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EDITED BY
Michael Carbajales-Dale,
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REVIEWED BY
N. L. Panwar,
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Tarek MF Ahmed,
Northumbria University, United Kingdom

*CORRESPONDENCE
Olufemi Michael Oladejo,
oladight@yahoo.com
Elvin Shava,
shavae@ukzn.ac.za
Tigere Paidamoyo Muringa,
muringa@ukzn.ac.za

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The feasibility of implementing renewable energy systems by local municipalities for households and economic entities

Olufemi Michael Oladejo*, Elvin Shava* and Tigere Paidamoyo Muringa*

Discipline of Public Governance, University of KwaZulu-Natal, Durban, South Africa

As the urgency to combat climate change, environmental degradation and energy security intensifies, nations globally are exploring sustainable energy alternatives to reduce dependence on fossil fuels. This growing concern has urged local governments to seek renewable energy solutions. Municipalities are in an advantageous position to implement these systems, as they are often at the forefront of service delivery and the government closest to the people. Local municipalities can benefit households and economic entities by implementing renewable energy systems. More so, renewable energy sources, such as solar, wind, and hydroelectric power, are often more cost-effective and efficient than traditional ones, particularly in rural or remote areas. This study adopts a qualitative research approach using face-to-face interviews guided by a semi-structured interview to explore the technical, economic, and environmental feasibility of supporting households and economic entities in implementing renewable energy Seven (7) stakeholders from South Africa's renewable energy sector were selected for the interviews using purposive sampling. Data collected was recorded and later transcribed into Microsoft Word for thematic analysis. The results revealed that local municipalities must invest in renewable energy systems to support households and business entities in implementing renewable energy. In addition, the result also showed that local municipalities must leverage the resources within their jurisdictions, such as wind, land, organic waste from landfills, agriculture, and municipal sanitation systems, to achieve their RE target. The study's conclusions suggest that local municipalities must develop policies for best renewable energy practices to achieve renewable energy autonomy to support households and business entities in South Africa.

KEYWORDS

feasibility, renewable energy, renewable energy systems, renewable energy technologies, local municipality

1 Introduction

The global transition towards a more sustainable and environmentally conscious energy landscape has brought renewable energy systems (RES) to the forefront of energy solutions (Panwar et al., 2013). Renewable energy (RE) sources have gained significant attention due to their ability to provide clean, sustainable, and often cost-effective alternatives to traditional fossil fuel-based energy generation (Tian et al., 2023). Moreover, integrating renewable energy technologies (RET), such as solar, wind, and biomass, holds immense potential to address the pressing concerns of climate change, energy security, and economic development (Malik et al., 2020; Kwok et al., 2019).

Several socio-economic challenges, including energy, are a burden in South Africa. The country has been facing serious power shortages, affecting several crucial economic and health sectors, which need a continuous energy supply. This has led to several emergency measures, such as load shedding. In their legal obligations under the Municipal Systems Act (2000), local municipalities have assigned a department to foresee and run sustainable energy provision. Thus, RES may be implemented parallel to conventional main grid sources (eThekwini municipality, 2020). However, transitioning towards a green energy economy is a complex process that needs careful consideration in selecting the best technologies that are economically viable, socially acceptable, and legal (Hirwa et al., 2023). Furthermore, as households and business entities are encouraged to embrace RET as viable alternatives, implementing and successfully adopting these technologies depends on the government's enabling techno-socioeconomic policy environment.

The urgent need for a transition to RES involving the people at the grassroots has attracted scholars within and outside the field of public governance. For instance, Kostevšek et al. (2013) highlight the need to demystify the complexity of RES into a multifaceted renewable value chain, covering all vital sections such as demand, supply, technology, etc. In another study Fiaschi, Bandinelli and Conti (2012) advocate the integration of RES into public space while involving stakeholders in all the sections. Lucas, Pinnington and Cabeza (2018) emphasise bridging the gaps in the RE sector through education and training while Lerman et al. (2021) proposed the triple helix (TH) model, comprising the university, the industry, and the government. The study explores the collaboration of these stakeholders in developing innovative RE policies.

Despite these studies, there is a lack of scholarly works focusing on implementing RE at the grassroots level. Previous studies have failed to provide a detailed analysis of RE implementation by the local government at the grassroots level. This gap in literature leaves practitioners and policymakers without evidence-based outcomes to make informed decisions. Hence, resources and time are initiatives based on anecdotal evidence. This study explores the technical, economic, and environmental feasibility of supporting households and economic entities in implementing RES. This study is structured into several sections. Section 2 provides a review of the relevant literature concerning the technical, economic, and environmental viability of assisting households and businesses in adopting RES. Section 3 details the methodological approach used to meet the study's goals. Section 4 presents and analyses the research findings. Finally, Section 5 addresses the study's limitations, explores practical implications, and offers concluding remarks.

2 Literature review

This section reviews scholarly studies on local government implementation of RES at the grassroots level. The study emphasises the importance of the technical, economic, and environmental feasibility of supporting households and economic entities in the RES transition. The concepts of RES implementation have emerged as vital subjects in the study of RE and sustainability. As the world grapples with global warming issues and their consequences, the implementation of RES has gained prominence across various levels of government. Often seen as the frontline of environmental policy implementation, local governments are uniquely positioned to implement RES and RET. Hence, developing RE at the grassroots is recognised as essential for building a sustainable future.

2.1 Technical feasibility

The technical feasibility of RES is a critical factor in its widespread adoption. Recent advancements in RET have made them increasingly efficient, reliable, and cost-effective. There are several technologies to support the RE transition in pursuit of decarbonising the energy sector. These technologies include green hydrogen, wind energy, hydro, biomass, wind, solar, solar photovoltaic systems (PV), and concentrating solar-thermal power (CSP) (Akinyele and Rayudu, 2016; Ali et al., 2023; Aliyu et al., 2018). Solar photovoltaic systems, for instance, have seen significant improvements in conversion efficiency and a steady decline in installation costs, making them an attractive option for both household and commercial applications (Phuangpornpitak and Tia, 2013). Hence, several households and business entities across the globe are increasingly adopting these technologies to reduce their carbon generation and enjoy carbon-free energy at a lower cost. However, as good as this sounds, it depends on how much the government, especially the local governments, are willing to put in to guarantee availability and reach to the households and the economic entities.

According to Phuangpornpitak and Tia (2013), before these technologies become accessible to households and business entities, there is a need for a techno-economic assessment. Techno-economic assessment (TEA) is a method that analyses the economic performance of an industrial or organisational service using mathematical models. The TEA provides decision-making for authorities considering the implementation of viable business models. The tool uses input parameters such as capital and expenditure costs, revenue generation and other financial parameters (Manfren et al., 2021). Naicker and Thopil (2019) list major technical feasibility parameters such as local availability of materials, technological maturity, ease of transfer of skills, and ease of maintenance.

2.1.1 Resource assessment

2.1.1.1 Wind energy

Wind energy has been proven to be the most viable option in South Africa due to massive winds in the coastal areas. Wind energy is generated when the wind flows past through the blades of the turbines (eThekwini municipality, 2020). Coastal areas are the best to locate wind energy because of high onshore winds. The South African Department of Energy (SADE) mapped and characterised areas with high wind potential and generated maps (Diab's Wind Atlas) that can be used by local municipalities for decision-making (Akinbami et al., 2021). Diab's wind Atlas shows that the Western, Northern and Eastern Cape have the highest wind potential. In contrast, KwaZulu-Natal and areas of the Drakensberg have medium potential, and the least is the North West province, which is more inland (Akinbami et al., 2021). A comprehensive Wind Atlas for South Africa (WASA) has been developed by the South African Wind Energy Project (SAWEP) to guide entities in choosing the best site for a wind farm. A study by the Council for Scientific and Industrial Research (CSIR) showed that 80% of South African land mass has sufficient winds to satisfy a load factor of >30% (Sustainable Energy Africa, 2017), confirmed to be far larger than Germany's potential (eThekwini municipality, 2020). A feasibility study done in eThekwini metropolitan municipality in 2011 identified ten sites where 86 turbines can be installed to generate 215 MW of electricity at a wind speed of between six and 7.3 m/s and a height of 100 m (eThekwini municipality, 2020). However, about 27 wind farms have been launched in the Eastern and Western Cape between 2008 and 2017.

Despite variations in wind speeds across the country, smaller turbines can be considered for household generation. For example, a feasibility study done in Maluti-A-Phofung municipality showed that even when the wind direction and speeds are not ideal for large-scale generation, they can be downscaled to the household level (Mapuru et al., 2022). Cases have been reported in which households are producing electricity using small-scale wind generators in the Westville and Sherwood areas of Durban (Sustainable Energy Africa, 2017).

