

An Integrated Approach to Renewable Energy Strategic Planning: Energy Policy Optimization and Artificial Intelligence for Sustainable Development

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Abstract

Strategic energy planning has become the central focus of energy developments and sustainability in pursuit of energy security and reliability. Energy policy reform is the key framework in shaping the vision and roadmap to energy transition. It provides a strategic direction for economic development, job creation and energy investments. In addition, the impact of effective and strategic energy planning has the potential to ensure successful implementation of such frameworks for energy developments. To achieve this, an integrated approach which comprises of tools, techniques, framework and technologies must be deployed to ensure adequate energy value chain. Advance technologies optimizing artificial neural networks has responded to potential renewable energy risks by deploying modern intelligence to risk response and risk mitigations. Technological developments in artificial intelligence have not only brought capabilities of control and monitoring but has enhanced the speed, reliability and predicting modelling. Therefore, integrated planning approach to renewable energy must incorporate both energy framework and capabilities of technological advancement for future outlook. The reason for this is to ensure sustainability, economic growth, energy security and energy investments. The data was analyzed through qualitative and quantitative research methods. The results obtained from the proposed methodology shows that policy reform is the key driver and backbone of energy development and critical factor for social, environmental and economic growth. Furthermore, the deployment of advanced technologies such as artificial neural networks have enhanced the preventative and predictive models and improves grid reliability and stability. For example, the optimization of AI technologies plays a critical role in generation and distribution networks by significantly mitigating the impacts of intermittency through deploying sophisticated techniques of machine learning, deep learning and data acquisition generated by renewables to improve energy storage, decision making and reducing carbon emission.

Keywords

Energy Planning, Renewable Energy Transition, Artificial Intelligence, Decarbonization, Policy Optimization

1. Introduction

Globally the energy demand has significantly increased over the years, in year 2024 it has increased by 4.3% compared to year 2023 which it increased by 2.5%. The rise in energy demand has been notable since year 2010, and up to year 2023 by 2.7% (Global Energy Reviews Report 2025). Furthermore, it is noted that energy consumption has increased by almost 1080 TWh globally. This energy acceleration has been witnessed by almost every region in the world since year 2012. Consequently, the energy growth in China has increased over the years and is among the largest energy consumption globally. Despite significant electrification growth and bold interventions to mitigate gap between energy demand and energy supply globally, it is estimated that more than 600 million people in Africa are still without access to energy (International Agency Energy Report 2025.). The International Energy Agency (IEAs) Report 2025, has presented challenges for the development and energy growth and emphasizes the need for the deployment of strategic interventions such energy policy and framework reform, decentralized energy technologies and energy investments to improve energy access by year 2030 (International Agency Energy Report 2025). The energy inequality is particularly and mostly is experienced by rural communities in many parts of the world. For example, Nigeria, Democratic Republic of Congo and Ethiopia are some of the major regions in Africa which accounts for almost 40% energy deficit (Ndukwu et al 2020 and Ebotha and Tabakov 2024). The goals and objectives of many global institutions to achieve reliable, sustainable and affordable energy remains degraded by factors such as policy, corruption, governance, investments, technology and planning (Ebotha and Tabakov 2024). These areas of concerns are not only applicable to particular regions, they are however challenges that impact all areas of the world.

Despite these devastating global statistics in energy developments, significant progress has been achieved by other regions in the globe to acquire reliable and sustainable energy. For example, African Development Bank has invested more than USD 1 billion to support energy sustainable development and energy security in Africa (The new energy deal for Africa Report 2025). Similarly, the South Africa Renewable Energy Independent Power Producer Procurement Program has invested approximately USD 17.32 billion (Eberhard and Naude 2021). These energy investments and other investments in other parts of the world has created opportunities in energy transition and enhance low carbon and decarbonization. As a results, REIPPPP in South Africa has played a prominent role in supplying and distribution of energy in both urban and rural areas. Through this and other initiatives power utility and municipalities have managed to electrify almost 9,9 million households in South Africa (Meyer and Overen 2021). Despite this great effort, (The DMRE Report 2025) indicates that more than 3.5 million households are still living without electricity. Owing to this, high rate of cost of electricity has also made it impossible for poor communities to afford continued increasing prices of electricity. Similarly, the increasing cost of electricity has resulted in slow economic growth while organizations both private and government which are still highly dependent on utility's power supply have suffered profit loss, decreased investments, loss of employment and production (Meyer and Overen, 2021). Meanwhile, the subject of sustainability and decarbonization has continue to haunt power utility because of the challenges of environmental compliance due to flue gases such as carbon dioxide, Sulphur dioxide and nitrogen oxide to an acceptable level. The power utility has estimated an amount of USD 14,4 billion to achieve full carbon emission across all its power generating plants by 2030 (Meyer and Overen 2021). This noncompliance has however threatened the stability and energy generation of about 22GW capacity shutdown by 2030.

Therefore, because factors such as environmental compliance, energy geopolitics, investments, urbanization, increasing energy demand, infrastructure developments, unplanned outages which has devastating impacts on performance, supply and distribution of electricity, an integrated planning approach is vital to ensure success of energy supply, sustainability and energy poverty reduction. Strategic energy planning begins with the identification of risks associated with supply of energy and energy transition. The risks therefore can be due to procurement of renewables, limited distribution networks, land, cost and many other critical areas. For example, the continued energy crisis, unplanned outages, aging infrastructure, maintenance, corruption in coal fired power plants are some of the factors affecting energy stability and reliability (Erero 2023). These and other risks will then formulate the basis of various strategic planning, policy developments and technological advancement to ensure continued energy security. Knowing that policy developments and strategic frameworks, good governance can help to shape and provide vision and direction to sustainable energy, it is crucial to ensure that policy promotes investments, technology, inclusive economic growth and job creation (Engineering Report 2025). For decades now, energy transition has been the subject of concern for many countries, institutions, organizations and companies. Similarly, researchers have been working on advancing technological integration of renewable energy to grid-interconnection by utilizing artificial intelligence

(AI) concepts for preventative and predicting models. Moreover, globally renewable energies are growing rapidly because of cost-effectiveness, policy driven, energy security, and sustainability (Mnukwa et al 2025).

Despite several interventions and planning at global platforms to reduce greenhouse gas emissions (GHG) and other global pollutants, individual countries still face numerous challenges to keep up with global environmental expectations. This has been part of discourses in United Nation and has led to interceding of financial institutions like world bank investing in renewable energies in developing countries. Global renewable energy investments have surpassed USD 286 million expenditure in year 2015 with a target of USD 2300 billion by 2030 (Kanoglu et al 2020). Furthermore, several reports such as United Nation Environmental Program and International Renewable Energy Agency (IRENA) have reported that through these investments and others, over 2.3 million job opportunity globally (Gholamzadeh et al 2019 and World Energy Outlook 2026). According to Energy Institute Statistical Review of the World, the global energy supply is still predominantly comprising of fossil fuels (oil, natural gas and coal) which accounts almost 86% of global energy consumption (Statistical Review of the World Energy Report, 2025). Similarly, International Energy Agency (IEA) world outlook report 2024, provides that globally renewable energies continue rapid growth where in 2023 it provided 30% of electricity supply and by 2035 it is estimated to surpass global energy generation by 40% (International Energy Agency Report 2024). Therefore, developing countries and emerging markets has the responsibility to underpin and overcome barriers to energy developments and completely eliminate carbon footprint and strive towards zero emission through deployments effective policies, good governance and planning (Figure 1).

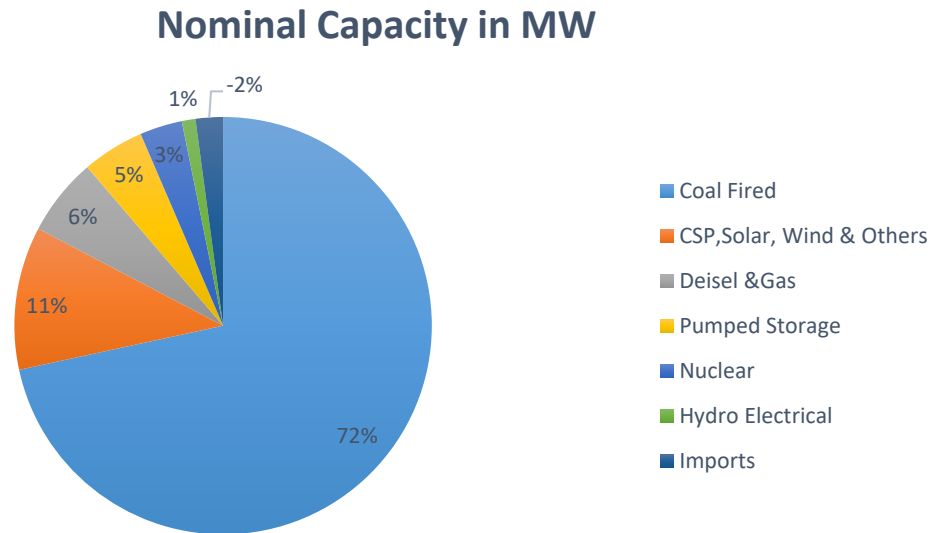


Figure 1: Nominal energy generation capacity in MW

South Africa is not immune to the above global statistics as its power supply is still predominantly coal fired power plants with almost 72% energy generation. Energy supplied by renewables is 11%, while diesel and gas are 6%, pumped storage contributes 5% to the grid and nuclear energy is 3%. Consequently, over the past decade South Africa has an increased total capacity in energy mix of 38 GW for coal power plant, nuclear plant has 1.8 GW, hydropower plants has 2.8 GW, 3.7 GW for renewable energies, hydropower power has 1.7 GW and diesel with 3.8 GW (Kanoglu et al 2020). The implementation of strategic planning involves concepts of strategic management, technological innovation, and integrated approach in renewable energy technologies (Gholamzadeh et al 2019). The key objective of integrated approach to strategic planning is to promotes decision making, innovation, cost-effectiveness in renewable energy value chain to communities. Innovation in strategic planning and policy development plays a crucial role to ensure effective use of advanced technologies and creativity to promote sustainable development and energy management.

