

An Analysis of the Adoption of Virtual Power Plants in the South African Energy Sector

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Abstract

Since the onset of load shedding in 2007, which reached an all-time high of over 6900 hours in 2023, South Africa has sought alternatives to diversify the energy mix and to increase energy production capacity. This is evidenced by the rapid increase in the country's renewable energy capacity through the Renewable Energy Independent Power Producer Procurement Programme, which aims to reach over 19 GW by 2030. Further driving this transition is South Africa's ratification of the 2016 Paris Agreement, aiming to reduce greenhouse gas emissions. Given the increase of these distributed energy resources, a platform is necessary to integrate them effectively with the national grid. Virtual power plants are intelligent, cloud-based solutions that integrate distributed energy resources, storage systems, and controllable loads into a real-time, unified system to enhance grid flexibility. Therefore, this research evaluates the feasibility of adopting virtual power plants to integrate renewable energy sources within the South African energy sector. Using a social, technical, economic, environmental, and political (STEEP) approach, this study addresses the current limitations of the national utility, Eskom, in its demand-response-focussed virtual power plant, identifying critical challenges and opportunities for a broader, renewable-centric model.

Keywords

Virtual power plants, distributed energy resources, renewable energy

1. Introduction

Energy demand is growing across many countries globally due to economic development and population growth (Ritchie, Rosado and Roser, 2020). The authors elaborate that if this increased demand for energy is not offset by improvements in energy efficiency and production then the global energy consumption will continue to increase annually. According to Mossie, Khatiwada, Palm and Bekele (2025), security of electricity supply is necessary for socioeconomic growth, sustainable development and industrialisation.

The African continent has significant population growth resulting in higher energy demand. However, due to the current energy insecurity, its ratio of energy consumption to world energy consumption remains small. In 2022,

the International Energy Agency (IEA) reported that approximately 600 million people in Africa, predominantly in sub-Saharan Africa, lacked access to electricity (IEA, 2022). South Africa is also one of many African countries struggling to meet its growing energy demand.

1.1 The South African Energy Sector

South Africa experienced its' worst load shedding in 2023, with over 6,900 hours of power cuts frequently reaching stages 5 and 6 (Fernández, 2025). These higher stages resulted in daily blackouts of up to 10 to 12 hours for businesses and households. Research by Ateba, Prinsloo, and Gawlik (2019) highlights that even lower stages, stages 1 and 2 (2 to 4 hours) of loadshedding have a drastic economic impact, as stage 1 power cuts can still cause significant daily production losses for major industries such as mining, manufacturing, and service, thus lowering the economic growth of the country. However, as of 13 March 2026, South Africa had reached a significant milestone of 300 consecutive days without load shedding (Eskom, 2026). Eskom (2026) reports that this is due to the continued recovery and improvement of its generation fleet, anchored by its Generation Recovery Plan, launched in 2023. The plan focuses on reducing unplanned outages, increasing planned maintenance, repairing key power stations, deploying distributed energy resources (DERs) to strengthen supply in remote and high-demand areas, and installing smart meters to improve grid stability (Eskom, 2025).

Due to the abundance and low cost of coal, South Africa still relies heavily on coal for electricity production, accounting for approximately 77% of its energy mix as of 2025 (DMRE, 2026). However, to alleviate the load shedding crisis, address concerns about the environmental impact of fossil fuels, and meet its ratified Sustainable Development Goals (SDGs) on net-zero emissions targets, the country has sought cleaner alternatives. As a first step, in 2010, the South African Department of Energy (DoE) formulated the Integrated Resource Plan (IRP) 2010-2030 (IRP 2010), which is an electricity infrastructure development plan to forecast the country's future energy demand needs, for the 20-year period from 2010 to 2030 (DoE, 2019). The IRP aims to predict future energy demand and determine the energy mix that would meet this demand while accounting for its costs and the environmental impact of electricity supply (DMRE, 2023). The IRP is a living document that is regularly updated, and the current IRP is IRP 2025, which maps the energy generation capacity from 2025 to 2050. According to the current IRP 2025, South Africa's approach is in line with international trends and developments, as it continues to pursue a diversified energy mix to ensure security of supply while complying with its emission reduction plan (DMRE, 2025). In addition to the IRP policy, the South African government established the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), managed by the Department of Mineral Resources and Energy (DMRE), which awards renewable energy projects to successful private bidders. Through this programme, the South African government added approximately 6000 MW to the grid by the end of 2023 (DMRE, 2023).

As South Africa attempts to diversify its energy mix through renewable sources, this research investigates the adoption of intelligent systems, particularly virtual power plants and demand-response solutions, to optimise the integration of renewable energy in its' energy mix.

1.2 Research Objectives and Questions

The primary objective of this study is to determine the feasibility of adopting virtual power plants for renewable energy integration in the South African energy sector, with a focus on Eskom, the country's primary power utility.

The research objectives of this study are:

- To determine the feasibility of the adoption of virtual power plants in the South African energy sector using the STEEP model.
- To determine factors that may prevent the South African energy sector from transitioning into an intelligent power-controlled system that incorporates virtual power plants to integrate distributed energy sources, using the STEEP model.
- To determine the possible benefits of adopting virtual power plants in the energy sector.

Given the objectives, the research questions are:

- What is the feasibility or potential of adopting virtual power plants for renewable energy in the South African energy sector?
- Which factors may prevent the South African energy sector from transitioning into an intelligent power-controlled system that incorporates virtual power plants to integrate distributed energy sources?