Wind energy generators are one of the most mature technologies that can be used with minimal difficulties. Based on a TEA done by Naicker and Thopil (2019), wind energy ranked the best (4 out of 4) in terms of technological maturity, availability of local champions, ease of skill transfer (3.5 out of 4) and ease of maintenance (3.2 out of 4). The ease of maintenance score is lower due to certain technical issues. For example, wind farms should be located away from residential areas, rendering the distribution of electricity expensive and creating other technical challenges, such as voltage fluctuation (Akinbami et al., 2021). Despite these technical issues in maintaining wind energy, Naicker and Thopil (2019) argue that South Africa is technically equipped to operate wind farms without problems.

Wind farm establishment costs are very low. Doorga et al. (2022) report that the levelised costs of constructing wind farms in South Africa are 16.7% lower than those of constructing coal-powered electrical stations. The levelised cost of constructing solar farms in appropriate areas of Egypt is 29.7% lower than the establishment of combined gas turbines and 37% lower than diesel generators.

From the foregoing, wind energy is one of the most mature RE technologies that can provide commercial-scale energy in areas with >6 m/s wind at 100 m. In areas where the wind is lower, wind technology can provide electricity to households and businesses. The establishment costs for wind energy are generally lower than for conventional coal-based energies.

2.1.1.2 Solar energy

Solar energy emerges as a highly reliable and feasible RET for widespread adoption in South Africa, owing to its ample annual radiation intake. A solar photovoltaic system (PV) is defined as an electrical system that converts solar energy into electricity. Northern Cape has the highest DNI (Daily Natural Irradiance) in South Africa, reaching as much as 3,200 kW h/m^2, which is very low in KwaZulu-Natal (1,400 kW h/m^2) (Akinbami et al., 2021). A solar PV yield, just like wind energy, is affected by meteorological conditions such as solar radiation, aspect and seasonal variations. South Africa has one of the best conditions for solar PV because it receives 8–10 h of sunshine, which translates to a national average of 2,500 h per year and 4.5–6.6 kW h/m^2 of radiation level (Jain and Jain, 2017). Currently, South Africa has 21 solar PVs producing approximately 1 300 MW of power: Northern Cape (13), North West (3), Free State (2) and Eastern Cape (3) (Akinbami et al., 2021). However, there are fewer CSP projects (five parabolic troughs and one power tower) in South Africa, which all generate 500 MW for the national grid.

Municipalities have the chance to invest in RE across various scales, including households and commercial enterprises. A TEA of solar PV energy at the household level in Durban, South Africa, demonstrated its technical viability (Ebhota and Tabakov, 2021). Solar energy is one of the solutions to the prevailing energy insecurity at the household level in South Africa. For example, the use of solar energy for heating water was estimated to reduce total energy consumption from the main grid by 18% (DMRE, 2004). This reduction can save a lot of energy from existing power blackouts, considering household consumption constitutes 23% of the total energy consumption per sector (Bohlmann and Inglesi-Lotz, 2018).

2.1.1.3 Biomass energy

There is also an opportunity to tap into biomass energy, considering the vast organic waste streams available from South African landfills, agricultural waste, livestock products, and paper companies. Biomass energy is the form of RE obtained directly or indirectly from organic matter in a liquid, gaseous or solid form (Akinbami et al., 2021). There are global energy opportunities for biomass energy; for example, China and Greece have the potential to cover between 99% and 135% of their energy needs from livestock and agricultural residues only, respectively (Aravani et al., 2022). However, other municipalities, such as eThekwini municipality (2020), have been considering harnessing biomass energy for household consumption. Waste streams in 2007 show that the municipality can produce approximately 1.5 GW of power from available organic material. However, the general contribution of biomass to the overall energy demand for KwaZulu Natal is 0.06% (Mutombo and Numbi, 2019). Biomass energy is shown to be the least matured technology when compared to solar PV and wind energy. According to an assessment by Naicker and Thopil (2019), biomass energy had the lowest Digital Maturity Model (DMM) scores in terms of technology maturity, availability of local actors and ease of skills transfer. Mbazima et al. (2022) consider biogas energy cheap and clean. However, its use is currently not taken seriously in South Africa. Six out of the 17 planned projects have been successfully implemented. They are generating approximately 15 MW for the local grids of KwaZulu Natal, Gauteng, and Western Cape provinces. Mbazima et al. (2022) single out the reliance on coal, which is abundant in South Africa, as the major barrier to prioritising landfill gas energy. Other techno-economic issues were a lack of municipal and institutional capacity to operate and maintain such projects, skills shortage and inadequate waste stream quality and quantity research. Otherwise, more research and development centered on biomass energy production is crucial.

2.1.2 Infrastructure

2.1.2.1 Grid integration

South Africa is fighting two intertwining challenges: energy security and climate change mitigation. The South African IRP (Integrated Resource Plan) has emphasised the need to mix energy sources from renewables and bring them to the national grid to meet local demands and promote economic development (DMRE, 2019). Considering the large potential for solar PV and wind energy in South Africa, it is imperative to understand the capacity of existing infrastructure to accommodate extra energy. There are existing challenges with integrating Independent Power Producers (IPPs) onto the national grid. One is inadequate information on the technical risks and mitigation strategies to include RE in the national grid (DMRE, 2019). Another challenge is the nationwide South African grid maintenance backlog, especially in the Cape Province, where wind and solar energy generation potential is high (DMRE and DTICC, 2023). The state-owned transmission and distribution company, Eskom does not have the financial capacity to maintain its infrastructure (Eskom, 2019). Despite financial constraints, the South African Renewable Energy Masterplan (SAREM) proposed that Eskom develop an implementation plan for infrastructure that will consider transmission and distribution networks, clear grid access rules, and best RE deployment (DMRE and DTICC, 2023).

Government policy enhancements create opportunities for increased electricity integration into municipal grids. These revisions allow IPPs, including Small-Scale Embedded Generation (SSEG), to supply energy to municipalities and the national grid without the previous bureaucratic hurdles of the National Electricity Regulator of South Africa (NERSA) registration (DMRE and DTICC, 2023). Addressing infrastructure constraints could unlock the potential for all IPPs to contribute to the national grid, contingent upon enhanced energy market capabilities, and bring succour to households in South Africa.

2.1.2.2 Energy storage

Power generation from RE is dynamic; for example, solar and wind generation depends on prevailing climatic conditions. Firstly, the energy will be lost if it is not captured and stored. Secondly, South Africa needs extra energy during high-demand periods, which can lead to load shedding, so battery storage may help alleviate the situation (Mirzania et al., 2023). There is a range of batteries that can be used for energy storage, which include Lead-acid, Lithium-ion, Sodium Sulphur, Nickel Chloride, Zinc Bromide and Vanadium Redox Batteries (VRB) (Thango and Bokoro, 2022). According to the authors, Lithium-ion batteries are the most viable for large-scale energy storage based on economic and technical parameters. Some technologies, such as VRB, are still to be tested at a utility scale, and they may need further research before being considered.

The South African economic landscape presents significant opportunities for growth in the LED batteries manufacturing sector and green energy storage solutions. As reported by DMRE and DTICC (2023), adopting E-mobility applications has led to a substantial surge in energy storage technology deployment, increasing from 0.5 GW-hour (GWh) in 2010 to 997 GW h in 2021. This trend extends to the Vanadium Redox Flow Battery market, which is projected to reach an annual installed capacity of up to 30 GW h by 2030. Additionally, the University of Western Cape's hydrogen initiative is currently exploring practical applications of the hydrogen economy within the South African context (DMRE, 2019).

Thango and Bokoro (2022) have highlighted the technical challenges associated with lithium-ion batteries in a review. These challenges encompass output power smoothing, load cutting off, frequency regulation, plant dispatch ability, and energy arbitration. The authors propose that these issues can be addressed by implementing specifically designed algorithms, underscoring the need for advanced technical skills to operate such systems effectively.

2.2 Economic feasibility

The economic viability of RES is a crucial consideration for both households and economic entities. The initial investment required for installations can be a significant barrier for some individuals and organisations, however, municipalities are inclined to invest in sustainable and economically viable technologies. Numerous studies have examined the economic viability of RET throughout the entire service chain in contrast to conventional energy sources (Rediske et al., 2021; Mbazima et al., 2022). Rediske et al. (2021) outlined economic feasibility parameters as crucial in site selection for RE, including land costs, total investments, construction expenses, operation and maintenance costs, and government support. Mbazima et al. (2022) also evaluated economic feasibility based on electricity generation sales and certified emission reductions.