1.1 Objectives

The objective of the research study is to investigate, analyze and review challenges that affect sustainable energy transition and energy security. The research will further investigate factors of strategic energy planning, policy reform, technological innovation to enhance energy affordability, reliability and sustainability. Knowing this, energy access and energy inequality has major negative impact on socio-economic upliftment, energy trade and infrastructural development. The article assesses strategic planning, policy reform as the key drivers of renewable energy transition, technological innovation and energy efficiency. The specific research objectives are:

- Analyze renewable energy strategic planning and policy and regulatory reform.
 - Examine new artificial intelligence approach to energy security
 - Assess the impact of artificial neural networks in predicting and preventative with maintenance strategies
- The above specific objectives intends to reveal the impacts of effective planning in providing strategic vision, goal and roadmap to accomplish total accessibility to energy by all communities. In addition to this, the assessment and effects of policy reform and advanced technologies are established to critique its contribution to energy value chain, and energy security.

2. Literature Review

The potential of energy policies to shape and achieve economic and industrial growth and to create decent sustainable investments while mitigating carbon dioxide emissions cannot be underestimated. Similarly, strategic energy policies, and frameworks like Energy Act 04 of 2004, Integrated Energy Plan (IEP), National Development Plan (NDP), Renewable Energy Independent Power Producers Programs (REIPPPP), Battery Energy Storage Independent Power Producers Procurement Programs (BESIPPPP) have deliberately enhanced the provision of energy access and energy security. Furthermore, through REIPPPP, BESIPPPP project Bid (Windows 1 to 7), an estimated USD 14 billion has been invested by both private and public partnership which has a great impact on local economic growth, social improvement and reduction in carbon emission (Jaramillo and Pablo 2010). Below Table 1 demonstrate the vision and objective of frameworks developed to enhance energy reliability and grid stability. For example, Integrated Energy Plan (IEP) has framework which promotes energy access and security of energy supply while minimizing the cost of energy. On the other REIPPPP focuses on the procurement of renewable energy and improve private sector investments in energy value chain.

Table 1: Policy framework for energy developments

<i>Integrated Energy Plan (IEP)</i>	<i>REIPPPP</i>	<i>Integrated Resource Plan (IRP)</i>	<i>Energy Action Plan (EAP)</i>	<i>South African Renewable Energy Masterplan (SAREM)</i>
Promote Energy Access	Focus on Renewable Energy and Procurement	Reduction of greenhouse gas emission (GHG)	New Capacity Development	Driving Industrial Development
Ensure Security of Supply	Improve Private Sector Investments	Improve Eskom Plant Generation	Battery Energy Storage Roll-out	Building Capabilities
Minimize cost of Energy	Create Decent Local Jobs	Promote Energy Efficiency	Reduction of plant breakdowns	Fostering Inclusive Energy Development
Minimize Environmental Impacts	Provide Grid Stability and Reliability	Develop skills to enhance energy production	Tax Incentives and financial Support	Support South African Energy Masterplan

The need for reliable energy has become the greatest need for economic sustainability in the world and many strategic energies planning has revolved around this (Yadav et al 2018). Therefore, without effective energy planning the generation, transmission and distribution of energy supply is doomed. Part of strategic energy planning takes in to consideration factors such as management and leadership which plays a pivotal role in strategizing the vision and mission of planning while ensuring effective engagement with all stakeholders. Energy planning need to promote energy investments and infrastructural developments. The latter can be achieved through public and private sector collaboration.

Below Figure 2 presents energy planning strategy which comprises of energy pillars of sustainability, management and leadership, asset management, energy management, efficiency and reliability, energy availability and energy security. For example, the key focus of the pillar of management and leadership is to provide a strategic vision, mission and roadmap to achieve, policies, framework and regulatory of energy value chain. Furthermore, effective management and leadership ensures implementation of its vision through policy reform and good governance. Similarly, one the key role of management and leadership energy pillar is planning. Planning in its entirety includes the development, monitoring and control of the supply of energy to all communities. This involves the security and protection of energy infrastructure against malicious damage, theft and vandalism. Despite the view that energy theft is insignificant, however energy theft and infrastructure vandalism should be treated with high priority as it cost power utilities huge amounts of revenues. For example, it is estimated that illegal electricity connection and infrastructure vandalism cost the power utility about USD 1.3 billion annually and has resulted to significant loss of lives and injuries. Most areas of informal settlement and low-income communities are susceptible to participate in energy theft and energy infrastructural vandalism due to non-affordability. This act has serious consequences in the stability of the grid and increases unallocated energy supply. Similarly, it raises a safety and environmental concern because live electrical wires are connected to live transformers which can create explosion and kill innocent community members and children.

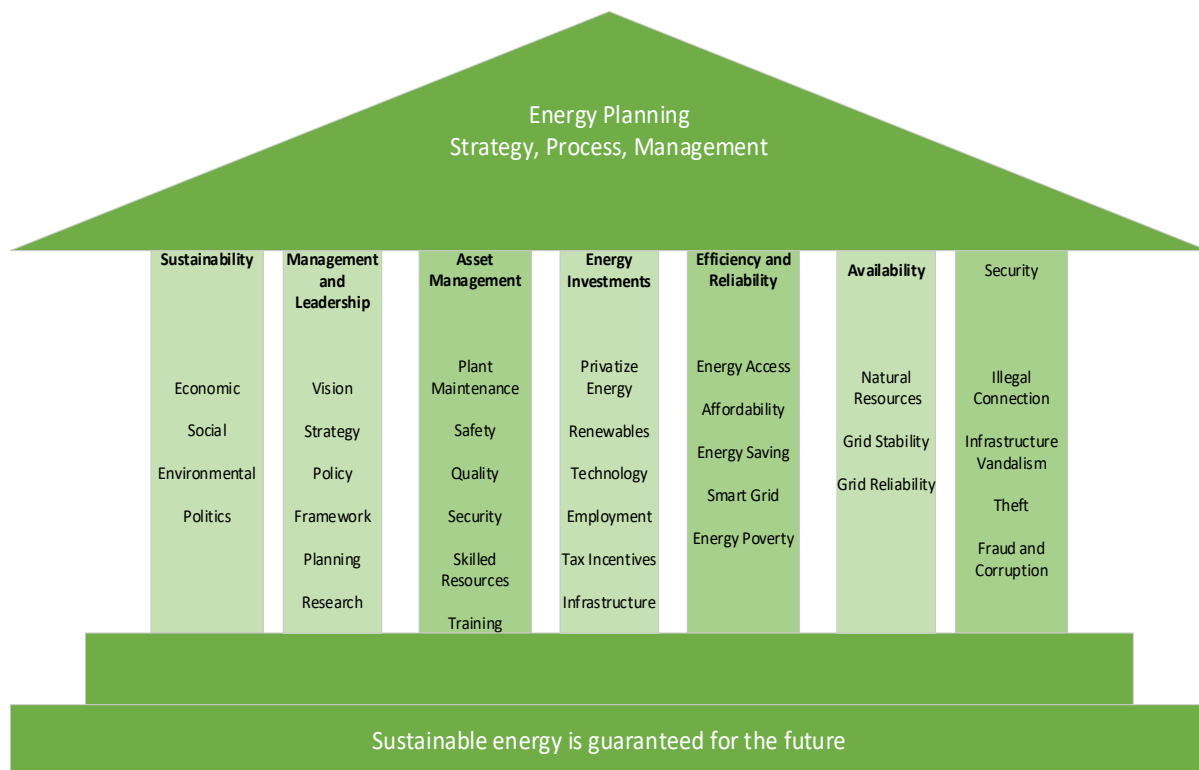


Figure 2: Energy planning strategy

In addition, the strategy further makes reference to critical area of energy politics. Energy politics is defined as a political power and political influence in the development of energy value chain (Shaffer 2009). In his study Shaffer (2009) develops literature in energy politics and suggest politics plays a significant role in modelling energy developments. One of the key role of politics is developing and approving policy framework. It is important to note that in South Africa legislative energy policies are shaped and approved by parliament. Therefore, parliament comprises of representatives from all different political parties in South Africa. Political factor in energy development can have a positive and negative impacts. The developments of new policies, infrastructural projects and job creation

can be viewed as positive political influence in energy value chain. For example, the construction of Medupi and Kusile power stations to boost economy and improve energy security is a positive energy politics outcome.

On contrary, energy politics can have a detrimental effect in the economy and energy project developments if used for agenda of personal and political gains. Political gains refer to personal political interest in energy value chain, which involves corruption and theft. Furthermore, this can also be aligned to the illegal appointment of political figures in key government political positions so to influence the decision making and policy formulation. In the Judicial Inquiry into State Capture Report: Part IV, Zondo (2023) there are several findings by the commission for negative attempt by political power to influence and capture National Treasury.