- What are the benefits (for example, economic or sustainability) of adopting virtual power plants in the South African energy sector?

A virtual power plant is a new innovative concept of smart grid aggregation (Chudý et al., 2022). Virtual power plants are intelligent systems that integrate distributed energy resources, controllable loads, and energy storage systems to support grid operations and participate in the electricity market. Fang, Yu, and Xin (2022) argue that a virtual power plant (VPP) is a key technology in increasing the penetration of renewable energy.

Eskom already has a Virtual Power Station (VPS), which acts as a virtual power plant; however, it has historically operated as a demand response system that aggregates load reductions from large customers (such as aluminium smelters) rather than generating renewable energy. This means that Eskom's VPS, developed since the 2008s functions primarily as a Demand Response (DR) tool that aggregates large industrial customers with interruptible loads to reduce demand during shortages (Enerweb, 2026).

2. Literature Review

2.1 Challenges faced by the South African Energy Sector

The loadshedding challenge in South Africa became the centre of discussion as of the 2020s, with several articles and news publications disseminated on the matter (Banderker and Naidoo-Chetty, 2024; Ngoepe-Ntsoane, 2025; Cloete, Davids, Van der Merwe, Meyer, and Pienaar, 2025). Load shedding is a manual reduction of load by switching the power off, implemented by Eskom to prevent the collapse of the national electricity grid and to ensure supply and demand balance (Eskom, 2023). As previously mentioned, the South African energy sector, primarily Eskom, faced a crisis due to its inability to meet the country's growing energy demand. This is evident in Figure 1, which shows Eskom's monthly breakdown of generation capacity from April 2022 to November 2023.

South Africa experienced the worst load shedding in 2023, according to Statista (2025), and the timeline in Figure 1 is deliberately chosen to reflect the trend in generating capacity during that period.

Figure 1 also shows the monthly ratio between the maximum availability and all unavailability occurrences (Planned Capability Loss Factor (PCLF), Other Capability Loss Factor (OCLF), and Unplanned Capability Loss Factor (UCLF) in percentages, excluding renewables, IPPs, and international energy imports (Eskom, 2023). As shown in the diagram, the energy availability factor (EAF) decreased from 2022 to 2023. Ideally, the EAF should be 70% to 80% at most; the remaining 20% unavailability of the power station should account for the planned capacity loss factor (PCLF), unplanned capacity loss factor (UCLF), and other capacity loss factors (OCLF) (Madel, 2023).

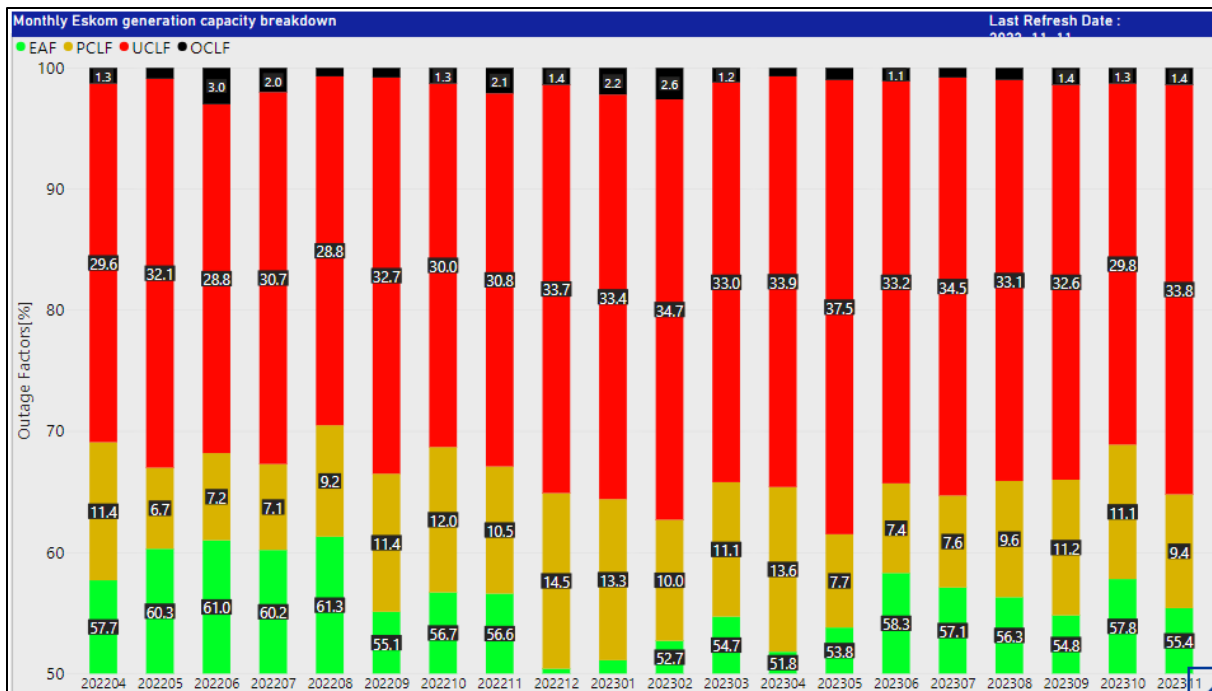


Figure 1. Eskom's monthly breakdown of generation capacity from 2022 to 2023 [Eskom Data Portal (2023)]

Despite the fact that, in 2021, South Africa ranked first in Africa by electricity production capacity (Global Economy, 2021), Eskom was failing to cope with the imbalance of its energy supply and demand, which left loadshedding as a last resort.