Most RETs are economically feasible in terms of returns on investments. The Levelised Cost of Electricity (LCOE) is a constant value that shows an electricity-generating unit's total construction costs and operations over its lifespan (Naicker and Thopil, 2019). The LCOE of various RETs is lower for wind and solar energy than coal power (Doorga et al., 2022). Transmission costs and voltage variations may reduce reliability and power yields from wind farms (Akinbami et al., 2021). In this regard, a voltaic source converter can be used for overhead and cable transmission (Acaroğlu and García Márquez, 2023). The availability and low cost of materials to optimise electricity generation and transmission from wind farms provide an opportunity for low-cost production for households in South Africa (DMRE and DTICC, 2023). The same applies to the local availability of spare parts for RETs. A techno-economic analysis of solar PV equipment manufacturing in Steve Tshwete municipality shows that the material can be made at a lower cost in South Africa than imported (Semelane et al., 2021). The authors suggest this is more economically viable if governmental incentives are injected. The same applies to the High Voltage Direct Current (HVDC) for long-distance energy wheeling from wind farms in Turkey, in which its costs could not break even if there were no government subsidies (Acaroğlu and García Márquez, 2023). A study was done to assess economic viability and technical concerns arising from third-party transportation of energy between an Independent Power Producer (IPP) and an industrial consumer in South Africa (Murray, 2018). The LCOE and Net Present Cost (NPC) analysis showed wind energy generation is very economically viable and grid parity can be reached faster with larger wind systems. Wheeling costs were presumed to be very high, but the authors suggest that tariffs can offset the costs. However, deregulation of the electricity markets is required to open competitive markets. The recent draft of

SAREM shows that the government is fast-tracking the growth of all market segments as part of the unbundling of Eskom (DMRE and DTICC, 2023).

The recognition of the importance of RE in households is prominent in South Africa, as evidenced by the scrutiny of existing policies that hinder the implementation process. For example, the SAREM seeks to align its policies and programs with RE and storage locations. One of its interventions is to reactivate the 12i tax allowance incentive to support RE and battery manufacturing value chains (DMRE and DTICC, 2023). This intervention allows manufacturing companies to access incentives for smooth RE material availability. This is part of the bid to ensure access to RE by several households in South Africa.

Depending on the scale, RE sources such as solar PV can save energy costs for various entities ranging from small-scale energy at the household level (Kassem et al., 2023), rural microgrids (Akinyele and Rayudu, 2016) and even large national and international grids (Acaroğlu and García Márquez, 2023). With efficient energy integration on a smart grid, the municipalities have the potential to generate energy at economies of scale. A life cycle analysis done in Turkey by Acaroğlu and García Márquez (2023) showed that HVDC overhead transmission lines could reach a breakeven point one5 years earlier than the Voltage Source Converter (VSC) and the Line Commuted Converter (LCC) technologies.

South Africa has opportunities for ethanol production from vast sugarcane and forestry biomass in KwaZulu-Natal (eThekwini municipality, 2020) and municipal solid waste (Godfrey et al., 2020). These sources can be tapped for energy production at an economic scale. For example, an economic feasibility study for biogas production on a small island system showed a payback time of 4–5 years due to savings in maritime transport and avoiding waste disposal on land. Currently, municipalities do not have enough financial resources to invest in RET that can operate profitably (SALGA, 2021). Municipal financial capacity may not be a barrier to economically viable energy generation if co-financing sources from private investors are considered. This option is viable if private-public partnerships are prioritised to operate energy production at scale (DMRE, 2004; Mungodla et al., 2018; Nel, 2015).

2.3 Environmental feasibility

Global action on climate change mitigation is the major driver for the consideration of RE as part of the 2015 Paris Agreement (Mungodla et al., 2018; Mutombo and Numbi, 2019; Todd and McCauley, 2021). South Africa has the largest reserves of coal in Africa, contributing magnificently to greenhouse gas (GHG) emissions (Todd and McCauley, 2021). The use of RE sources such as solar and wind provides clean energy without any emissions (Kassem et al., 2023). A study by Heidari and Heravi (2023) showed that the use of solar PV in Iran will prevent 101 million tons of carbon dioxide emissions in 20 years. Life cycle analysis of solar PV in a small community in Nigeria showed that a solar PV microgrid (SPM) has an emission rate of 56.7 g CO2-eq/kWh, which equates to between 8.15% and 9.84% of the emission rates of the diesel system.

The implication of RE on the environment, in terms of household, wildlife, and aesthetics, is of utmost importance. Despite the perceived environmental benefits, the implementation of RE has several environmental implications concerning land and resources, esthetics and pollution (noise pollution) (Acaroğlu and García Márquez, 2023; Yaqoot et al., 2016). South Africa has vast land to support RE without any problems with the natural habitat. For example, 37% of the South African landmass is ideal for solar farms, while 57% is ideal for wind farms (Gaeatlholwe and Langerman, 2023). However, this is not the case in all municipalities. Some municipalities, such as eThekwini, do not have adequate sites to install wind turbines due to scattered settlements (eThekwini municipality, 2020). The operation of wind turbines generates noise that is not pleasant to residents nearby and may chase animals away from their natural habitat (Akinbami et al., 2021). Large-scale wind turbines create areas of low pressure, which is fatal to birds when they fly closer, leading to high fatalities (Akinbami et al., 2021; Rediske et al., 2021). Over 250 bird fatalities were reported for the first set of wind turbines installed under the Renewable Energy Independent Power Procurer Procurement Program (REIPPPP) program in South Africa (Akinbami et al., 2021). Mitigation strategies in that regard include proper planning and avoidance of such areas (Rediske et al., 2021). The Environmental Impact Assessment (EIA) is mandatory for large-scale installation of wind and solar farms, as per the South African NEMA. However, the EIA requires technologies such as wind turbines to be installed away from households to avoid noise or even switching off the turbines during certain periods of the year (Sustainable Energy Africa, 2017).

2.4 Technical issues to renewable energy and installations

Transitioning to RE provides a viable route towards a sustainable future by lessening the effects of climate change and enhancing energy security. However, broad implementation of RETs encounters considerable technical hurdles involving resource fluctuations, grid integration, materials science, system reliability, and potential environmental consequences. These challenges are explored further. Figure 1 shows the hierarchy of barriers to RE in South Africa.

2.4.1 Technical expertise and capacity

The South African government has set ambitious targets to increase the share of RE in the country's energy mix. Moreover, there have been some exemplary cases of RE implementation by local municipalities in South Africa. However, the overall technical expertise and capacity are inadequate (Mathu, 2014). Many municipalities lack the necessary skills, knowledge, and resources to plan, design, and implement RESs. The successful implementation of RES in South Africa is a critical challenge that requires the active participation of local municipalities. While the South African government has introduced legislation and funding to support RE initiatives, local municipalities' capacity and technical expertise to effectively implement these systems remains a significant obstacle (Baker and Sovacool, 2017). According to the authors, South Africa's wind and solar industries have been celebrated internationally, yet tensions exist within the national government between commercial priorities and requirements for economic development, including local content. The introduction of a regulatory framework for

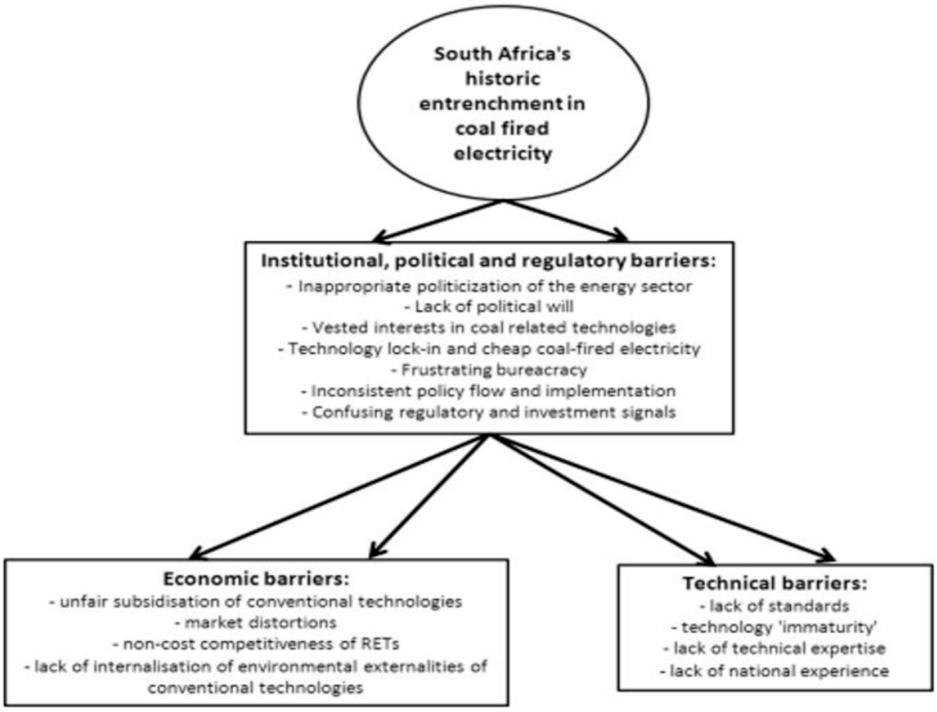

FIGURE 1
Hierarchy of barriers to RE in South Africa Source. Reprinted with permission from Tshehla (2014), p. 38, Copyright 2014 Stellenbosch University.