Furthermore, the report makes a key finding to the dismissal of Minister of Finance Mr Nene by the president Mr Zuma for his resistance to participate in wrongdoings in the procurement of nuclear energy deal. The report further indicates that the dismissal of Mr Nene had a devastating impact in South African economy with a loss of approximately USD 30.175 billion. Therefore, energy politics in energy planning must be properly addressed to avoid these and other challenges. Energy strategic planning further makes reference to management and leadership. The objective of this pillar is to provide strategic direction and vision while formulating policies, framework and plans in pursuit of energy planning. It therefore plays a crucial role in modelling measures and mechanisms to achieve energy security. In addition, leadership has to engage research activities in energy planning. Research ensures that latest technologies and technology trends are adopted in energy generation. Through research and inspections plant failures can be detected and effective maintenance measure applied before a complete plant breakdown. Management of assets in energy value chain also serve as a critical requirement in order to achieve effective energy and planning. Asset management can be achieved through technology monitoring, maintenance, safety, quality and training of resource. Monitoring technologies like supervisory control and data acquisition (SCADA) can help to monitor real time performance of any asset, communicate deficiencies to minimize breakdowns (Udo and Muhammad 2021). Furthermore, the SCADA system consist of series of sensors that are used to monitor the plant performance, detect abnormal asset operation, record data of asset on the database and report information. Skills and competency are of great importance for the retrieval of SCADA information and to ensure effective plant maintenance.

Energy Investments in energy generation particularly in renewable energy are of great importance in pursuit of energy security. Energy investment is to be achieved through public and private sector participation. Several renewable energy projects in South Africa are already implemented including battery energy storage (BESS). For example, Highveld Solar Consortium and Palladium Solar 1 Consortium are some of key strategic energy investments projects implemented to maximise energy capacity. These and other energy investments initiative are crucial part in energy planning. As a result, energy investment has created jobs and continue to reduce poverty. It emerges from study (Naidoo et al 2010). that energy [R]evolution scenario could be a major employment creator with approximately 78 000 jobs in 2030. Furthermore, it an estimated 29% Growth Without Constraints scenario by the year 2030.

It is that noted over the years that energy wastage and energy vandalism are some of contributing factors to energy poverty. Efficiency and reliability are off great importance in adding value to the grid and reducing energy consumption. According to Reddy (2013), energy efficiency is directly related to energy management and provide framework for energy optimization. Firstly, energy efficiency proposes measures of energy reduction in consumption which include among others:

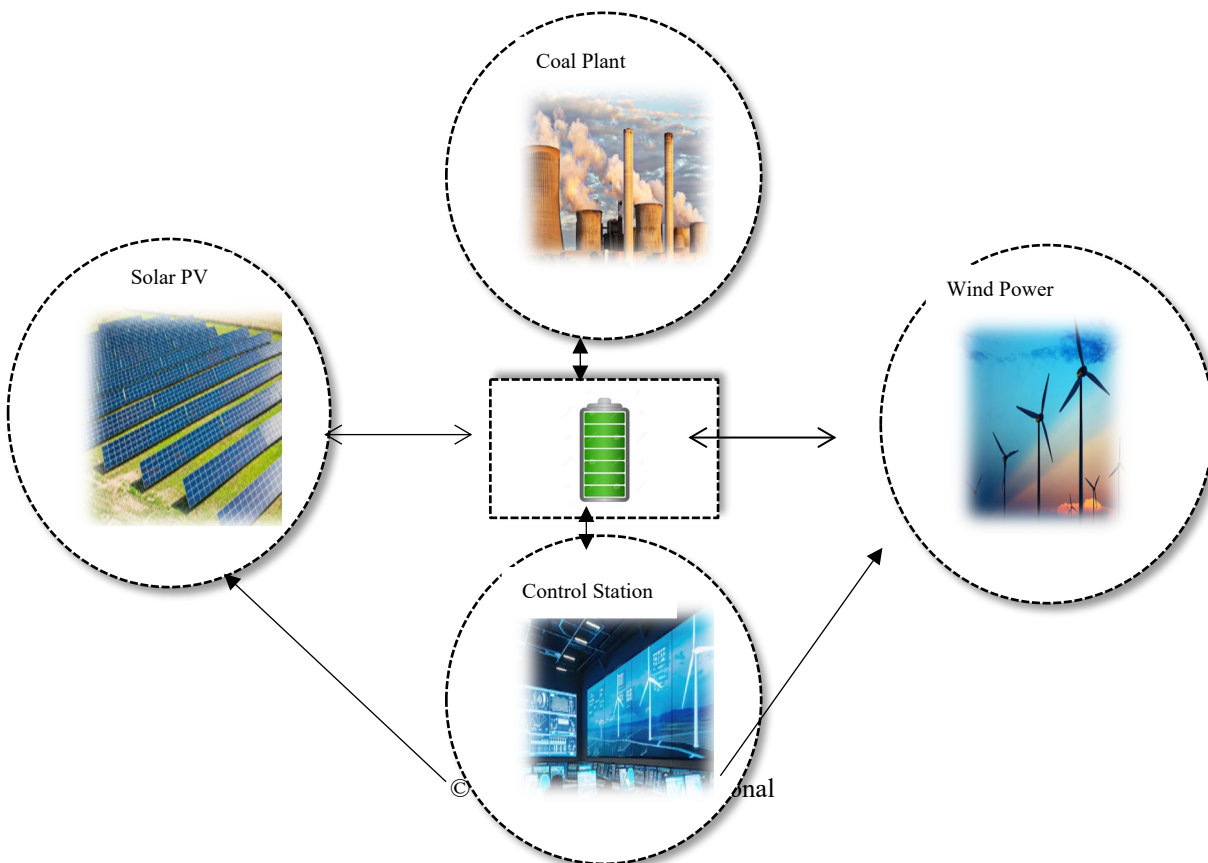
- Shift towards approved energy efficient technologies and energy savings.
- Reduce energy cost.
- Develop energy awareness programmes and training.
- Shift towards renewable energy and smart grids
- Reduce environmental impact

Despite several interventions to successfully achieve above energy efficiency measures, a number of authors have reflected on the challenges and barriers to energy efficiency. It emerges from study by Rhourin et al (2024) that achieving high level of energy efficiency in pursuit of economic growth is not easily acquired due to barriers that hinders opportunities for technologies, investments and energy savings. The author argues that barriers to energy efficiency are classified differently as micro, meso and macro and are relatively classified according to their barrier contribution to energy efficiency. For example, the author continues and classify policy implications as a macro barrier in energy efficiency. This is because any inefficiencies in policy framework can easily influence and reduce private sector energy investments. On the other hand, Nathaniel et al (2021) reflects on energy efficiency barriers as an increase in industrialization, urbanization and growth in population as the key factors straining energy demand. Therefore, both of these authors concur that stringent measures are required to achieve effective energy efficiency.

For example, lack of energy incentives, awareness and technical expertise, framework and strategy interventions, and planning are significantly affecting successful adoption of energy efficiency.

Fossil fuels like coal, oil, natural gases and renewables continues to play a pivotal role and their availability are the cornerstone of energy value chain (Rhouirin et al 2024). The author argues that the availability and other resources yield to improved social and economic benefits. Interestingly, more than 80% of South African energy is generated through coal and certain researchers argue that to preserve natural resources like coal and minimize its complete degradation, it is of great importance to explore other energy mix and just energy transition (Nathaniel et al 2021). Both authors concur about the need and criticality to evaluate and assess the depletion and degrading energy resources. However, these authors do not reflect on the importance of energy planning as the pillar in energy value chain process. Therefore, energy planning needs to take into consideration and assess the availability of natural resources Electricity theft and illegal connections is a devastating act that has adversely affected supply utilities and municipality infrastructure across the world. In his article Louw and Bokoro (2019), suggest that Eskom loses approximately twenty billion rand in revenues because of electricity theft and infrastructure breakdown. The author further argues that because of extreme migration to urban areas population tend to increase and impact on basic social needs like water and sanitation, electricity and households. Then the study discusses the techniques to detect electricity theft and further advises that smart technologies can be deployed to mitigate the use of electricity illegally. Then the study concludes that zero sequence current is an effective technique in mitigating electricity theft. It is noted that the study however does not discuss prevention measures for people who already illegally connected and continue to do so. Perhaps the study should have addressed the innovative measures through energy transition in order to eliminate energy theft. This would help to provide sustainable energy and shift towards reducing energy poverty and provide energy access.

Artificial intelligence approach is mainly concerned with grid stability and reliability while utilizing real time monitoring and predicting models to enhance energy production and reducing energy costs. In his study Olatomiwa et al (2016), suggests that renewable energy are characterized by intermittency and variability which greatly affect the stability of supply. He further indicates that energy management is a systematic approach designed to monitor and control processes and integrated technology which is influenced by type of energy system and grid interconnection. To successful implement energy management strategy, an energy system need to comprise of central control and monitoring interfaced with supervision like system control and data acquisition (SCADA). The study further presents the integration of smart meters, wind and irradiation sensors provide complete intelligence for energy management. The author also presents the fuzzy logic controllers to model energy management in hybrid energy systems. The study concludes that challenges of predicting irradiation and wind velocity can be accurately overcome by incorporating fuzzy logic model and advance energy management.