Another challenge is the environmental impact of electricity generation in South Africa. According to Jain and Jain (2017), South Africa is the 7th-largest international coal producer, and, most of its electricity is generated from coal. As of 2021, South Africa was the 6th largest producer of electricity from coal globally (Statista, 2023). In 2022, the country generated 405 million metric tons of carbon dioxide ($MtCO_2$) emissions from fossil fuels, and currently, South Africa is the 15th biggest emitter of carbon emissions (Statista, 2023). Therefore, the country still needs to curb its greenhouse gas emissions by adopting cleaner energy sources, such as solar and wind.

Upon the review of literature on challenges faced by the South African energy sector, Naidoo (2023) argues that loadshedding is the culmination of poor management, poor leadership, and ageing infrastructure; and it also the results of the country's complex regulatory environment which hampers economic growth. Ateba, Prinsloo and Gawlik (2019:1326), agree that the causes of loadshedding are the "ageing grid and increasing consumer demand". In contrast, Gwaka (2025) argues that there is an energy imbalance in supply and demand because of Eskom's endeavours in powering disadvantaged communities to address past social and economic injustices brought about by the apartheid government, but without prior planning on generation capacity improvements.

On 23 January 2023, the South African President cited a lack of investment in generation capacity, poor maintenance, corruption, and criminality as the main causes of the energy crisis (SA Government, 2023). While the debate over these exact causes is ongoing, Eskom has taken it upon itself to implement practical solutions to address the challenges at hand.

2.2 Potential Solutions

Based on several research studies as well as the current global trend (for example, projects in Europe, China, and Australia), governments worldwide are investigating renewable energy solutions and smart grid energy systems such as VPPs to resolve energy challenges (Liu, Xing, and Li, 2023; Ullah, Arshad and Nikahi, 2023; Zhang, 2022).

2.2.1. An overview of intelligent systems in the energy sector

Due to rapid technological developments (such as artificial intelligence, Internet of Things, and smart systems), globalisation, and population growth; energy demand has increased. Electricity has become critical to economic development and human well-being, especially in South Africa, where the electricity supply is insufficient to cater to its demand. This increase in energy demand puts a strain on power networks as well as the global environment (Zhang, 2021). Therefore, as a preliminary solution, distributed energy resources (DERs) gained more attention and rapid development due to their low environmental impact, reliability, economic and flexibility advantages (Zhang, 2021). However, due to the stochastic, intermittent and fluctuating nature of DERs, this affected their reliability as well as grid stability (Zhang, 2022). Consequently, a virtual power plant (VPP) concept was developed to attempt stabilisation of the national grid.

The VPP concept can be traced back to 1997, when it was first proposed by Awerbuch and Preston (Zhang, 2022). Currently, VPP research is mostly concentrated in Europe and North America, where typical projects, according to Yu, Fang and Liu (2019) include:

1. the EU virtual fuel cell power plant project (in Denmark, Netherlands and Spain);
2. the EU FENIX project (in France, Spain and the United Kingdom);
3. the German VPP project; and
4. demand response (DR) and renewable energy projects in North America, *to name a few*.

Figure 2 illustrates recent VPP projects worldwide.