Renewable Energy Independent Power Producers (REIPP) has been a positive step, but more needs to be done to ensure that local municipalities have the necessary technical expertise and resources to capitalise on the country's abundant RE potential. Several studies have highlighted the abundance of wind resources in South Africa, which can position the country as a leader in wind power generation on the African continent if the resource is properly harnessed (Mathu, 2014; Olatayo et al., 2018). Olatayo et al. (2018) submit that the government's target of 8.4 GW of new-build installed wind capacity by 2030, with a recommendation for off-grid small wind technology to contribute to this goal, is commendable. However, off-grid technology is still in its infancy in the country, and public support policy programs are needed to promote the mass uptake of this technology. More importantly, enhancing the technical expertise and capacity of local municipalities in South Africa to implement RESs is crucial for achieving the country's RE targets. By addressing the challenges and implementing the proposed strategies, municipalities can develop the necessary skills, knowledge, and resources to plan, design, and implement RES, ultimately contributing to a sustainable energy future for South Africa.

2.4.2 Intermittency and reliability challenges

South Africa's energy landscape has undergone significant transformations in recent years, marked by a growing emphasis on incorporating RE sources into the country's largely coal-dominated electricity generation (Thopil et al., 2018). The authors argued that RE-based microgrids have garnered increasing attention as a viable solution for electrifying remote rural communities in South Africa, where access to the central national grid is limited. The decreasing costs of RETs, coupled with the high expenses of fuel-powered plants, have made microgrids an attractive investment option for various stakeholders. However, the integration of these distributed generators into the utility grid has raised technical concerns, such as the stability and reliability of the system (Thopil et al., 2018; Motjoadi et al., 2020).

Municipalities are struggling to incorporate these technologies effectively, mainly because of intermittency and reliability concerns. Solar and wind power, crucial components of the RE strategy, are intrinsically intermittent, resulting in fluctuating power generation and potential disruptions. This poses a significant obstacle for South Africa's already strained electricity grid (Thopil et al., 2018). Adding to the challenge, the reliability of RESs is often compromised by weather and other external influences, making them generally less dependable than conventional fossil fuel plants. Given the urgent need for reliable electricity, the implementation of RE sources must be carefully planned and executed to prevent further instability in the power grid. Adedeji. (2020) recommend a multifaceted approach to navigate the challenges of intermittency and reliability in implementing RESs. However, the authors emphasised that this approach should consider the physical, climatic, human, prosumer, and political factors influencing energy availability and sustainability in transitioning to a low-carbon economy. Additionally, utilising intelligent data-driven decision-making processes and drawing insights from power generation, transmission, and distribution sectors can play a crucial role in informing and optimising the deployment of RESs.

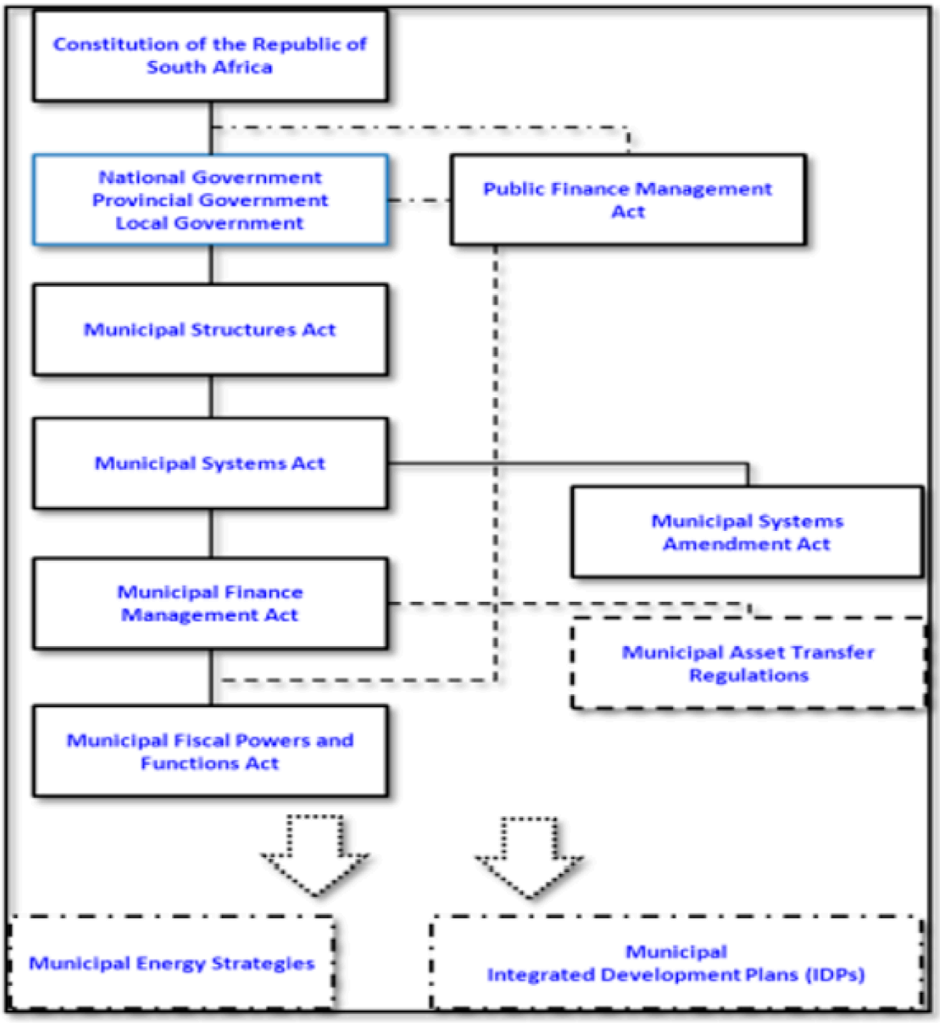

FIGURE 2
Local government's policy regulation representation. Reprinted with permission from Tshehla (2014), p. 38, Copyright 2014 Stellenbosch University.

2.5 Social issues

Successful transitioning to RE depends on social perceptions and attitudes from local communities, stakeholders and policymakers. The strictness and institutional dedication to promoting market value chains may depend on the perceptions of top management in the municipality. The same applies to adopting RET, which may encounter some taboos and resistance, as with biogas energy in Nepal (Yaqoot et al., 2016). The biogas project failed in Indonesia because of local taboos, and the same applies to the use of cooking fires in Nepal. Some investors may not be willing to invest in businesses under high-risk political and economic environments (Averchenkova et al., 2019). Therefore, this section describes social issues that need consideration to successfully implement RE at the municipal level.

South African communities have a positive perception of using RE, which could be triggered by pressing energy poverty issues. The DMRE conducted a household survey in 2013 and found a positive perception of their access to energy, with an average means score for the Electricity Satisfaction Index (ESI) of 63.8 out of 100, ranked second after social grants (DMRE and DTICC, 2023). A study done in Bergville, South Africa, showed that people are willing to adopt and pay for new technologies, such as solar sources, regardless of knowledge about climate change. Despite showing a positive perception of RE, people lack adequate knowledge of the benefits associated with its use, which might affect the adoption rate. For example, the DMRE (2013) survey further showed that only a few of the studied population (37%) understood that switching from conventional electricity to solar would save them energy costs. Therefore, awareness campaigns are needed to educate people on the importance of using RE, as suggested by DMRE (2013), concerning the Energy Awareness Index (EAI) on energy saving in South Africa.