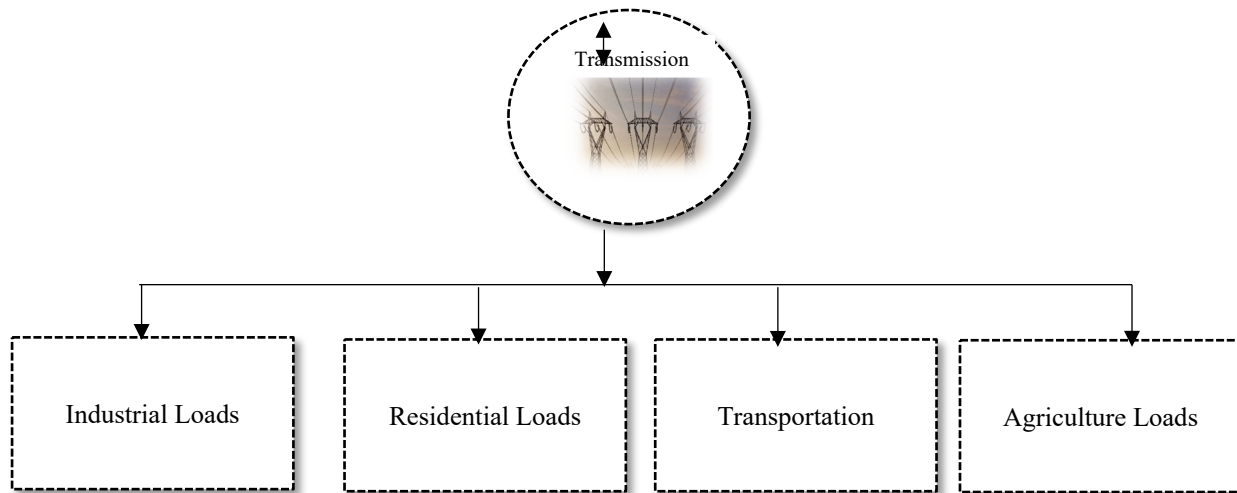


Figure 3. Energy Management Strategy overview.

Concurrently, In his article Ibrahim (2024) when reviewing energy management strategy of hybrid renewable energy system portrays an overview of energy management strategy depicted in Figure 3. It is shown that the above overview comprises of interfacing units such as smart meters, energy management systems controller, utility control and operators, hybrid energy arrangements and the load. Most critically, Figure 3 also shows the provision of communication and interfacing between different grid integration. Effective communication is the key in reporting all data and information captured by monitoring devices like smart meters and sensors. The role of control operator is to monitor the performance of the system, report on any deficiencies. Furthermore, control operators manage the flow of energy during peak times and off-peak times. The primary takeaway is the importance of the controller to be able to manage critical loads and furthermore manage grid integration. This is particularly crucial to ensure maximum benefits of renewable energies. This presents energy management strategy for energy generation and provides the required strategy to advanced control and monitoring techniques for effective operation. Part of energy storage management strategy provides variety of optimization to improve power reliability and stability. Battery management systems (BMS) offers variety of dynamic grid power solutions which includes among others management of battery autonomy, battery voltage monitoring, power measurements and overall battery control. Its notable that in energy management strategy optimization is to improve scheduling, cost efficiency and control of internal energy flow. The primary focus of energy management strategy presented by Shafiullah et al (2022) is in the development of microgrid. Part of the review of energy management strategies in microgrids among others includes load management, power generation management, and energy storage management. The author suggests that it is critical that energy management strategy to assess the type of load the power system is supplying. Similarly, it is crucial to preserve a balance between energy generated and energy supplied to the load. The argument implies that loads are subdivided into critical and non-critical or essential and non-essential loads. Among others critical loads in microgrids are classified as hospitals, communication infrastructure, transportation, food processing centres, and other agricultural centres.

Consequently, energy management strategies in hybrid renewable energy have mostly been dominated by techno-economic strategies, in which mostly focuses on improving lifespan and grid performance, while decreasing energy costs. Moreover, energy management systems use fuzzy logic controllers, artificial neural networks, and intelligent software like HOMER to effectively monitor and control performance of renewable energy systems. Several studies have reflected and discussed concepts and process of energy management strategies in hybrid and microgrids. In his article Yazdi (2024) systematically investigates the impacts of emerging technologies integration with renewable energies to enhance efficiency, sustainability and reliability. The study highlights the significance of artificial intelligence optimization in solar and wind energy. Firstly, it emerges that AI tools and techniques like machine learning and deep learning play a crucial role in producing accurate forecast and real time data that can be utilized in maintenance and energy management. Secondly, study presents that AI has been instrumental in analysing complex data and providing real time data to enhance operational efficiency of RE. Thirdly, study urges leaders and policy makers to foster the integration of AI in energy developments and formulate policies that strive to improve skills developments and research. Then the study concludes that the application of AI technologies continues to strengthen grid stability and ensure continuity of supply to the load.

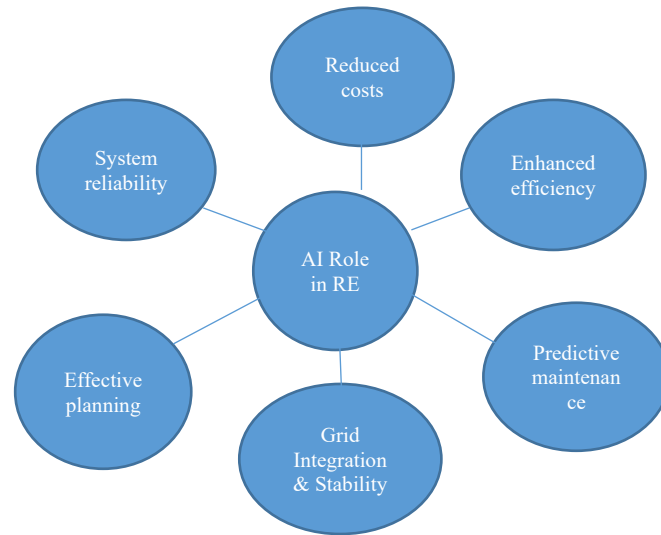


Figure 4: Role of AI in renewable energies

Over the past decade renewable energy has gone under transformative phase through its integration with artificial intelligence which underpin a strategic shift in technology deployment in RE (Aisha 2023). It is with no doubt that the integration of renewable energies with artificial intelligence has led to improve grid stability and reliability. According to Gidiagba et al (2023), the role of artificial intelligence is presented in six distinct areas as depicted in Figure 4.

- Improved system reliability
- Minimal energy generating costs
- Increased operating efficiency
- Reduced energy power losses and improved grid stability
- Improved predictive maintenance planning
- Increased longevity in components functionality.

Despite several scholars, academics and researchers substantially agreeing that renewable energy power plants require less maintenance compared to fossil fuel power plants, it is of great importance to ensure effective maintenance strategies are applicable in renewable energy systems and explore the most suitable and appropriate strategy for each system and applications. The series of studies in the book Yazdi (2024) reflects on computational mathematics for industrial systems reliability and maintainability. The primary takeaway from the series of articles contained in the book is the optimization of maintenance strategies. The study discusses the principal methodologies that institutions can utilize to ensure effective assets performance and maintainability. The approach of the study demonstrates benefits of deploying correct maintenance strategy for specific systems and further illustrate that maintenance strategies are not supposed to be a blanket approach. Therefore, maintenance strategies applicable to each industrial systems must be studied and be in line with systems specifications, functionality and application. This is particularly true because maintenance strategies applicable to fossil fuel power plants cannot be the same strategies applicable to renewable energy power plants. For example, in fossil fuel power plants the strategy used in turbine plant does not become fit for purpose in boiler plant. On the other hand, maintenance strategy deployed in solar inverters cannot be the same strategy applicable in wind turbine plant. Then maintenance strategies presented by the study are preventative, predictive, corrective, and proactive strategies. The study further presents the optimization of artificial intelligence to achieve predictive analysis, reliability- centered maintenance, condition-based maintenance. and risk-based maintenance. The crucial role highlighted by the study with regards to effective maintenance strategies is cost reduction, reduce systems failures, increase in productivity.

Table 2: Maintenance strategies

<i>Preventative</i>	<i>Predictive</i>	<i>Corrective</i>	<i>Proactive</i>
Can be able to detect prevent	Provides effective planning and scheduling	Susceptible plant failure and increased outages	Increased plant reliability
Reduce maintenance costs	High costs	High cost of plant maintenance	Improved cost savings
Improved planning	Predicts faults before the occur	Low plant production	Reduced risk of accidents
Increased machine longevity	Easy control and monitoring	Fatalities and injuries	Improved planning time
Routine maintenance	Use of advanced technologies	Little time for planning	Improved safety
Improved operational efficiency	Analysis of equipment's performance	Difficult to plan for equipment spares	Provides continuous improvement
Improved cleaning and calibration	Provide specialties of AI and machine learning	Non availability of spares immediately can increase plant down time	Increased operational efficiency
Parts replacement	Real time data analysis	Challenging to plan for resources	Equipment longevity
Equipment reliable and efficient	Provides databases for equipment failures	Difficult to estimate maintenance budget	Resources are adequately planned
Provide historical maintenance data	Interfaced with computer software	No software required	Software can be used for planning
Requires more budget for planning and additional resources	Requires network integration	No network integration required	
Preventative maintenance softwares can be used.	Statistics modelling softwares can be used		

The above Table 2 provides key aspects of individual maintenance strategies which are used widely in various engineering management technologies, and engineering industries. Additionally, the above strategies also present reliability-centered maintenance strategy, condition-based and risk-based strategies. Artificial intelligence approach in maintenance strategies is crucial to ensure maximum performance of system, reliability and stability. Equipment and plant maintenance has become crucial aspects in improving plant reliability, stability and performance. In renewable energy, various technologies have been implemented for continual improvement in operations and maintenance systems. In his study (Aisha 2023), pays particular focus on the maintenance models to improve reliability, production and maintenance of two renewable power plants namely, Sokoto solar power plant and Katsina Wind power plant. The author suggest that the functionality of any system is subjected to faults and failures and its functionality deteriorates due to aging. It emerges from the study that to achieve effective maintenance strategy the must be a balance between maintenance planning and cost optimization. As part of maintenance planning, the study presents three models based on preventative maintenance. The deployment of artificial neural networks (ANN), support vector regression (SVR), and analytical technique are individually evaluated in wind and solar plants to determine the most suitable model of prediction. These models of prediction are then used as the basis for maintenance strategy realization and development to improve systems efficiency.