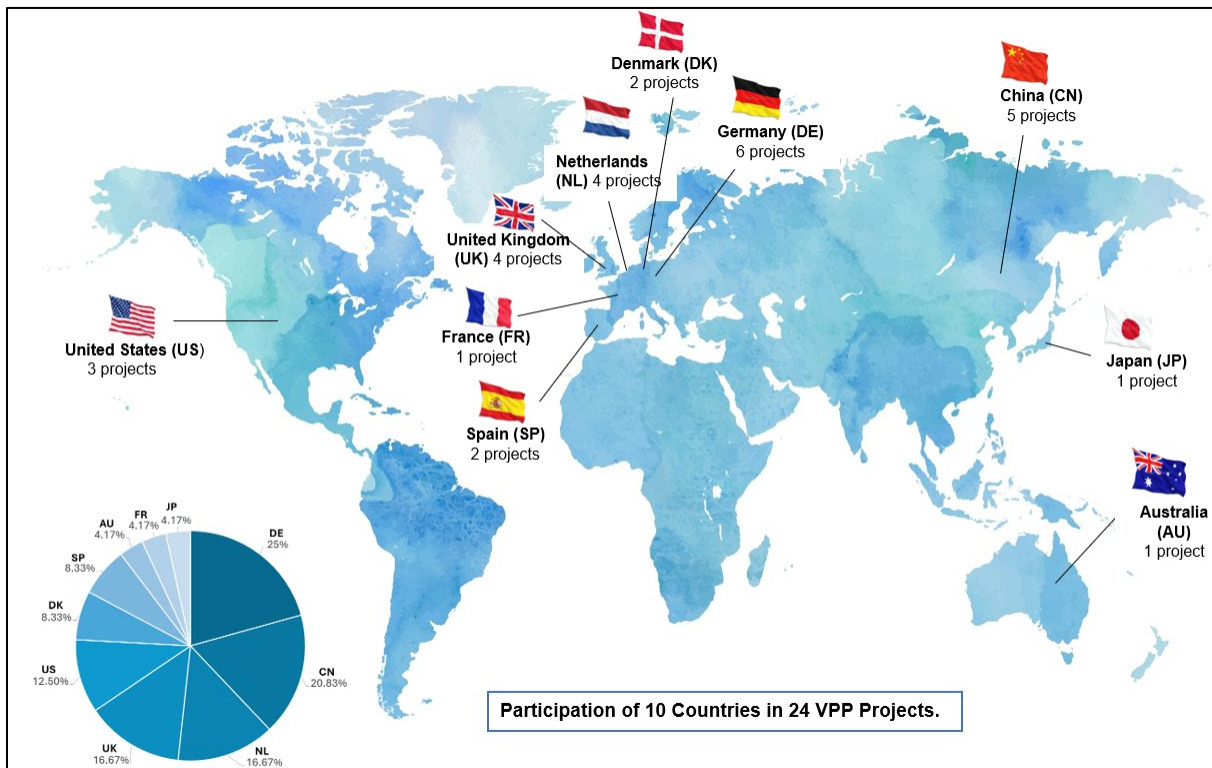


Figure 2. VPP projects worldwide [Source: Venegas-Zarama et al. (2022)]

Several definitions of a VPP exist:

Definition 1: A virtual power plant (VPP), as defined by Yu et al. (2019), is generally a cloud-based distributed power plant that integrates the capabilities of heterogeneous distributed energy sources (DER) to increase power generation, as well as to sell or trade electricity on an open market.

Definition 2: Zhang (2022: p.3) defines a VPP as “a cloud-based platform which connects several DERs, flexible loads, storage facilities, and can provide real-time monitoring through a two-way communication network, to

establish a decentralized and distributed power plant for improved energy management as well as to facilitate cross-system trading.”

Definition 3: “Virtual Power Plants (VPPs) are a new innovative concept of smart grid aggregation” (Chudý et al., 2022). Fang, Yu and Xin (2022) argue that a virtual power plant (VPP) is a key technology in increasing the penetration of renewable energy.

VPPs enable the aggregated management of diverse power technologies in systems of different complexity, connectivity, and size (Venegas-Zarama et al., 2022). They comprise of a coordinated cluster of generators for flexibility, as well as energy storage systems that render demand and response management capabilities (Chudý et al., 2022). A typical structure of a VPP is depicted in Figure 3.

Figure 3 shows that the VPP local control centre is a central hub for both data and power exchange between distributed energy resources (conventional power plants, photo-voltaic power plants, and wind power plants), the energy storage system, dispatchable loads, and electric vehicles.

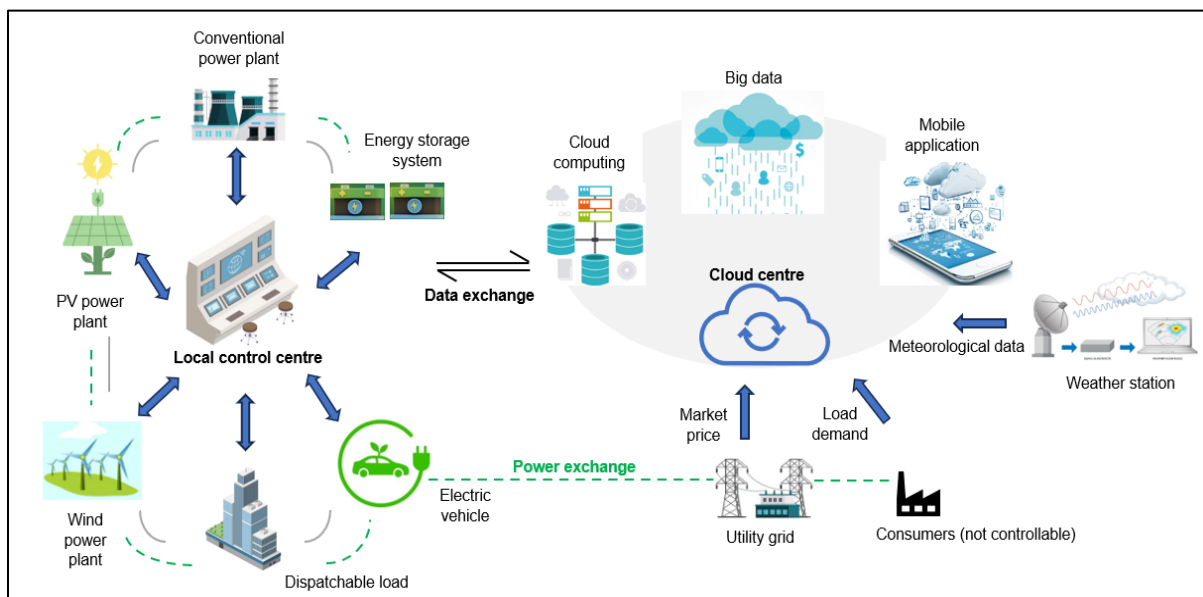


Figure 3. Structure of a VPP [Redrawn from: Yu et al. (2019: p.455)]

From the above description and diagram, it follows that, for an operational VPP, the following systems are required:

- a robust communication system that allows for real-time coordination of distributed energy resources;
- an energy management system (EMS) for management, monitoring, and control of the different energy devices;
- an optimised energy storage facility; and
- lastly, to reach its full potential, optimisation of the VPP.

Other elements of intelligent energy systems include demand response systems (to balance supply and demand), energy storage systems, and smart grids for intelligent power control, all of which form part of the VPP ecosystem.

Benefits of VPPs

The main benefits of VPPs, according to Yu et al. (2019), are:

- **Protection of the environment and renewability:** VPPs use renewable energy sources and energy-saving technologies, which reduce the use of fossil fuels.
- **High efficiency:** VPPs ensure the correct integration of internal distributed energy resources (DERs), effective management of controllable loads, and compatibility between traditional energy and renewable energy. VPPs also optimise power production and load demand (Venegas-Zarama et al., 2022).