Besides positive perceptions of adopting RE, local municipalities need to address various drawbacks. These can be socio-cultural, like displacement from culturally inherited land, perceived environmental pollution, trust issues on the technology developers, distortion of the social fabric and community development (Amigun et al., 2011). In some cases, the most suitable site for effective energy harvesting and storage might be traditional land with cultural history for respective communities. Displacing people from such areas may trigger resentment and rejection of projects. According to Pasqualetti (2011), wind farms faced some resistance in the USA because people were scared of being displaced from their traditional land, and the same was reported from a study done by Amigun et al. (2011) on the Eastern Cape biodiesel project. The site selection process must be done in consultation with local communities, traditional leaderships, and the Department of Agriculture Land Reform and Rural Development (DALRRD) to obtain communal land lease agreements (Mokone, 2020; Yaqoot et al., 2016).

Access to the RE for marginalised groups is of global interest. A study done in India by Pandyaswargo et al. (2022) recognises the need for equitable access to energy in off-grid rural areas; hence, they used several sustainability parameters, including social assessment, to design an appropriate RE system for off-grid areas. This consideration means that technology design must not overlook social issues such as acceptance and attitudes, which determine the specific applicability of a technology. Based on their findings, a people-centred private-public partnership business model and enabling policy and regulatory environment are crucial for RE's success. An empirical study was done by Li et al. (2023) to assess the effects of socio-economic productive capacity on RE development within the countries of *Brazil, Russia, India, China, and South Africa* (BRICS). The authors suggest integrating productive assets, business skills, industrial linkages and policymakers to boost the socio-economic potential of RE. It implies that transformative approaches integrating various stakeholders in a transdisciplinary innovation platform are needed rather than working in silos.

One of the reasons for public rejection is the lack of awareness of the importance of RET, in this case, their contribution to energy security and social and economic development (Naicker and Thopil, 2019). South Africa is a country that has a sensitive historical background where some ethnic groups who were displaced in marginalised areas lacked access to basic services and are living within high poverty lines. Mirzania et al. (2023) describe the concept of energy transition in terms of socio-technical and socio-political dimensions, highlighting these factors as crucial for promoting the transition to RES. These authors propose the just transition feasibility framework to evaluate how feasibility constraints may affect the South African RE transition ideology and its commitments to energy justice. The authors challenge the REIPPP that it triggers energy vulnerability and misrecognition of places. Energy vulnerability refers to a group of people living in energy poverty and likely to face energy insecurity. Therefore, the authors propose changing South African energy policies by realigning the minerals energy complex to just transition in terms of the RE electrification program, community development and empowerment and sustainable socio-economic structures. Implementing the REIPPPP program also brought several socio-economic problems, such as the loss of diverse perspectives on the roles played by government officials, foreign investors, and community representatives (Herbst and Lalk, 2015). Sharma et al. (2023) took an in-depth global examination of the green energy transition, focusing on green hydrogen. The study explains the need to establish socially sustainable energy structures that are cost-effective and stable. These structures will meet SDGs such as affordable and clean energy as well as increasing human welfare, reducing inequalities, employment creation, sustaining cities, climate change mitigation and reducing poverty in alignment with the South African Local Government Association (SALGA) Energy Efficiency (EE) and RE strategy (SALGA, 2021).

Acknowledging these factors, the government has enacted robust policies to promote a just transition across all economic sectors, including energy accessibility. The IRP aligns with constitutional rights to ensure RE contributes to energy security for disadvantaged groups (DMRE, 2019). Additionally, energy initiatives must address the socio-economic concerns outlined in the NDP (National Development Plan), such as employment generation, skills development, and rural advancement (Naicker and Thopil, 2019). Municipalities can be crucial in leveraging community resources to lead RE awareness campaigns.

The issue of social perceptions is not only limited to local communities but also to stakeholders involved. The RE investors are attracted when there are low investment risks driven by several factors such as a conducive political environment, evidence-based information on technological capacity, enabling policy environment creating viable markets for RE and institutional arrangements within the country. Nel (2015) conducted a multistakeholder study to understand stakeholder perceptions towards introduction and investments in RE. The stakeholders were mainly academics and private and public sector employees. From their perspective, investment in RE may be risky due to structural challenges such as the lack of market forces, decision-making, and planning. The authors found that stakeholders' perceptions indicate a lack of consensus on the roles and responsibilities of various stakeholders. They suggested representative stakeholder participation through varied stakeholder appointments, building consensus through public awareness, and clarifying policies and goals. Lastly, the government should guard against actions that may lead to politically based risks or losses.

Municipalities must overhaul their institutional structures and enhance their credibility with investors. Akhtar et al. (2023) report that top management awareness plays a mediating role in the relationship between institutional and market factors. Clear out unethical issues that create more risks in RE investments can be counteracted by regulations to bring perpetrators to accountability and implement a Just Transition Tribunal (JTT) to prosecute perpetrators (Mirzania et al., 2023).

2.5.1 Policy, institutional and regulatory issues

Enabling policies and a robust legal and regulatory framework provide a foundation for the smooth operation of RE initiatives. South Africa has established strong policies and legal structures to support the transition to RE in a manner that fosters equitable economic development and creates a favourable environment for sustainable businesses. The South African Constitution (Act No. 108 of 1996) enshrines rights that align with the National Energy Policy (DMRE, 2019), including the right to a healthy environment. The White Paper on Energy Policy (1998) outlines a comprehensive legal framework for the energy sector, emphasising emission reduction, improved energy access for marginalised communities, enhanced governance, economic stimulation, health management, and supply security through diversification.

There are programs in which municipalities can leverage funding and support for RE in both on-grid and off-grid areas. The Integrated National Electrification Programme (INEP) is a South African Government non-grid policy to help finance Eskom and municipalities to clear up electricity backlogs as per the White Paper policy (SALGA, 2021). The recently launched South African Just Energy Transition Investment Plan (JET-IP) sets out the scale of need and the investments required to support programs linked to decarbonisation. The program was set up to explore zero-carbon technologies such as green hydrogen and spearhead a transition in the energy sector by protecting vulnerable groups from coal and other fossil-related emissions. Implement rigorous approaches for creating an enabling policy environment and defining the role of the private sector, promote local energy chains from micro to medium enterprises thus stimulating local economic development and creating a low-emission economy through opportunities for technological innovation and private investment.

The issues of grid integration and energy storage are vital in the transition to RE. South Africa is facing an energy crisis characterised by extensive blackouts, putting economic development at risk as well as causing the loss of local and foreign investors whose businesses are affected. However, there are policies to promote a smooth transition to RE by enhancing battery storage value chains. The South African government's DTIC, DSI and DMRE, in consultation with civil society groups, the private sector and research institutions, came up with SAREM (DMRE and DTICC, 2023), which focuses on enhancing RE and battery storage value chains in support of the transition process for societal benefits and contribution to economic revival.

The bidding process for the implementation of RE at scale can be done rigorously and transparently, ensuring that it aligns with the government's economic development structures. The REIPPPP is a government-led bidding program initiated in 2011 to allow a rigorous selection process for RE service providers (DMRE and DTICC, 2023). This programme allows municipalities to bid for energy production and sales as a service provider as stipulated in the SALGA strategic plan.

The government has legislation to regulate electricity distribution from producers to the grid and customers. The Electricity Act (Act 41 of 1987) mandates that NERSA control electricity distribution, marketing, and tariffs. All the uses of more than 5 GWh per annum must register with NERSA (DMRE, 2019). They regulate the quality of supply, mediate disputes and address customer complaints. Regulatory reforms have been done since 2021, including loosening up the registration process and removing the licensing requirement of IPP (DMRE and DTICC, 2023). In addition, SSEG has been allowed to provide electricity to the grid, and they have been incentivised in some municipalities.

2.5.2 Policy development for renewable energy autonomy

Achieving RE autonomy in South African municipalities hinges on strategic policy development and effective resource mobilisation. Energy independence necessitates robust legal frameworks that support decentralised electricity generation and distribution, as underscored by the South African Renewable Energy Masterplan (DMRE and DTICC, 2023). This plan emphasises the crucial need for localised regulatory policies that empower municipalities to independently produce power, urging collaboration with national regulators to streamline licensing for small-scale RE producers. However, policy fragmentation remains a significant obstacle, hindering municipalities from fully utilising their renewable resources despite technical feasibility (Mirzania et al., 2023).