In his article Yazdi (2024) discusses the adoption of reliability-centered maintenance strategy in renewable energy. The author highlights that intermittence presents a disadvantages of load losses for example inconsistencies of radiation and fluctuation in wind speeds give unpredictable output. Therefore, the author suggests that reliability in renewable energy need to be studied as discipline for the analysis of the overall systems performance. The study then presents key primary objective and significant components in reliability.

- Probability Analysis

- Failure Mode and Effect Analysis
- Lifecycle Assessment
- Fault Tree Analysis
- Design for Reliability

The above reliability models are used by various industries such manufacturing, energy generation, transportation and others with a primary objective to improve operational longevity of the system. Therefore, a key finding of the study is that the application of reliability models in renewable energies provides systematic approach to minimize power outages, components failure, plant breakdowns and maintenance costs.

The application of failure mode and effect analysis in reliability provides a systematic approach in analysing the failure patterns of components, systems and machines in an attempt to define their effects and how they can be resolved. The study by Patil et al (2024) proposes assessment of risks in solar photovoltaic panels by utilizing systematic approach of failure mode and effect analysis. The study argues that just like any other system components solar panels presents degradation, failure, poor system performance and safety concern. The methodology used by the study is reliability data testing, field failure data and expert analysis. To achieve this reliability analysis the study further makes reference to fault tree analysis, probability distribution, Markov analysis and monte carlo simulation. Analysis is further conducted in data extracted from databases such as Sandia National Laboratories Photovoltaic Reliability Database and National Renewable Energy Laboratory. This provides more concise measuring, modelling and analysis of data from different solar PV plants failure modes stored in the national database. Therefore, the study concludes that faults in solar panels are due to glass deformation and soil particles formation in panels. In addition, due to intermittence bypass diodes to contribute to critical failures of solar panels and almost 52.8% failure modes are due to back sheet. It is noted however that the study does not propose any solutions and risk mitigation to these critical failure modes presented. On the other hand Nel (2015) reflects on the significance of Design for Reliability (DfR) in renewable energy and power electronics. The objective of the study is to review concepts of DfR to minimize failure rates and cost implications due to breakdown in renewable energies. The study proposes two case studies in renewable energy which include 2MW in wind turbine and 6kW in solar photovoltaic systems. This approach is utilized to predict the longevity of systems components and improve any design failures. It emerges from the study that design for reliability is intended to ensure that the design of the system or components during design phase accounts for the highest reliability and address all reliability challenges before the system is put in operation. Design for Reliability approach as applied to both wind turbines and solar PV analysis has provided component life-time prediction has demonstrated reliability capabilities. A key finding of this study is through DfR there is an improved effectiveness from traditional failure analysis to physics of failure prevention.

3. Data Collection and Research Methodology

The proposed research methodology for the study is both qualitative and quantitative research techniques. Qualitative research method is used to collect and gather information from relevant studies, journals, books, and energy reports. The objective of both qualitative and quantitative research methods is to investigate strategic planning, policy reform, artificial intelligence, energy framework and strategies. The objective of qualitative research method in this study is to collect data based on historical records about energy demands, energy supply, tariffs and renewable energy (Figure 5).

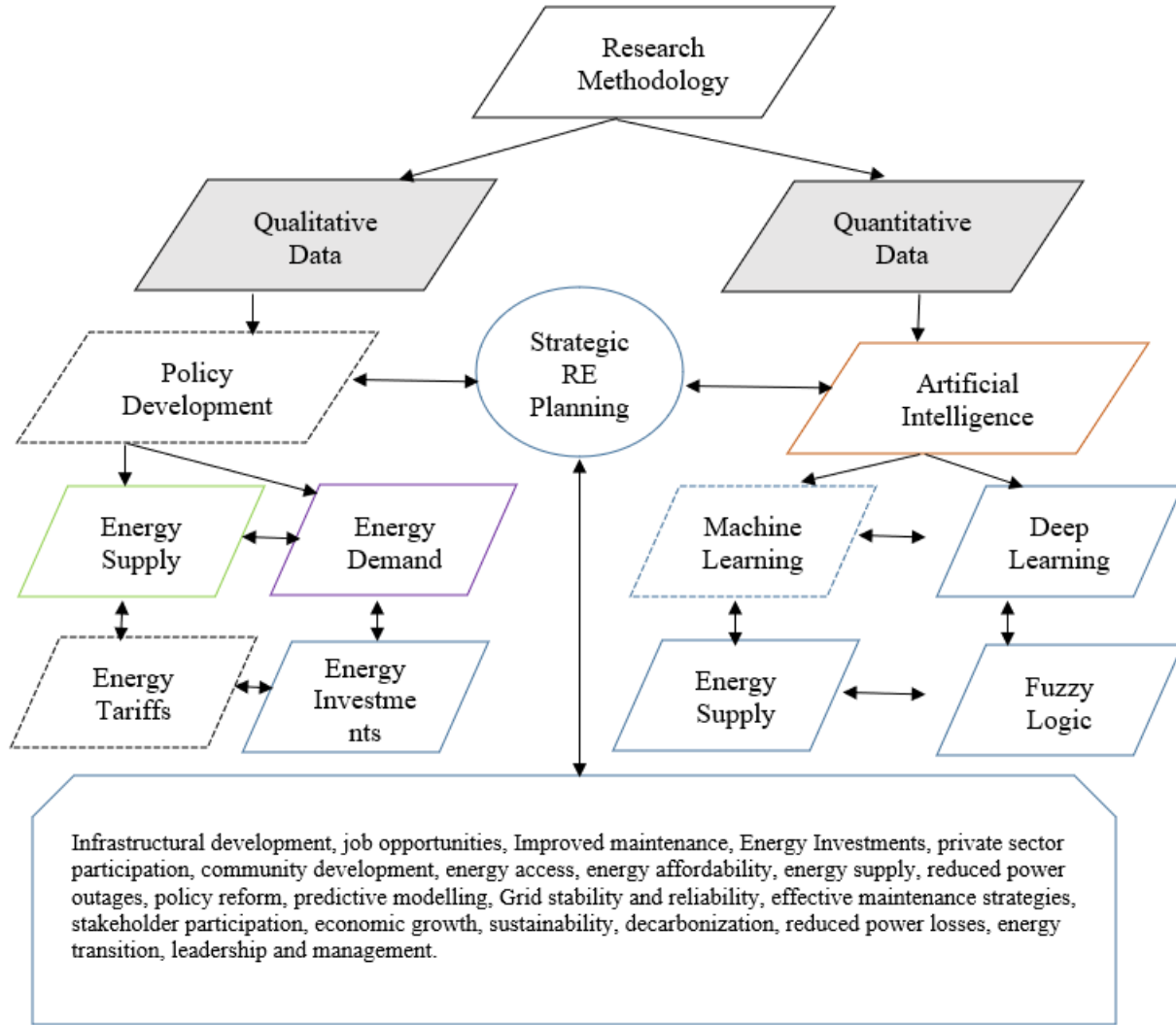


Figure 5. Research methodology

5. Results and Discussion

Energy generated in South Africa is still predominantly fossil fuels particularly coal fired power generating power plants. In Figure 6, it is noted that in 2023 to 2024 coal energy generated has increased by 7% while pumped storage increased by 8%. Furthermore, renewable energy penetration to the grid has witnessed a marginally drop of 1%. Despite this slow renewable energy growth in South Africa, it is anticipated that by 2030 the country's renewable energy sector is projected to generated 32 GW through policy reform, advance technologies and private investments. Up to this far, a significant development has been made in renewable energy through programs such as Renewable Energy Independent Power Producer Procurement Program (REIPPPP) and Battery Energy Independent Power Producer Procurement Program (BEIPPPP) (Figure 7).