- **Synergy and interactivity:** VPPs can integrate several types of DERs in different areas and achieve coordinated dispatching through energy management systems (EMS). They can interact with market participants and can assist in network management (Yu et al. 2019).
- **Balance:** VPPs can balance demand and supply by replacing traditional energy generation during peak periods.

Potential challenges with VPPs

Although the implementation of VPPs offers several benefits, several studies indicate significant obstacles, namely:

- scheduling algorithms, uncertainty factors, as well as technical and economic limitations (Zhang, 2022).
- cybersecurity and data privacy, as well as issues with regulation and compliance (Abdelkader et al., 2024).

2.3 Summary

In recent years, there has been rapid development in research of intelligent systems in the energy sector. This research encompasses virtual power plants (VPPs), the smart grid, distributed energy resources (DERs), renewable energy and energy storage facilities. Governments worldwide have also taken an interest in distributed power generation technology brought about by DERs, due to its benefits (Zhang, 2022). Several studies focus on optimising VPPs through various ways such as stochastic optimal scheduling models (Guo, Cai, Shi, Xie, and Zhang, 2021), as well as through optimising VPP elements such as the use of smart batteries in energy storage (Chudý et al., 2022).

Although VPP research (and the practical projects that follow) seems to be making great strides, this is not the case in Africa. As shown in Figure 3, it is quite clear that Africa has not had any VPP-related projects yet. Furthermore, in South Africa, which is the focus of this research project, the adoption of renewable energy sources is progressing at a slow pace. Nel (2017) argues that there are major barriers that hinder the successful deployment of IPPs for renewable energy production. These include a lack of effective decision-making and transparent planning, which encourages corruption, alongside a lack of political commitment. Furthermore, several regulations remain unfavourable to IPPs, such as land licences and permits to generate energy. Finally, the underdeveloped renewable energy market in South Africa features low competition, adding uncertainty for new industry players who could provide required investment (Nel, 2017). On the contrary, the International Renewable Energy Agency (IRENA) reported that, as of 2024, South Africa still leads Africa in the adoption of renewable energy sources, with 13.5 GW of renewable energy capacity, fuelled by private-sector investments and supportive policies such as the REIPPPP.

This research therefore investigates the potential of adopting VPPs in the South African energy sector.

3. Methods

As established, intelligent energy systems (for example VPPs, smart grids, and microgrids) are prevalent in developed regions such as Europe, North America, Australia, and China, whereas Africa lags behind global development in this field. Consequently, there are currently no universally adopted VPP models suitable for South Africa, as the technology remains novel and local infrastructure and market conditions differ significantly from those where VPPs are already established. Hence, the initial step of this research was to develop a conceptual model tailored to the South African context.

Development of the Conceptual Model: A viable conceptual model based on the social, technological, economic, environmental, and political (STEEP) model developed by Ullah et al. (2023, 2024) was used, as indicated in Figure 4. A STEEP analysis tool resembles the strengths, weaknesses, opportunities and threats (SWOT) analysis in that it assesses the challenges, opportunities, and benefits of the VPP in the energy sector market. It is an effective tool in

the South African context because it scrutinizes the challenges posed by social, technological, environmental, economic, and political implementation barriers that impede the adoption of these intelligent energy technologies.

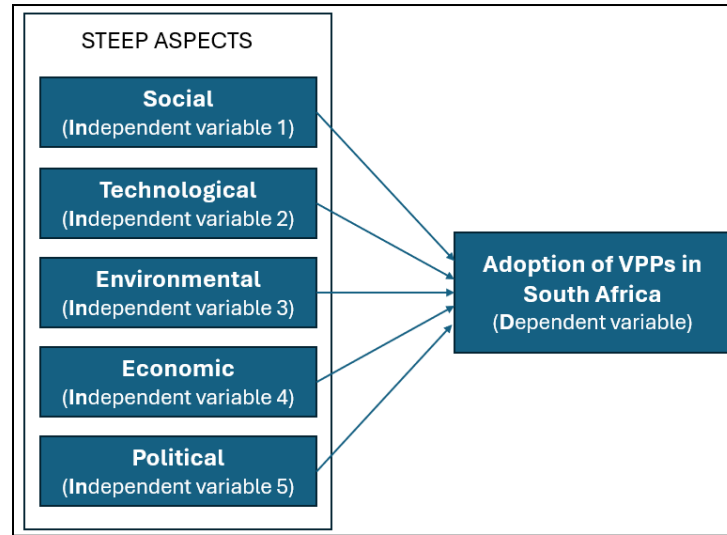


Figure 4. Proposed STEEP conceptual model

The conceptual model implies that each of the STEEP (social, technological, environmental, economic, and political) aspects is an independent variable that influences the adoption of VPPs in South Africa, the latter being the dependent variable.

3.1. Research Approach and Design

To establish a comprehensive foundation for this study on Virtual Power Plants (VPPs), a comprehensive literature review was first conducted. The primary gap that was identified is the lack of empirical literature addressing VPP adoption specifically within the South African energy landscape.

The study adopted an exploratory qualitative research design because the adoption of virtual power plants (VPPs) for renewable energy integration remains an emerging and under-researched phenomenon in the South African energy sector. A qualitative approach was appropriate because the research sought to obtain expert insight into the feasibility, perceived benefits, and implementation barriers associated with VPP adoption, rather than to test predetermined statistical relationships. This design enabled the researchers to capture context-specific interpretations from participants with direct knowledge of renewable energy, grid operations, demand response, and intelligent energy systems.