Policy incentives play a vital role in encouraging municipal energy investments. Research suggests that government incentives like feed-in tariffs, tax credits, and subsidized loans can accelerate local energy independence (Naicker and Thopil, 2019). Furthermore, municipalities can leverage international climate finance initiatives for RE project funding (Ali et al., 2023). However, the absence of clear municipal policies on RE integration could render these financial incentives ineffective, highlighting the need for policy alignment between local and national governments to create a supportive environment for energy transition (Thango and Bokoro, 2022).

While South Africa has introduced various policies to promote RE, a practical policy framework is essential for successful municipal-level implementation. Significant gaps persist in aligning national energy policies with local realities, hindering municipalities' ability to facilitate RE projects due to regulatory restrictions, financial constraints, and policy ambiguity (DMRE and DTICC, 2023; Eskom, 2019). Although the Renewable Energy White Paper (DMRE, 2004) laid the foundation for RE policy, it lacks direct mechanisms for municipal-level integration. Similarly, the Integrated Resource Plan (DMRE, 2019) focuses primarily on large-scale independent power producers, limiting opportunities for municipal or community-led initiatives. Municipalities' reliance on Eskom's centralized electricity supply further restricts their ability to develop independent RE projects.

The Electricity Regulation Act (Act four of 2006) presents regulatory challenges, requiring municipalities to obtain licenses from NERSA for electricity generation and distribution. While recent amendments have relaxed licensing requirements for private entities generating up to 100MW, municipalities still face approval processes for procuring or generating electricity from independent sources, leading to bureaucratic delays. The Municipal Finance Management Act (MFMA, 2003) also poses challenges, with stringent financial governance rules and limited grant allocations hindering municipalities' ability to secure funding for RE projects. While the Energy Policy Roadmap for Local Government (SALGA, 2021) acknowledges these constraints, it lacks concrete implementation strategies to empower municipal RE investments (Gaeatlholwe and Langerman, 2023).

Learning from successful international models, such as Germany's Renewable Energy Act (EEG, 2000) and Denmark's municipal energy cooperatives, can inform the development of effective policy frameworks in South Africa. Adopting similar approaches, such as introducing municipal energy cooperatives and providing regulatory support for localized grid integration, can empower municipalities to take ownership of their renewable energy future.

2.5.3 Renewable energy autonomy, a case of Germany and Japan

This section explores how national policies and local initiatives interact to shape energy transitions, comparing Germany and Japan as contrasting case studies. In Germany, the federal structure grants local governments, especially municipal energy companies, significant autonomy, yet this independence is not absolute. Despite their constitutional authority, these entities largely function as extensions of higher levels of government, with state-level regulations defining their operational scope and creating variances in autonomy across different federal states (Kuhlmann and Bogumil, 2021). This dependence can lead to financial instability, necessitating reliance on state and federal support, which limits their administrative and entrepreneurial capabilities despite their vital role in providing energy services.

On the other hand, Japan's energy system exhibits strong centralization. Dominant utilities, supported by the Ministry of Economy, Trade, and Industry (METI), actively resist decentralization, citing concerns about grid compatibility. Their control over energy transmission and distribution effectively restricts local energy access. However, growing public disapproval of nuclear energy, increased municipal participation in energy generation, electricity market deregulation, and local environmental groups' advocacy of local electricity retail initiatives are creating opportunities for local involvement. Hager and Hamagami (2020) demonstrate these opposing dynamics in Germany and Japan, which exemplify how national policies and local efforts intricately influence energy transitions.

While some research emphasises policy as the primary driver of innovation, potentially neglecting the influence of local actors and portraying them as passive recipients of policy decisions (Jordan and Matt, 2014; Maruyama et al., 2007; Musall and Kuik, 2011), grassroots activism is a crucial factor in RE implementation. Local communities often first recognise the economic and demographic advantages of RE investment, ensuring a "socio-political space" for its development and ensuring long-term support for RE policies (Jordan and Matt, 2014; Levin et al., 2012). Therefore, understanding these local-national dynamics is crucial for designing effective policies that create positive feedback loops and accelerate the global response to the climate crisis.

The German and Japanese experiences highlight the importance of local authority in RE implementation. Local recognition of the economic and demographic benefits of RE investment (Musall and Kuik, 2011) plays a crucial role in creating the "socio-political space" required for RE technology development (Lauber and Jacobsson, 2016, p. 148) and stabilising national energy transitions, which prevents the reversal of low-carbon policies. As Rosenbloom et al. (2020) argue, integrating the transition into society by cultivating a supportive "ecosystem" of local authority and private organisations is essential for this stabilisation.

2.5.4 Land and space issues

South Africa is well-positioned to capitalise on its abundant RE resources, particularly solar and wind power (Pegels, 2010; Jain and Jain, 2017). The country's favourable climate, with an average of 2,500 h of sunshine per year and significant wind potential, presents a promising opportunity for municipalities to invest in RESs (Jain and Jain, 2017). More importantly, local municipalities in South Africa face a pressing need to adopt RESs to decrease reliance on fossil fuels and combat climate change (Department of Energy, 2019). However, a critical aspect of this transition is the significant land and space needed to implement these systems.

Land requirements vary significantly depending on the RET employed. Solar photovoltaic (PV) systems, for instance, generally require 1–2 ha of land per megawatt (MW) of installed capacity (IRENA, 2021). Wind farms, which harness kinetic energy, necessitate a larger footprint, ranging from 1 to 5 ha per MW (Council, 2017). Biomass power plants, relying on organic matter for fuel, demand the most significant land allocation, requiring approximately 5–10 ha per MW (IEA Bioenergy, 2018). Beyond the immediate footprint of energy generation, RESs also require space for supporting infrastructure. This includes transmission lines to transport electricity, which can require 10–20 m of space per kilometer of line (Eskom, 2022). Also, substations which are vital for voltage regulation and distribution, demand approximately 0.1–1 ha each. Furthermore, energy storage facilities are crucial for grid stability with intermittent renewables, which occupy roughly 0.1–1 ha per facility, depending on the technology and scale (IEA, 2020).

These land and space demands present challenges for South African municipalities. Acquisition or leasing of suitable land can be a protracted and complex process, often involving competing land uses and stakeholder negotiations (National Planning Commission, 2012). Space limitations may constrain RE deployment, particularly in densely populated urban areas. Furthermore, environmental concerns, such as habitat disruption and visual impact, may need careful management and mitigation strategies (DEA, 2017). However, these challenges are not insurmountable. Opportunities lie in innovative land management strategies. Co-location of RE projects with existing land uses like agriculture (agrivoltaics) or conservation areas can optimise land use efficiency (WRI, 2019). Compact designs and vertical integration of infrastructure can minimise space requirements. Crucially, meaningful community engagement and participatory planning processes can facilitate smoother land acquisition and ensure public support for RE initiatives (DFFE, 2021).

While the land and space implications of implementing RESs are substantial, careful planning, innovative approaches, and community collaboration can enable local municipalities in South Africa to successfully navigate these challenges and accelerate the transition toward a sustainable energy future.

2.5.5 Maintenance and operational costs

Despite South Africa's bright and promising effort in early RE, energy efficiency has not yet yielded substantial results (Pegels, 2010). According to the author, the RE sector faces challenges due to these technologies' inherent costs and risks, which subsequently affect investment decisions. Although the government has implemented support mechanisms like feed-in tariffs, their true impact requires further scrutiny. However, internal and external political influences surrounding South Africa's RE sector are complex.

While the wind and solar industries have gained international recognition, the national government balances commercial goals with fulfilling economic development mandates, including the promotion of local content. The incorporation of RES by local municipalities is critical for both decarbonising the energy sector and meeting national climate change targets (Department of Energy, 2019). However, the long-term economic viability of these initiatives hinges on effectively managing the maintenance and operational costs related to RES infrastructure. Hence, it is important that cost-reduction strategies are explored, such as leveraging economies of scale through large-scale projects, utilising technological advancements in RES (IRENA, 2021), and ensuring public-private partnerships (PPPs) to distribute financial responsibilities and expertise (Baker, 2016; National Treasury, 2004). Ultimately, proficient maintenance and operational cost management are essential for achieving a sustainable and affordable transition to renewable energy at the local level throughout South Africa.