ENERGY GENERATED 23/24

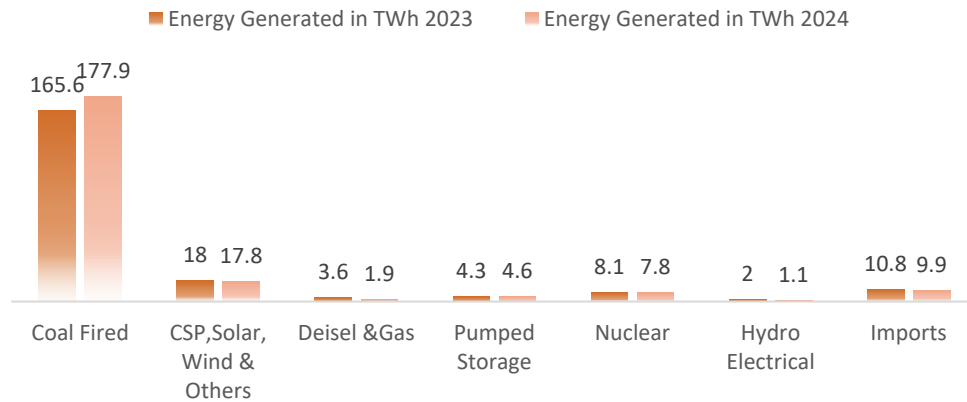


Figure 6: Energy generated in year 2023/24

Renewable Energy in MW

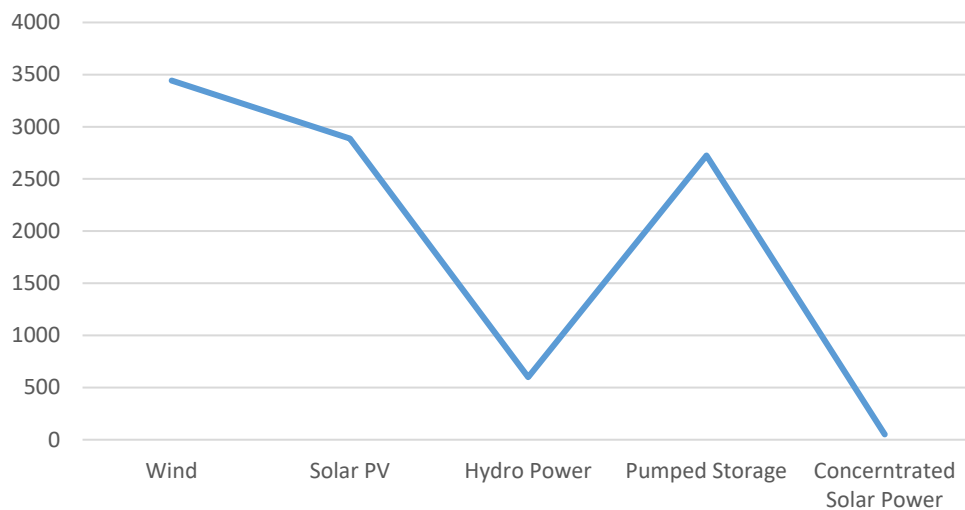


Figure 7: Renewable energy capacity generation in MW

Despite national development plan vision 2050 which specifies the importance of complete energy transition and adopting renewables to promote social, environmental and economic developments, the reality is energy generated by renewable energies is far from superseding coal generation. More than 60% energy generation gap between renewables and coal plant generation. Consequently, to overcome this huge gap in between the two an effective policy drivers, advanced technology and investments are the key success factors to be mastered.

Wind energy generation is currently dominating capacity in renewables with almost 37 wind farms in operation producing approximately 3.5 GW of electricity. The estimated annual wind capacity contribution is almost 47 GWh which makes it a significant contributor to energy mix. As of 2024 Solar energy is noted to be producing about 2.9 GW electricity.

National Energy Regulator of South Africa (NERSA) is the responsible governing body with full authority in regulating electricity tariff, piped gas and petroleum industry levies. NERSA is established in terms of NER Act 20

of 2004 with an objective of regulating energy industries in accordance with government laws, policies, standards and international best practices in support of sustainable developments while improving social and economic growth. The establishments of NER Act 20 of 2004 is established in line with Electricity Act 41 of 1987, Gas Act 48 of 2001, Gas Regulator Levies Act 75 of 2002, and Petroleum Pipeline Act 60 of 2003. All of the above frameworks are developed and adopted by national government through legislature to ensure a functioning state of electricity, gas and petroleum imports and exports. NERSA's role is particularly significant in encouraging private participation in single monopoly energy distributors such as Eskom and Sasol, and further provide licenses, approving tariffs and charges. Furthermore, the energy regulator subject itself to four critical distinctive critical roles which includes electricity infrastructural planning, electricity pricing and tariffs, Electricity policy and framework reform, and Electricity compliance and licensing. On an annual basis electricity distributor such as municipalities and private distributors will submit a proposal to NERSA for electricity increases and this will be subjected to scrutiny based on tariffs benchmark and Eskom prices. NERSA will then prepare and approve tariff guidelines in conjunction with tariffs schedule for proposed adjustments according to class of customers.

Table 3: Energy annual increase from 2006 to 2016

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Average price increase %	5.10	5.90	27.50	31.30	24.80	25.80	16	8	8	8	12.69
Average c/kWh	17.91	18.09	25.24	33.14	41.57	52.30	60.66	65.51	70.75	76.41	79.73

From the above Table 3, the energy tariffs are presented from year 2006 to year 2016. The average price increase is shown for each year together with average cost per kilowatt hour. During this decade South Africa was confronted with the most devastating energy crisis due to unplanned power cuts and outages. From the table it is noted that from year 2008 to year 2011 energy tariffs increase with more than 25% and this was due to server power shortages in the country. From 2011 to 2016 a significant decrease in energy tariffs is noted and this was due to significant interventions in maintenance and energy restoration.

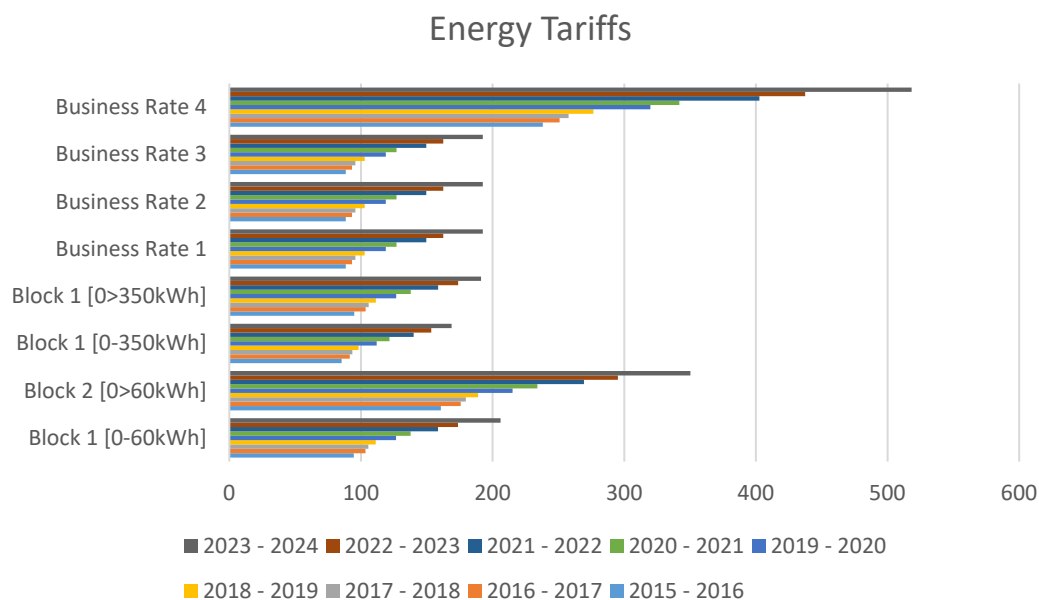


Figure 8: Energy tariffs since 2014.

In Figure 8, presents different customer categories tariffs and associated increases form year 2016 to year 2024. The above tariffs distinguish between homelight tariffs and business tariffs. Homelight tariffs are designed for low-income household with consumption from 20A to 60A single phase load. The categories of homelight tariffs are classified

and charged according to power consumption ranges from 0-350kWh, 0>350kWh and 0-600kWh, 0>600kWh. Irregardless of the category of customer classification, Figure 7 depicts that on annual basis energy tariffs continue to increase rapidly. It is estimated that in year 2024 to 2025 energy tariffs have increased by 12% to 12.75%. Consequently, energy tariffs have increased by almost 190% since year 2014. Renewable energy and artificial intelligence have a significant contribution to minimize growing energy tariffs. Increasing competitiveness and private participation in energy supply and distribution has the potential to generate and sell more energy at low cost which will ultimately reduce single supply dependency. Below key energy policies have played a crucial role up to this far as the key driver of renewable energy in South Africa.

Integrated Resource Plan (IRP): The target of IRP is to generate renewable energy capacity of about 18000 MW by year 2030. IRP policy seeks to advance energy mix that will provide future energy security. This comprehensive document comprises of critical strategy to strike the balance between energy demand and energy supply at an affordable cost. Additionally, another basic key formulation of this frame work is to increase the deployment of RE technology from 17GW to 45 GW by 2030 whilst reducing carbon emission of 168Mt by 2030. The IRP 2025 further presents an investment opportunity of USD 131 billion investments opportunity. This framework is also inclusive of green hydrogen economy and further makes references to policies such as electricity Regulation Act 04, of 2004, Climate Change Act 22 of 2024.

Renewable Energy Independent Power Producer Procurement Program (REIPPPP): This framework provides for the increase of capacity generation through procurement of renewable energy generation by private participation and increase opportunities of investments and competition. Up to thus far, 123 projects have been assigned to independent power producers with a total of US 17. 32 billion investments. This key initiative has the potential to drive economic development and sustainability. Below table depicts project implemented through this program.

Battery Energy Storage Independent Power Producer Procurement Program (BESIPPPP): Provides strategic framework for the procurement of battery energy storage system. Through BID Window 3 with 616 MW procurement a total investment of USD 560 million has been invested with an anticipated 800 job creations. similarly Bid Window 2 with capacity of 615 MW presents an investment opportunity of USD 295 million with a potential of more than 900 job creation.

Just Energy Transition Investment Plan (JETP): This framework targets a capacity generation of 20 GW by 2030. The objective of this framework provides for the transition of fossil to low carbon future and enhance skill development and international partnership. JET aim at growing economy and create sustainable future for all communities.

South African Renewable Energy Masterplan (SAREM): It aims to develop strategic plan for inclusive development of renewable energy. SAREM underpin six key strategic pillars of economic development by fostering renewable energy and battery energy storage system. SAREM further makes proposition for the expanding industrial capacity.