A case-study approach was selected, with Eskom as the focal case, because Eskom remains the dominant electricity utility in South Africa and plays a central role in generation, transmission, system balancing, and demand-side interventions. The case-study design was therefore suitable for examining VPP adoption within its real-life institutional and operational context. It also allowed the study to consider the specific technical, regulatory, economic, and organisational conditions that may influence the transition from a demand-response-oriented virtual power station towards a broader VPP model capable of aggregating distributed renewable energy resources.

The STEEP framework provided the analytical structure for the research design by ensuring that VPP adoption was examined from social, technological, environmental, economic, and political perspectives. This was important because VPP implementation is not only a technical intervention, but also depends on stakeholder acceptance, grid readiness, investment requirements, environmental considerations, and supportive policy and market arrangements. The use of semi-structured interviews further supported this design by allowing consistent coverage of the STEEP dimensions while permitting participants to elaborate on issues that were specific to their professional experience and the South African energy context. Figure 5 outlines the applied methodological framework, illustrating the research perspective, mode of inquiry, and data collection instrument in alignment with the adopted conceptual model.

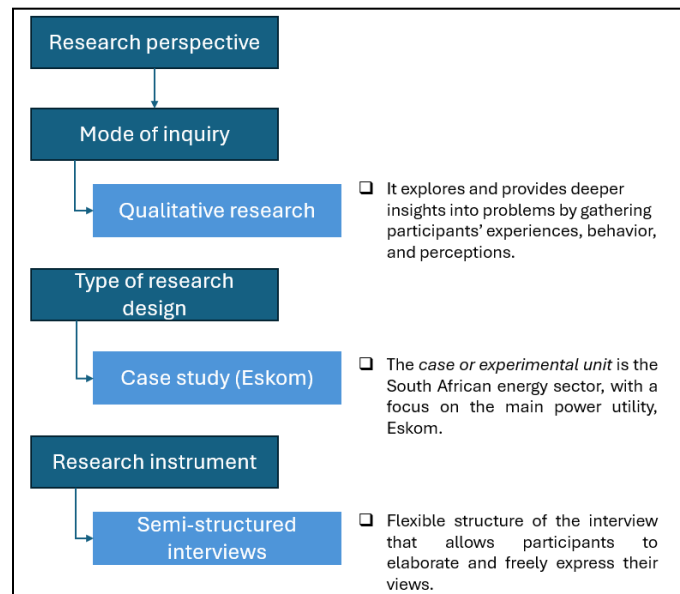


Figure 5. Research approach and design

4. Data Collection

4.1 Research Sampling

As virtual power plants (VPPs) are a novel technology within the South African context, it was necessary to select Eskom participants with specific experience in both VPPs and renewable energy sources; therefore, purposive sampling was employed. Since the participants for the interviews were identified based on combined VPP and renewable energy experience, a rare combination in this field of study in South Africa, only eleven participants were identified who matched the selection criteria. Of the eleven potential participants, only six attended the interviews; the remaining five participants were either unavailable or had transferred to other departments and were therefore unable to participate in the research. Despite the limited number of participants, the data collected during the interviews is considered rich due to their significant expertise and experience. The five Chief Engineers who participated possessed more than 15 years of experience in renewable energy and/or virtual power plant technology, while the sixth participant had over 10 years' experience.

4.2 Data Collection and Analysis

Qualitative research was considered the most effective mode of research inquiry given the small sample size, and the data was collected by means of semi-structured interviews with the identified Eskom experts. The STEEP analysis tool was employed to develop twenty interview questions, and the interview instrument aimed to identify the feasibility, benefits, and potential challenges of adopting VPPs for renewable energy in South Africa in each of the STEEP categories.

5. Results and Discussion

5.1 Results

The following discussion presents both the challenges and benefits of VPP adoption based on the participants' responses as per the delineated STEEP analysis tool.

A. The feasibility or potential of adopting virtual power plants for renewable energy in the South African energy sector

i. Social perspective

From a social perspective, all participants agreed that there is significant potential to adopt VPPs for renewable energy in the South African energy sector. However, there were conflicting views on the conditions required to ensure the successful implementation of VPPs. While two participants believed that social acceptance was unnecessary, the

majority (4 out of 6) believed that public approval makes the adoption smoother. They noted that it increases participation, curbs infrastructure vandalism, and provides better access to land for projects.

ii. Technological perspective

The participants agreed that VPPs are technically feasible and crucial for aggregating growing renewable energy capacity in South Africa. However, they noted that a lack of infrastructure, limited skills, and the intermittency of renewable energy sources could hinder adoption, despite benefits such as enhanced flexibility and fast frequency control.

iii. Environmental perspective

From an environmental perspective, the participants agreed that adopting VPPs is feasible and provides environmental benefits by scaling up, resulting in cleaner energy and reduced load shedding. However, participants also noted the potential issues that may arise with the disposal of the equipment of renewable energy sources (RES).

iv. Economic perspective

VPP adoption is economically feasible; however, there were concerns of potential high implementation costs.

v. Political perspective

From a political standpoint, VPP adoption in South Africa is feasible; however, the participants noted that concerns remain given that current policies and frameworks do not sufficiently accommodate VPPs.