3 Materials and methods

This research investigates the technical, economic, and environmental viability of supporting households and business entities in adopting RES by local municipalities in South Africa. Using a qualitative approach as shown in Figure 3, the study sought to gather detailed insights into the perceptions and opinions of key stakeholders regarding this support. Semi-structured interviews were conducted to capture a comprehensive understanding of the subject matter. Employing a purposive sampling method, stakeholders were selected based on a social network approach. The qualitative data obtained from these interviews were analysed using thematic analysis, which helped identify and interpret trends and patterns in the data. This process produced detailed narratives reflecting the experiences and viewpoints of the stakeholders involved. Participants included representatives from uMsunduzi local municipality (R1), Trade and Investments KwaZulu-Natal (TIKZN) (R2), the Council for Scientific and Industrial Research (CSIR) (R3), Nelson Mandela (R4), Bhesheni Energy Solutions (R5), Botswana University (R6), and Newcastle local municipality (R7). The insights gathered from these stakeholders reveal diverse perspectives on the feasibility of supporting households and economic entities by local municipalities in implementing RES in South Africa. Each interview lasted approximately 30–40 min, was recorded with the participant's consent, and later transcribed for analysis. This well-structured approach aimed to ensure both flexibility and consistency in data collection across all interviews. By engaging individuals with practical experience and knowledge in RES implementation in South Africa, the study sought to generate rich, meaningful data, offering a thorough understanding of the technical, economic, and environmental feasibility of supporting RE adoption. This strategy enhances the credibility of the findings. For ethical reasons and to facilitate efficient theme analysis, pseudonyms such as R1, R2, and so on were employed to track findings back to specific municipalities and respondents. In addition, the Ethics Research Committee of the University of KwaZulu-Natal (UKZN) approved the study.

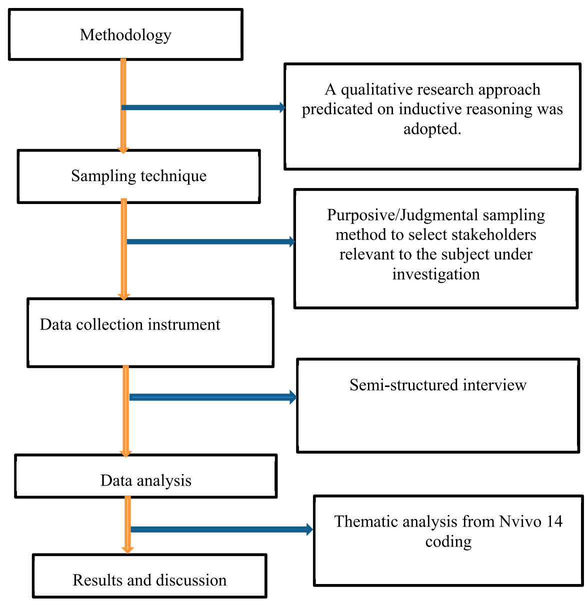

FIGURE 3
Methodology flowchart Source: Authors' compilation.

3.1 Research participants

The study adopts face-to-face interviews to collect in-depth, non-numerical data from seven (7) stakeholders in the RE sector at the local government level. The participants included representatives from three municipalities, three academic and research institutions, and one renewable energy company who were purposefully chosen based on their significant roles in the RE sector. Before each interview, the study's objectives, ethical considerations (such as anonymity, confidentiality, and informed consent), and the interview guide were communicated. A detailed interview guide was carefully designed to gather the information necessary to meet the study's objectives, ensuring the integrity and accuracy of the data collected. Additionally, observation notes were taken during the interviews to provide a comprehensive account of the discussions. This well-structured guide aimed to facilitate an exploration of the participants' insights into the technical, economic, and environmental feasibility of supporting households and businesses in implementing RE solutions in South Africa.

3.1.1 Sample

Although the sample size was limited to seven (7) participants, saturation was still achieved. Studies have shown that saturation can often be reached with sample sizes ranging from 5 to 30 in single-case and phenomenon studies (Guest et al., 2006; Kuzel, 1992: 41; Morse, 1999: 225). The use of purposive sampling was advantageous, enabling researchers to collect rich, detailed data and gain a holistic understanding of the participants' experiences. This information informed insights regarding the technical, economic, and environmental feasibility of supporting households and economic entities by the local municipalities in implementing RES in South Africa. The purposive sampling approach was specifically designed to capture the genuine experiences of stakeholders concerning these factors. A qualitative research methodology was adopted for this study, allowing for an in-depth exploration of the participants' experiences related to the phenomenon under investigation (Anso, 2014). This study sought to understand participants' perspectives on supporting households and economic entities by the local municipalities in implementing RES in South Africa. The purposive sampling method was particularly effective, yielding rich data and an in-depth understanding of the participants' experiences, which were then used to derive valuable insights into the essential role of local government in promoting renewable energy skills within communities.

3.2 Data analysis

Data analysis involves several processes such as coding, transcription, editing, and verification (Atiku et al., 2024). In this study, thematic analysis was used to transform raw data into a manageable size, revealing the patterns and trends (Cooper and Schindler, 2008). The audio recordings of interviews were transcribed verbatim and arranged into themes according to their content. In order to reduce the risk of confirmation bias, the authors engaged in independent coding, which was later verified by an external qualitative researcher to ensure accuracy, consistency, and objectivity (Kaupa and Olusegun Atiku, 2020; Steinke, 2004). Collaborative discussions among the authors led to a consensus on the preliminary themes, which were then further validated by the external investigator. In addition, a thematic analysis was carried out (Ganiyu and Genty, 2022; Atiku et al., 2024b). Transcriptions were imported from Microsoft Word, which facilitated the organisation of qualitative data into themes. The themes were compared with trends from previous studies (Bell et al., 2019), and the researchers' personal experiences played a significant role in interpreting the data.

4 Result and discussion

Stakeholder interviews and surveys were conducted to gather different perspectives on implementing RE to support households and economic entities at the local municipality level. Diverse views were given concerning the feasibility of implementing RES at the local municipality level. The participants' responses indicate their understanding of the phenomenon under study and how the process should be done. For instance, the decision-making process, enforcement policies, the readiness of local government to implement RE and assessing whether it is worth doing. The thematic analysis revealed four major themes: technological, economic, social and environmental. These themes correspond with the perspectives evidenced in the literature.

4.1 Technical feasibility

This theme emerged from the data analysis as one of the perspectives on the technical, economic and environmental feasibility of implementing RE at the local municipality level. The decentralised nature of the RETs allows for easier integration into existing infrastructures. Hence, local municipalities can benefit from advancements in smart grid technology to optimise energy distribution and manage consumption effectively. As homeowners and businesses adopt RES, municipalities can establish partnerships with service providers to enhance system reliability and efficiency. Participants further emphasised that technical feasibility is not a challenge when implementing RE (R1, R2, R6 and R7). They attributed this to the availability of conducive conditions such as adequate radiation and wind. According to one of the participants, each local municipality should find the best technology for their area based on existing maps available in the database. This view is presented below.

> Look what it is feasible or not is another story. I can tell you now just off the top of my head, I have seen it happen. It is feasible, but I told you the problem is that from a governance point of view, municipalities gotta get the houses in order (R2).

Apart from conducive climatic conditions for harnessing solar and wind energy, there are a lot of organic materials for waste-to-energy projects. According to R2, there is a lot of animal manure emanating from cattle production, piggeries, poultry and dairy farms in areas such as the uMgungundlovu District. Another participant pointed to the challenges in waste management at landfill sites and wastewater treatment sludges as possible opportunities for waste-to-energy projects. Private companies may negotiate with local municipalities to develop contracts that allow them to symbiotically manage organic wastes. Such concessions should be 20–30 years long to allow enough time for returns on investments.

> *That's at the Bizana roadside, so there are opportunities there. As I said, Davao, where you guys are located has opportunities there more rural municipalities. I think it becomes a bit of a challenge, but if, like I said, if policies are there that allow even rural homesteads where they, you know, cow dung, the biomass and methane generation there for point of use application becomes very useful. There is a vacuum of policies and I think how can the government encourage that* (R3).

From a techno-economic point of view, waste in the energy sector is a grey area that needs many optimisations through science and innovation and the application of best practices. In this regard, there are protocols to be followed in terms of licencing and standards and norms to follow. According to one of the participants, there are no established policies to regulate SSEG within their local municipality. Municipal laws should regulate the generation of energy above the expected limit for each generator.

> After all, they have been engaging COGTA and SALGA for assistance in developing context-specific regulations for renewable energy. There is a policy gap in this area in terms of sustainable management of waste-based projects. Land availability is not a challenge when it comes to RE, according to the participants. There is enough land in South Africa to support RE. (R7).

The response shows that the participant suggests that the focus should be on policy, financial and human resources, not land. According to another participant, even Newcastle municipality is considering making use of the airport land, which belongs to the municipality, for RES. This finding corroborates Sussman's (2008) study that submits that the critical role of the local government in climate change must enhance their resolve to adopt policies that promote best RE practices.