Energy Action Plan (EAP): This framework establishes interventions to reduce the loadshedding, improve energy security and pursue energy investments. EAP provides an additional capacity of 3.4 GW grid capacity.

South African Wholesale Electricity Market (SAWEM): This strategy proposes a multimarket participation in energy reform which enhances energy competition, transparency and efficiency. SAWEM aims to strategically shift from single monopoly electricity trading to a more inclusive and competitive electricity wholesale which promotes diversity, resilient, and investor-friendly system.

Free Basic Energy policy: Energy affordability has been addressed by this framework; Free Basic Energy policy is designed for low income-household which provides electricity of 50kWh to qualifying household. This initiative is designed to help to mitigate energy poverty and achieve sustainable energy.

The objectives and outcomes of policy framework is to improve energy development and sustainability. These energy frameworks are derived National Development Plan (NDP), as a strategic intervention to sustain energy supply throughout the country. They have played a crucial role in changing societal view of energy value chain, affordability and reliability. Large capital investments, energy infrastructural developments, skills developments, decent job creation and economic growth are some of the benefits and outcomes of these great initiatives. Similarly, these policies promote private sector investments, decrease monopoly supply and offer opportunities of wide range of electricity

competition. There is substantial evidence that these energy policies are fostering to achieve significant milestone in carbon emission reduction and stabilizing energy sustainability. The key milestone is the implementation of IPP programs to increase energy capacity generation by years 2030. Energy vision 2030 seeks to completely eliminate energy inequality and transition to low carbon economy. Through Bid Windows 1 to Bid Window 7 renewable energy development projects, more than 15 GW in total is anticipated to be generated in year 2045 by these renewable energy sources. This initiative will position South Africa as the largest renewable energy producer in Africa continent. Despite several successful initiatives policy reform, consequently there are a number of draw backs and challenges experienced by policy implantation. The transmission network in South Africa has not been fully expanded to handle the capacity of generation influx of renewable energies, parallel structures of renewable energy transmission need more attention as RE continues to expand and penetrate to the grid.

It emerges from figure 5 that there has been a marginal drop of 1% for year 2023 to year 2024 in renewable energy generation. It is further estimated that slow growth in renewable energy is estimated in the upcoming years. Part of the contributing constraint to this slow renewable energy growth is the expansion of transmission networks to accommodate key renewable energy development projects. Despite this power utility through its Transmission Development Plan (TDP) has identified such grid constraints where renewable energy will sit and idle whilst the is a challenge of energy shortage and loadshedding. Transmission Development Plan (TDP) has proposed an estimated budget of USD 25.898 billion for the expansion of transmission network which will cover provinces such as Northern Cape to Western Cape, Eastern Cape to Kwa-Zulu Natal, and Mpumalanga to Gauteng Province. Taking into consideration the distances and terrain to which this network will travel presents huge challenges before it can be put into operation. Meaning the issue of transmission constraints will persist until such developments are fully completed. Transmission network are crucial in renewable energy developments to ensure supply and distribution of renewable energy to each and every corner of community. Strategic planning approach in renewable energy developments must foster and address challenges whilst fast tracking of critical infrastructural developments.

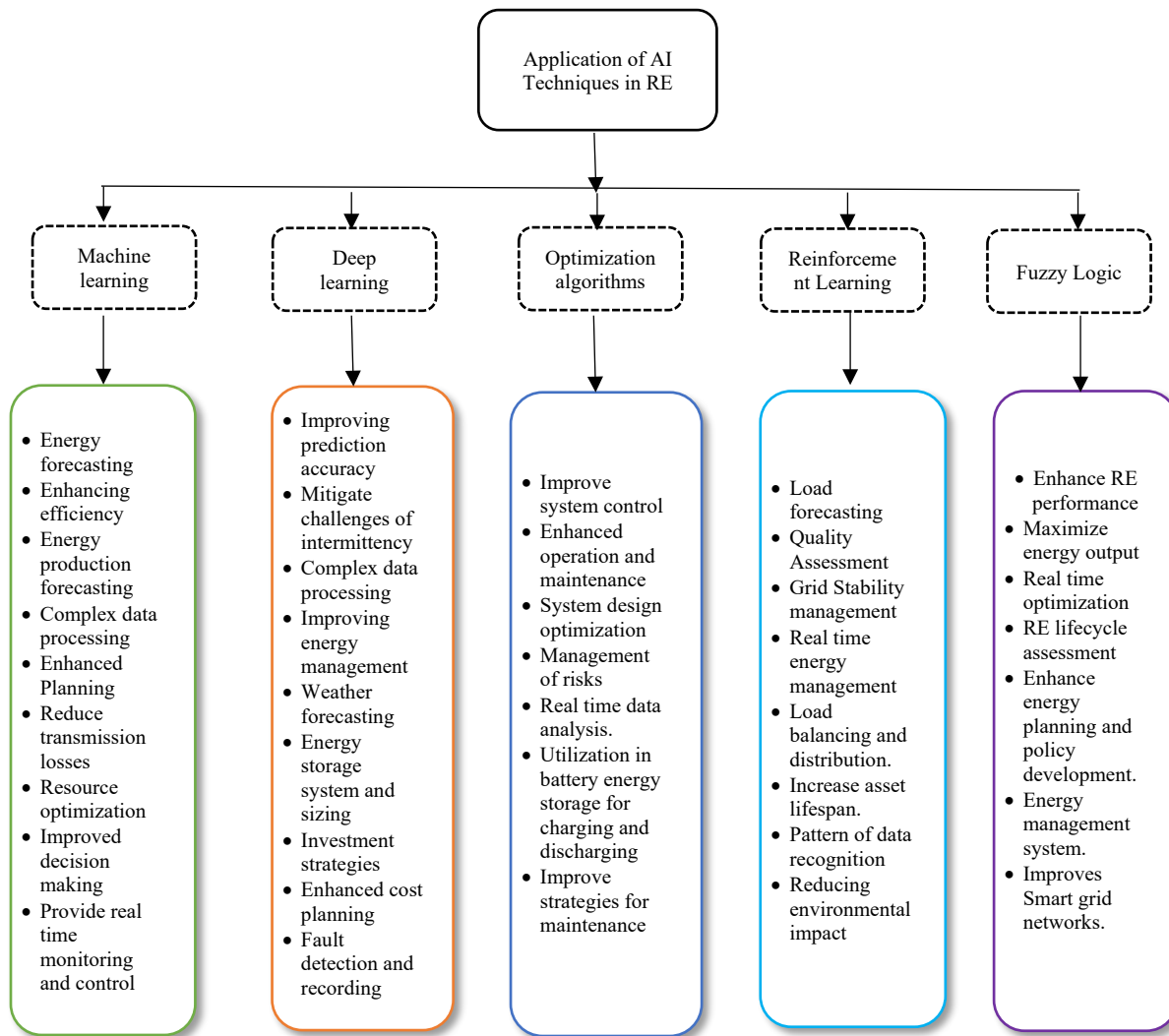


Figure 9: Application of AI Techniques in RE

Artificial intelligence has a significant role to play in the modern energy network and distribution particularly in preventative and predictive modeling in the energy network. It employs state of the art advanced technologies for data acquisition and monitoring. As shown in Figure 9, AI comprises of different techniques and models that are used in renewable energy network to acquire different data for human processing. Its capabilities of producing accurate real time data have made RE to be compatible energy generation and supply preferred in modern technologies. AI modelling techniques used in RE includes among others machine learning, deep learning, reinforcement learning, fuzzy logic and optimization algorithms. For example, machine learning is one technique widely used in RE networks for the purpose of energy production and energy forecasting. Machine learning also furnish strong intelligence in data analysis and processing. Thus, the data can be regarding weather condition i.e wind speed forecast or solar irradiation. Similarly, deep learning technique improves prediction accuracy whilst mitigate challenges of RE intermittency. Deep learning can further study the pattern of fault occurrence in the system, detect and record any system abnormalities and provide data for rectification and maintenance. This can further reduce plant breakdowns and maintenance costs while improve grid stability and reliability. With this in mind, the deployment of artificial intelligence further extends the life expectancy of equipment's which are heavily exposed to high voltages and currents particularly in grid integration. In renewable energy networks artificial intelligence fuzzy logic techniques uses its capabilities of prediction modelling to analyze and collect data for energy management which can consequently be used for policy development and energy planning. The latter can then be used to allocate energy generated according to energy demand during peak times. Strategic planning further takes into consideration management of assets and strategies for

maintenance to ensure reduction in plant breakdowns and optimize profitability. This provides the need and opportunity for the deployment of maintenance strategies which improves reliability, maintainability, and performance of generation and distribution networks. These strategies are characterized by implementation of systems such as computerized maintenance management System (CMMS) and supervisory control and data acquisition (SCADA) which have the ability to collect and store data such as asset performance and failure modes. Consequently, the performance and failure modes data can be utilized for operational maintenance, planning, critical spares and risk mitigation. This information can further help to create proactive engineering approach to reduce unplanned outages and improve design for reliability.

5.1. Proposed Improvements

Firstly, the proposed improvement is to strengthen energy planning and policy reform for energy infrastructural development particularly in the transmission of renewable energy lines. Many investments are mainly focusing on generation of renewable energies and completely forgot the transmission part of the network. There are currently a high number of RE projects and a smaller number of transmission networks where are already overwhelmed by energy generated by fossil fuels. Secondly, there has been a surge of increase in energy tariffs over the past decade which makes it difficult for low-income households to afford basic necessity of energy. Apart from NERSA as the regulatory energy body, there is a need for energy policy directly governing energy tariffs and focusing on energy access and affordability for previously disadvantaged communities and low-income households. Furthermore, the deployment of advanced technologies such as AI need to be compulsory and prescribed by these policies not only for renewable energy generation but also for fossil fuel power plants to promote competitiveness and energy stability.