B. Factors that may prevent the South African energy sector from transitioning into an intelligent power-controlled system that incorporates virtual power plants to integrate distributed energy sources

i. Social challenges

The identified potential challenges include potential public resistance and a reduced willingness to participate. Also, misalignment of stakeholders is a social challenge considering risks to project roll-out, delayed approvals, execution difficulties, and project delays.

ii. Technological challenges

Participants identified several technological challenges that may constrain the adoption and effective implementation of virtual power plants (VPPs) in the South African energy sector. A primary concern relates to the readiness of the existing grid infrastructure to accommodate high levels of distributed and renewable energy resources. Inadequate or ageing infrastructure may limit the technical feasibility of VPP deployment and may require targeted upgrades to support bidirectional power flows, real-time monitoring, interoperability, and secure communication between distributed energy assets, aggregators, utilities, and system operators. These infrastructure limitations may also create integration challenges, particularly where legacy systems are not designed to interface with advanced digital platforms and decentralised energy technologies.

Cybersecurity was also identified as a significant technological risk. Because VPPs rely on digital platforms, cloud-based systems, data exchange, and remote coordination of distributed energy resources, they may increase the exposure of the electricity system to cyber threats. These risks include unauthorised access, data privacy breaches, malware attacks, system manipulation, and hacking, any of which could compromise operational reliability and, in severe cases, affect the security of the broader energy system.

A further challenge concerns the availability of technical expertise and institutional knowledge required to design, implement, operate, and govern VPP systems. Participants indicated that local professionals may have limited understanding of VPP architectures, enabling technologies, data requirements, communication protocols, and integration mechanisms. This skills and knowledge gap will create uncertainty regarding the selection, deployment, and management of the technologies required for successful VPP implementation.

iii. Environmental challenges

Select participants identified the disposal of RES products presents a major concern; however, most of the participants believe that VPPs pose no or insignificant environmental challenges as they are merely aggregators.

iv. Economic challenges

High initial financial investment was identified as an economic challenge since VPPs require substantial upfront investment in cybersecurity, communications infrastructure, and grid upgrades. Also, funding from government initiatives or private investors, both local and international, was identified as crucial.

v. Political challenges

The participants identified national policies and frameworks as a significant potential challenge: policies and frameworks require a major revamp and update to accommodate the aggregation of renewable energy using VPPs. Parties involved in the required modifications include the National Energy Regulator of South Africa (NERSA) and the South African government. Also, the current tariff design does not accommodate VPPs as aggregators of renewable energy sources.

C. The benefits of adopting virtual power plants in the South African energy sector

i. Social benefits

The potential social benefits associated with the adoption of virtual power plants (VPPs) include improved energy security, enhanced consumer participation, employment creation, environmental sustainability, and potential cost efficiencies. Increased participation in VPPs may strengthen power system flexibility by enabling the coordinated aggregation and dispatch of distributed energy resources, thereby supporting demand–supply balancing and potentially reducing the need for load reductions during periods of system constraint. VPPs may also enable consumers and prosumers to participate more actively in electricity markets by contributing flexible capacity, generation, or demand response services, with the possibility of generating additional revenue streams.

From a socio-economic perspective, the deployment, operation, maintenance, and digital management of VPP-related technologies may create employment opportunities across technical, data-driven, and energy service functions. In addition, VPPs can support environmental sustainability by facilitating the integration of renewable energy resources into the electricity system, thereby contributing to reduced reliance on higher-emission generation sources. Improved system flexibility and grid stability will also support more efficient utilisation of generation assets and infrastructure, which could contribute to reduced operational costs over time and, where appropriately translated through market and regulatory mechanisms, may assist in moderating electricity costs for end users.

ii. Technological benefits

The adoption of virtual power plants (VPPs) may offer important technical benefits for power system operation. By aggregating distributed energy resources and coordinating their dispatch, VPPs can enhance grid flexibility and support system stability through services such as voltage control and fast frequency response. In addition, VPP platforms may improve real-time grid visibility by integrating data from multiple distributed assets into a unified operational system, thereby supporting more informed monitoring, control, and decision-making.

iii. Environmental benefits

The adoption of VPPs may contribute to environmental sustainability by enabling greater utilisation of distributed renewable energy resources and reducing dependence on coal-based generation. By supporting the integration and coordinated dispatch of cleaner energy sources, VPPs can contribute to lower greenhouse gas emissions and a reduced carbon footprint. In turn, reduced emissions may also have financial implications for high-emitting utilities, such as potentially lowering carbon tax liabilities where measurable emissions reductions are achieved.

iv. Economic benefits

The adoption of virtual power plants (VPPs) may offer economic benefits for utilities, consumers, and the broader electricity system. By aggregating and coordinating distributed renewable energy resources, VPPs may reduce reliance on higher-cost generation sources, including diesel-based generation during peak demand periods. This may create operational cost savings for Eskom and, where savings are reflected in tariffs or commercial arrangements, may contribute to lower electricity costs for consumers, particularly large energy users.

VPP adoption may also improve the investment case for cleaner energy by demonstrating the ability to integrate distributed resources into system operations in a coordinated and commercially viable manner. In addition, improved network visibility, flexibility, and asset utilisation may enhance network performance and reduce maintenance-related costs over time.

v. Political benefits

Politically, if VPPs were to be successfully adopted, grid reliability will be improved and consequently reduce load shedding. This will in turn have a significant positive political benefit for the government.

Figure 6 illustrates the key preconditions for successful VPP adoption for renewable energy in South Africa.

