid (icSmartGrid), Glasgow, United Kingdom 2025. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/11071831.

[17] M. J. B. Kabeyi and A. O. Olanrewaju, "Current and Future Trends in Energy Harvesting Technology and Applications," presented at the 2025 13th International Conference on Smart Grid (icSmartGrid), Glasgow, United Kingdom 27–29 May 2025, 2025. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/11071773.

[18] T. Ackermann, G. Andersson, and L. Söder, "Distributed generation: A definition," *Electric Power Systems Research,* Article vol. 57, no. 3, pp. 195–204, 2001, doi: 10.1016/S0378-7796(01)00101-8.

[19] C. Vezzoli *et al.*, "Distributed/Decentralised Renewable Energy Systems," in *Designing Sustainable Energy for All: Sustainable Product-Service System Design Applied to Distributed Renewable Energy*, C. Vezzoli *et al.* Eds. Cham: Springer International Publishing, 2018, pp. 23–39.

[20] G. Pepermans, J. Driesen, D. Haeseldonckx, R. Belmans, and W. D'haeseleer, "Distributed generation: definition, benefits and issues," *Energy Policy,* vol. 33, no. 6, pp. 787–798, 2005/04/01/ 2005, doi: https://doi.org/10.1016/j.enpol.2003.10.004.

[21] P. Wolfe, "The implications of an increasingly decentralised energy system," *Energy Policy,* vol. 36, no. 12, pp. 4509–4513, 2008/12/01/ 2008, doi: https://doi.org/10.1016/j.enpol.2008.09.021.

[22] M. J. B. Kabeyi and O. A. Olanrewaju, "Investigating the Optimum Energy Potential of an Operating Digester for a Slaughterhouse," in *Engineering Research: Perspectives on Recent Advances Vol. 12*, 2026, ch. Chapters, pp. 78–101.

[23] M. J. B. Kabeyi and O. A. Olanrewaju, "The Role of Biogas in the Global Energy Transition: Production Pathways and Sustainable Applications," in *New Horizons of Science, Technology and Culture* vol. 7: BP International, 2026, pp. 1–85.

[24] C. P. Ohanu, S. A. Rufai, and U. C. Oluchi, "A comprehensive review of recent developments in smart grid through renewable energy resources integration," *Heliyon,* vol. 10, no. 3, p. e25705, 2024/02/15/ 2024, doi: https://doi.org/10.1016/j.heliyon.2024.e25705.

[25] S. M. Situmbeko, "Decentralised Energy Systems and Associated Policy Mechanisms—A Review of Africa," *Journal of Sustainable Bioenergy Systems,* vol. 7, pp. 98–116, 2017, doi: https://doi.org/10.4236/jsbs.2017.73008.

[26] M. J. B. Kabeyi, O. A. Olanrewaju, and J. Akpan, "Biogas Production and Process Control Improvements," in *From Biomass to Biobased Products*, J.-L. Dr. Eduardo, Z. Dr. Leila Queiroz, and D. Dr. Rosangela Rodrigues Eds. Rijeka: IntechOpen, 2024, p. Ch. 9.

[27] M. J. B. Kabeyi and O. A. Olanrewaju, "The levelized cost of energy and modifications for use in electricity generation planning," *Energy Reports,* vol. 9, pp. 495–534, 2023/09/01/ 2023, doi: https://doi.org/10.1016/j.egyr.2023.06.036.

[28] M. J. B. Kabeyi, "Sustainable energy transition and optimisation of grid electricity generation and supply," Doctor of Engineering Dissertation Industrial Engineering, Durban University of Technology, Durban, South Africa, 2024.

[29] M. J. B. Kabeyi and A. O. Olanrewaju, "Wind Energy in Sustainable Power Generation and Supply," presented at the 6th European Conference on Industrial Engineering and Operations Management, Lisbon, Portugal,, July 18–20, 2023, 2023, 246.

[30] M. J. B. Kabeyi and A. O. Olanrewaju, "Application of Geothermal Wellhead Generators in

Sustainable Power Generation," *Geothermal Resources Council Transactions,* vol. 46, no. 2022, pp. 1692–1718, 2022, Art no. 1034703, doi: https://www.geothermal-library.org/index.php?mode=pubs&action=view&record=1034703.

[31] M. J. B. Kabeyi and A. O. Olanrewaju, "Hydropower In the Sustainable Energy Mix," presented at the 6th European Conference on Industrial Engineering and Operations Management, Lisbon, Portugal, July 18–20, 2023, 2023, 247.

[32] M. J. B. Kabeyi and A. O. Olanrewaju, "Solar Energy as a Sustainable Energy For Power Generation " presented at the 2nd Australian International Conference on Industrial Engineering and Operations Management, 2024. [Online]. Available: https://ieomsociety.org/proceedings/2023australia/244.pdf.

[33] M. J. B. Kabeyi and O. A. Olanweraju, "Sustainability Assessment for Non-Combustible Renewable Power Generation " presented at the 12th Annual Istanbul International Conference on Industrial Engineering and Operations Management, Istanbul, Turkey, March 7–10, 2022, 2022, Paper 429. [Online]. Available: https://ieomsociety.org/proceedings/2022istanbul/429.pdf.

[34] M. J. B. Kabeyi and A. O. Olanrewaju, "Hydropower In the Sustainable Energy Mix," presented at the 2nd Australian International Conference on Industrial Engineering and Operations Management, Melbourne, Australia, November 14–16, 2023 2024, 247. [Online]. Available: https://index.ieomsociety.org/index.cfm/article/view/ID/13879.

[35] M. J. B. Kabeyi and O. A. Olanrewaju, "Hydroelectric Power Plants and their Sustainability," in *Advances in Hydropower Technologies*, B. I. A. Ismail Ed. Rijeka: IntechOpen, 2025.

[36] M. J. B. Kabeyi and A. O. Olanrewaju, "Managing Sustainability in Electricity Generation," in *2020 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 14–17 Dec. 2020 2020, pp. 530–536, doi: 10.1109/IEEM45057.2020.9309994. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/9309994

[37] M. J. B. Kabeyi and A. O. Olanrewaju, "Smart Energy Systems and Use of Energy Plan as an Energy and Power Generation Planning Tool," presented at the 3rd Indian International Conference on Industrial Engineering and Operations Management, New Delhi, India, November 2–4, 2023, 2024, 163. [Online]. Available: https://ieomsociety.org/proceedings/2023india/163.pdf.

[38] M. J. B. Kabeyi and O. A. Olanrewaju, "The potential of grid power generation from municipal solid waste for Nairobi city," presented at the 2nd African International Conference on Industrial Engineering and Operations Management, Harare, Zimbabwe, 5–7 December 2020, 2020, 081 [Online]. Available: http://ieomsociety.org/harare2020/papers/81.pdf.

[39] M. J. B. Kabeyi and A. O. Olanrewaju, "Performance Analysis of Garissa Off-Grid Power Station," presented at the International Conference on Industrial Engineering and Operations Management, Manila, Phillipines, March 7–9, 2023, 2023, 614. [Online]. Available: https://ieomsociety.org/proceedings/2023manila/614.pdf.