6. Conclusion

There is a significant need to expand comprehensive strategies that outline process to acquire and expand the development of renewable energy. The comprehensive energy planning strategies need to consider key pillars such as: sustainability, management and leadership, energy investments, management of assets, efficiency and reliability, availability and security. These key pillars should then be broken down to critical components such as energy economics, research, policy, technology, job creation and employment, energy affordability, and energy security. Renewable energy strategic planning needs to support grid integration, foster economic growth and expand renewable energy market to mitigate the growing local energy demand. Similarly, strategic renewable energy planning should promote opportunities in public-private partnership, unlock potential of solar wind and battery energy storage systems. For example, frameworks such as South African Renewable Energy Masterplan (SAREM), Energy Action Plan (EAP), Integrated Resource Plan (IRP), Renewable Energy Independent Power Procurement Program (REIPPPP) and Battery Energy Storage Independent Power Producer Procurement Program (BESIPPPP) are some of the strategic frameworks designed to provide guideline to inclusive energy generation and distribution while unlocking clean energy integration. Policies need not to be a well written and documented framework without an action and implementation, it must be a document carefully crafted to weaponize and improve the living condition of communities. From the data collected in this study it is evident that the role played by stringent policy framework through effective energy planning can increase renewable energy capacity generation, create opportunities of investments and provide decent job to local communities and skills development. Further this unlocks opportunities in infrastructural development, promote socialism and economic growth. The greatest benefit is further to minimize environmental pollution through process of decarbonization which has a devastating impact in climate change. In the past years the country has suffered devastating floods in areas such as Kwa-Zulu Natal and Eastern Cape provinces of South Africa where communities suffered loss of lives and infrastructure through climate change. Therefore, renewable energies have the potential to reduce greenhouse gas emission which are created by gases such as carbon dioxide CO₂ and methane CH₄.

Artificial intelligence (AI) in renewables plays a critical role in predicting, forecasting renewable energy and is a great contributing factor to reduce energy poverty. Because of intermittency and nature of renewable energies, artificial intelligence provides an effective data modelling technique for measuring of temperature, humidity, wind speeds and other factors related to complex technical information processing. AI is driver of innovation and its capabilities provides accurate forecasts in grid reliability and stability, which in turn saves operational costs and improve sustainability. AI optimizes machine learning and deep learning techniques to provide the most accurate data for real time analysis which can ultimately enhance energy management. Understanding energy deficit can help accomplish effective strategic planning and have structured approach for energy distribution through the deployment of artificial intelligence approach. This further unlock energy investments, reduction in load shedding, and improve infrastructural

development. Electricity shortages and energy poverty have affected millions of households across the globe whilst renewable energy and AI provides opportunity to redefine energy value chain. Energy policy optimization and artificial intelligence are the potential drivers of energy development in developing countries. A strategic approach to renewable energy planning needs to take into account the optimization of energy policy and artificial intelligence to enhance economic growth.

References

- Aisha Sa'ad. Developing integrated maintenance strategies for renewable energy sources based on analytical methods and artificial intelligence (AI) : comparisons and case study. 2023.
- Eberhard, A. Naude, R. The South African Renewable Energy IPP Procurement Programme. University of Cape Town. School of Business. 2021.
- Ebotha, W. Tabakov, P. A Retrospective of Energy Demand and Potential of Sub-Saharan Africa : Leveraging Energy Deficit to Attain Clean Energy Hub Region. Arid Zone Journal of Engineering, Technology and Environment. Volume 20(1). Pages 261-294. 2024.
- Engineering Report. 2025. <https://www.energize.co.za/article/eskom-flags-r257bn-emissions-compliance-bill-as-2030-shutdown-risk-looms>. Assessed on 15/06/2025.
- Erero, L. Impact of loadshedding in South Africa: A CGE Analyses, Journal of economics and political economy. Volume 10. 2023.
- Gholamzadeh, A. Ariani, G. Mehdi, D. Jaromír, J. Seyed, M. Strategic Plan Method for Future Renewable Energy Technologies. CET Journal - Chemical Engineering Transactions, Vol 76, p1159. 2019.
- Gidiagba, O. Ninduwezuor-Ehiobu, N. Ojunjobi, A. Ensuring the Future of Renewable Energy: A Critical Review of Reliability Engineering Applications in Renewable Energy Systems. Materials & Corrosion Engineering Management. Volume 4. Issue 2. 2023.
- Global Energy Reviews Report. Electricity – Global Energy Review 2025 – Analysis - IEA. 2025.
- International Agency Energy Report. Africa's Energy Deficit: 600 Million People Still Lack Electricity -Empower Africa. 2025.
- Ibrahim, M. Energy management strategies of hybrid renewable energy systems: A review. Wind Engineering. Volume 48 (1). 2024.
- International Energy Agency. Report. [World Energy Outlook 2024 – Analysis - IEA](#). Assessed 14/03/2026. 2024.
- Jaramillo, N. & Pablo, D. R. Contribution of Renewable Energy Sources to the Sustainable Development of Islands. An Overview of the Literature and a Research Agenda Loraima Jaramillo Sustainability, 783–811. 2010.
- Kanoglu, M. Cengel, Y.A, Cimbala, J.M. Fundamentals and applications of renewable energy. Mcgraw-Hill Education: New York, USA. 2020.
- Louw, Q. Bokoro, P. An alternative technique for the detection and mitigation of electricity theft in South Africa. South Africa Institute of Electrical Engineers. Vol 110. 2019.
- Meyer, E. Overen, O. Towards a sustainable rural electrification scheme in South Africa. Analysis of the Status quo. Energy Reports. Volume 7. 2021.
- Mnukwa, E. Poube Eboule, S, Pretorius. J-H C. Adaptive energy management in carbon-constrained future : The role of energy policy in South Africa. International Journal of Environmental Sciences. Volume 11, No 21. 2025.
- Naidoo, K. Ndaiye Ntab, M. South African energy sector jobs to 2030: How the Energy [R]evolution will create sustainable green job. Greenpeace Africa. 2010.
- Nathaniel, S. Bekun, F. Alimshani, F. Modelling the impact of energy consumption, natural resources, and urbanization on ecological footprint in South Africa: assessing the moderating role for human capital. International Journal of Energy Economics and Policy. Volume 11. 2021.
- Ndukwu, M. Onwude, D. Bennamoun, L. Nigeria's Energy Deficit : The challenges and Eco-freindly approach in reducing the energy gap. International Journal of Sustainable Energy. Volume 14. Issue 3. 2020.
- Nel, D. Risk and barriers in renewable energy development in South Africa through independent power production. 2015.
- Olatomiwa, L. Mekhilef, S. Ismail, M. Moghavvemi, M. Energy management strategies in hybrid renewable energy systems: A review. Renewable and Sustainable Energy Reviews. Volume 62. 2016.
- Patil, R. Khalkar, A. Al-Dahidi, S. Pimpalkar, R. Pecht, M. A Reliability and Risk Assessment of Solar Photovoltaic Panels Using a Failure Mode and Effects Analysis Approach: A Case Study. Sustainability. Volume 16, Issue 10. 2024.
- Reddy, B. Barriers and Drivers to energy efficiency – A new texanomical approach. Energy Conversion and Management. Volume 7. Pages 403-416. 2013.
- Rhouirin, M. Alayabe, M. Benmoussa, S. Benssouda, M. 2024. Energy policy to overcome energy efficiency barriers: A literature Review. The 14th International Conference on sustainable energy information technology (SEIT). Marshall University, Huntington, WV, USA.
- Shaffer, B. Energy Politics. University of Pennsylvania Press. 2009

- Shafiullah, M. Refat, A. Haque, E. Chowdhury, H. Review of Recent Developments in Microgrid Energy Management Strategies. Sustainability. 2022.
- Statistical Review of the World Energy. Report. 2025. [Home | Statistical Review of World Energy](#). Assessed 14/03.2026.
- The DMRE Report. <https://www.dmre.gov.za/energy-resources/programmes-and-projects/integrated-national-electrification-programme/objectives-of-inep-policy-guidelines>. Assessed on 20/04/2025.
- The New energy deal for Africa Report https://www.africa50.com/fileadmin/uploads/africa50/Documents/Knowledge_Center/New_Deal_on_Energy_for_Africa_brochure_AfDB.pdf. 2025.
- Udo, W. Muhammad, A. Data-Driven Predictive Maintenance of Wind Turbine Base on SCADA data. IEEE Access. 2021.
- World Energy Outlook. www.ifpri.org/sites/default/files/publications/biofuelsreportec.pdf. Assessed 06/02/2026.
- Yadav. A, Pal. N, Patra. J, Yadav. M. Strategic planning and challenges to the deployment of renewable energy technologies in the world scenario: its impact on global sustainable development. Environment, Development and Sustainability. 2018.
- Yazdi, M. Advances in Computational Mathematics for industrial Systems Reliability and Maintainability. Springer Series in Reliability Engineering. 2024.
- Zondo, M. 2023. Judicial commission of inquiry into state capture Report: Part IV: The attempted Capture of National Treasury EOH HOLDINGS and the city of JHB. Vol 1. https://www.statecapture.org.za/site/files/announcements/680/OCR_version_-_State_Capture_Commission_Report_Part_IV_Vol_I_-_NT.EOH.COJ.Alexkor.pdf. Assessed on 01/06/2025

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