4.2 Economic feasibility

Economic viability is another issue of concern when it comes to investments in certain technologies. Local companies are business entities that earn revenue through activities such as buying and selling electricity. Therefore, any transition should not negatively impact their income generation. The participants mentioned innovativeness in terms of the economic feasibility of RE. One important issue is leveraging international markets and linking with other sector value chains. Products made from low carbon footprint innovations have high returns on investments due to the absence of carbon taxes. One of the participants highlighted the importance of RE in alleviating energy insecurity, which has multiplier benefits such as increased local investments due to guaranteed energy availability. It has socio-economic benefits such as local economic development. The view is captured below.

> And once you can do that in a way that mitigates the impact of both load shedding and climate change, then the local government becomes an investor, investor-ready destination. (R2).

From the response, business entities and local governments will reap the economic benefits of investing in RES when several technological considerations are taken into account to ensure successful implementation. This outcome is in line with Mbazima et al. (2022), who stated the investment that the local government can undertake, and Rediske et al. (2021), who outlined several economic benefits accruable to the local governments and the people, which include revenue generation and emission reduction.

4.3 Environmental feasibility

Environmental feasibility is not an issue of concern regarding clean energy sources such as solar, wind and hydro. Perspectives from some of the participants show that RE is environmentally friendly. One of the participants raised an idea about RE implementation as an approach to sustainability compliance as per the SDGs. In this regard, the municipality is making efforts to include it in their energy mix how to provide an example of simple solar power systems for heating in their municipal offices.

> So, whether it is energy or it is water, whatever the service is, the technical, economic and environmental feasibility is there. (R2).

Local municipalities are ready to implement RE, taking into consideration the environmental, technical and socio-economic perspectives. However, a few of the participants who perceive the local government as unprepared believe that governance structures need to be established beforehand, as outlined by R2. Additionally, R6 and R7 identified several hindrances, such as financial constraints and inadequate human resources. This revelation agrees with the submission from the empirical study conducted by Tshehla (2014) where the barriers to RE implementation at the local government level was classified as institutional, political, and regulatory. This classification summarises the issues that surround RE implementation at the local government including human capacity, policy and resources.

4.4 Social feasibility

Social feasibility was generated as one of the themes to explain the implementation of RE at the local municipality level. One of the highlighted social concerns of the study is regarding employment across the coal value chain, anticipating potential resentments from affected parties. Local municipalities, mandated to foster economic development within their jurisdiction, must carefully consider this aspect. Municipalities must seek assurances from RE providers that the transition process will create jobs without displacing existing ones. This response is shown below:

> *…issue coming up soon of curtailment and another issue that that that is going to come on board is the extent to which RE operations uh that platform can coexist with your traditional fossil fuel ones because you do not want to have one completely obliterating the other. And then you can have huge problems in terms of unemployment. There's gotta be a transition where the influx of RE vendors and players does not displace the existing ones. So that level of harmony is going to be quite crucial in the not-too-distant future, particularly because you do not want to have a RE program at the expense of people being employed.* (R1).

The concern raised above shows the average thinking towards embracing RES, hence the need for municipalities' support in implementing RES in households and business entities. Another evident concern was whether the municipality should be given autonomy to implement RE. In this regard, most participants believe that if local municipalities are given the liberty to purchase electricity directly from IPPs, they will be able to operate their revenue sustainably. The finding agrees with Efthymiou et al. (2022) who posit that when it comes to the energy transition, the municipality-led option is the best for the people because the Municipality's decisions will always be to favour the grassroots. The draft of SAREM also included the liberation of municipalities to purchase their energy directly from IPPs (DMRE and DTICC, 2023). This inclusion creates opportunities for their revenue streams, as one participant mentioned.

> *I think the idea of the end goal is for our municipality to also purchase energy from IPPs and then not so that the in-concert idea of the policy is to write it in such a way that our electricity department will have the power to deal with these types of things and not every time go to council. So it is to make it easier once the national government allows us to purchase from independent power producers. It is not easy, but that's what we try to do with that policy to purchase from IPs as an electricity department in future.* (R4).

Transitioning to the RE pathway addresses several issues of both national and international concern, such as climate change, resource extraction, energy insecurity for future generations, and the future of economic development (DMRE, 2013). This trajectory needs a strict approach in all governmental atmospheres to communicate a single language and also carry the people along (Amigun et al., 2011). Many participants strongly believe that participation in RE should be mandatory for all local municipalities to fully commit to this course. It is a question of integrating policies that guide municipalities in strictly enforcing the RE agenda.

5 Practical implications

This study examines perspectives on the feasibility of implementing RE support for households and economic entities at the local municipality level in South Africa. The study significantly enriches the understanding of the technical, economic and environmental feasibility of implementing RE in households and economic entities, highlighting the pivotal role of the local municipalities. The research provides evidence-based recommendations for Local authorities, enabling them to develop policies for best practices for the technical, economic and environmental feasibility of implementing RE to support households and business entities at the grassroots level. Additionally, the study provides four actionable reforms that local governments can implement for RES support for households and businesses at the grassroots. These include 1. Streamline regulations - simplifying permitting processes, implementing net metering policies, and establishing robust Renewable Portfolio Standards. 2. Provide financial incentives - Encourage investment through tax credits, grants, and the issuance of green bonds. 3. Modernise infrastructure - Upgrade the electric grid, promote energy storage solutions, and implement smart grid technologies. 4. Build capacity and awareness - Offer training programs, launch public awareness campaigns, and actively engage communities in renewable energy initiatives. Furthermore, the study emphasises how local municipalities can take advantage of the resources at their disposal and develop RE initiatives to transition from a carbon-based economy to RE. It stressed caution regarding job security despite the need to embrace RE initiatives at the grassroots level. The study advocates for RE autonomy for local municipalities. It underscores its advantages in terms of economic benefits and capacities at the community level. Additionally, this study lays the groundwork for future studies in RE adoption at the grassroots level.

6 Limitation and future research

One of the major limitations of this study is its methodological framework. The exclusive use of qualitative methods, particularly inductive reasoning based on interviews, narrows the range of data and perspectives considered. Adopting a quantitative or mixed-method approach would be advantageous to strengthen the rigour and validity of future research in this field. This shift would enable the collection of both qualitative and quantitative data, leading to a more comprehensive understanding of the phenomenon under investigation. Additional the small sample has also been recognisd as a limitation. Future studies should expanding their sample size and including the community leaders to enrich the analysis and promote a more thorough exploration of the relationships between local governments, community engagement, and RE implementation.

7 Conclusion

This study evaluated the economic, techno-social and environmental feasibility of implementing RE systems in local municipalities. The implementation of RE should be gradual, allowing municipalities to have autonomy in implementing RE initiatives and addressing various national and international concerns, including climate change, resource extraction, and energy security for future generations. The economic development trajectory is adopting RE to be mandatory for all stakeholders and regulating SSEGs within local municipalities without established policies.

Given the country's climatic conditions, solar and wind energy stand out as the most technically viable options for assessing the feasibility of RE implementation in South African municipalities. The Northwest province offers significant solar energy potential, while coastal areas in the Western, Eastern, and Northern Cape hold promise for wind energy. Additionally, biomass energy presents an opportunity for energy generation, leveraging organic waste from landfills, agriculture, and municipal sanitation systems.

Most RE technologies are economically feasible in terms of returns on investments if production is done at economies of scale, proper tariffs are set to meet production and wheeling costs, and more subsidies are channelled towards RE material costs. Although municipalities are financially constrained, they can operate RE systems through PPPs. The use of RE is environmentally friendly and is one of the approaches to climate change mitigation strategies. The use of solar and wind energy provides clean energy with fewer emissions compared to coal-based energy production. The only environmental issues of concern include noise pollution, the death of birds from wind turbines, and the disturbance of natural habitats.

Social perceptions and attitudes from local communities, stakeholders and policymakers play a role in implementing and adopting RE. Generally, people have a positive perception since they are energy insecure. However, the awareness level for the benefits of RE is very low. Transition to RE has social implications that should be considered, and these include displacement from culturally inherited land, perceived environmental pollution, trust issues with technology developers, distortion of the social fabric, and community development.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University of KwaZulu-Natal Human and Social Science Research Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants

provided their written informed consent to participate in this study. The manuscript presents research on animals that do not require ethical approval for their study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

OO: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. ES: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. TM: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenrg.2025.1517054/full#supplementary-material

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