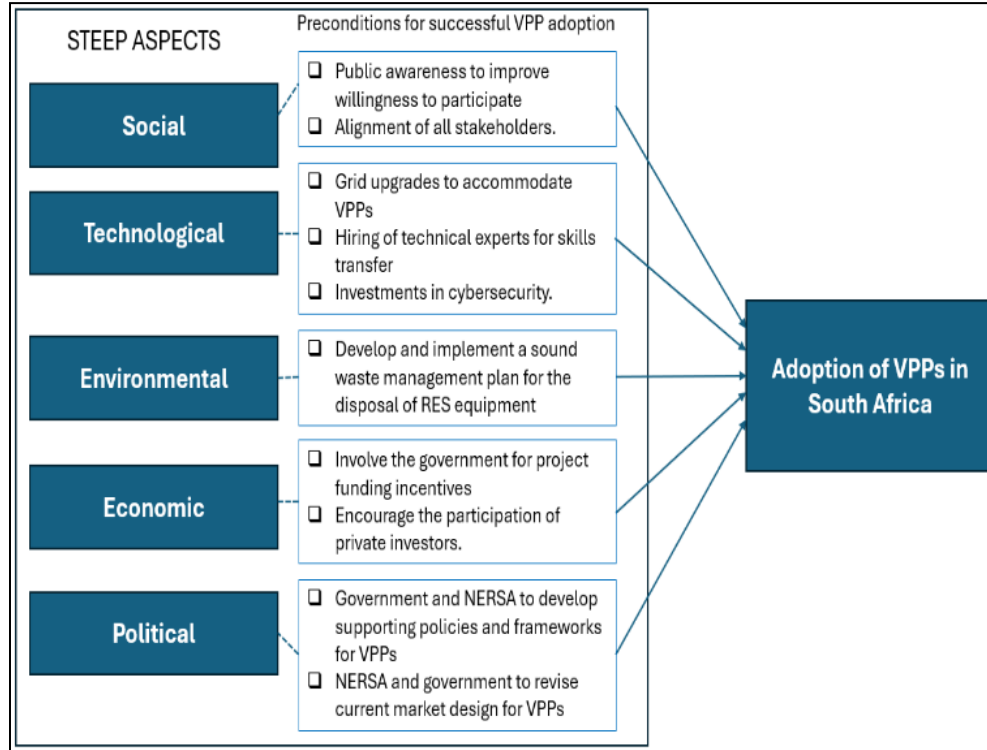


Figure 6. Conditions for successful VPP adoption in SA

5.2 Discussion

The aim of this research was to determine the feasibility of adopting virtual power plants for renewable energy in South Africa. Therefore, the developed research questions (based on the STEEP analysis tool) sought to identify any potential challenges impeding the successful adoption and the benefits thereof. Subject matter experts from Eskom were interviewed, and their responses were evaluated to address all research questions.

Based on the responses, it is highly feasible to adopt VPPs in South Africa; in fact, there is already a virtual power station (VPS) that serves as a VPP, albeit with limited functionality (demand response only) (Enerweb, 2026). Therefore, research participants believed that the grid could adopt VPPs, provided a few preconditions were met.

The necessary preconditions were the following:

- From a **social perspective**, public awareness of VPPs is necessary to improve the participation of both consumers and producers. It is also crucial to consider all relevant stakeholders to ensure smooth project execution.
- From a **technological perspective**, the existing electricity grid lacks adequate infrastructure to support VPP adoption; therefore, significant upgrades are first required.
- From an **environmental perspective**, VPPs are primarily aggregators of renewable energy sources; therefore, they do not pose significant pollution (waste disposal) risks. However, renewable energy sources pose a potential waste management problem for manufactured products such as batteries and solar panels. A comprehensive lifecycle waste management plan is therefore essential to mitigate potential disposal risks.
- From an **economic perspective**, upgrading electricity grid infrastructure requires significant and capital-

intensive investment. The only way to finance projects of such scale is through government incentives and individual local and foreign funding.

- From a **political perspective**, it is necessary for the South African government, as well as the National Energy Regulator of South Africa (NERSA), to implement new regulations and update market structures to accommodate VPP adoption in the country.

6. Conclusion

This study examined the feasibility of adopting virtual power plants (VPPs) to support renewable energy integration in the South African energy sector. The paper addresses an important research gap, as existing VPP research and implementation are concentrated largely in Europe, North America, China, and Australia, while limited empirical work has examined VPP adoption within the South African context. By applying a STEEP framework and drawing on expert insights from Eskom, the study provides a context-specific analysis of the social, technological, environmental, economic, and political conditions that may influence VPP adoption.

The findings indicate that VPP adoption in South Africa is feasible and has potential value for improving grid flexibility, enhancing real-time system visibility, supporting renewable energy aggregation, reducing reliance on high-cost and carbon-intensive generation, and enabling broader participation in the electricity system. The study also contributes by identifying the key preconditions required for successful implementation, including public awareness and stakeholder alignment, grid infrastructure upgrades, cybersecurity investment, technical skills development, appropriate waste-management planning, investment mechanisms, and updated regulatory and market frameworks.

However, the study is exploratory and is limited by the small purposive sample, which was necessary given the limited number of local experts with direct knowledge of both VPPs and renewable energy integration. The findings therefore provide rich, expert-informed insight but should not be generalised without further empirical validation. Future research should expand the participant base to include regulators, municipalities, independent power producers, aggregators, technology providers, investors, and large energy users. Further studies could also examine VPP business models, regulatory design, cybersecurity governance, pilot implementation, and the technical architecture required to support scalable VPP deployment in South Africa.

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