Prospects for artificial intelligence to manage load-shedding in South Africa

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DECLARATION

I, Nomea Lerato Shakoane, declare that this research article is my own work except as indicated in the references and acknowledgments. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration in the Graduate School of Business Administration, University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Signed: Nomea Lerato Shakoane

Signed at ……………………………………………………

On the …………………………….. day of ………………………… 20…..

DEDICATION

Thank you, Master Jairo, for daring me to walk the path.

ACKNOWLEDGEMENTS

My gratitude goes out to the God Almighty for guiding me through this journey. Thank you to my family, friends, and co-workers who have shown me such great support. Thank you to the individuals who participated in this study. As a final note, I would like to thank my supervisor, Professor Gregory Lee for his continuous support and guidance throughout this process.

ABSTRACT

Eskom, a state-owned utility in South Africa, is currently facing significant challenges and experiencing severe power shortages. While there is a growing expectation of adopting renewable energy in the future, a sudden and complete transition is unlikely. Legacy power systems, characterized by poor performance, breakdowns, and unpredictability, have received limited attention in AI research. This raises the question: What actions should be taken to quickly address maintenance issues in older power plants and increase generation capacity in the short term?

The objective of this study is to explore AI solutions in the electrical sector and assess the feasibility and cost-effectiveness of integrating AI into Eskom's power system. The findings of this study will provide Eskom and the South African government with valuable insights to make informed decisions regarding the incorporation of artificial intelligence. These AI solutions can include detecting power and cable theft, optimizing energy usage and distribution, and implementing predictive analytics for demand planning and power production optimization.

To gather data, a survey questionnaire was distributed to participants primarily located in South Africa, following a snowball selection process. The survey collected responses from a minimum of 50 participants and covered various aspects, such as load shedding at Eskom, artificial intelligence, data-AI enablers, and AI prospects.

The study revealed that inadequate maintenance within the power generation division was responsible for load shedding. As a result, the implementation of AI solutions such as predictive maintenance, fault detection, and power demand monitoring systems emerged as crucial priorities for Eskom. However, it is important to note that implementing AI requires substantial capital investment. Considering Eskom's current financial situation and South Africa's mounting debt, it is challenging for Eskom to secure the necessary funds without seeking support

from the South African government or major corporations like the IMF or World Bank.

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1. INTRODUCTION

1.1. PURPOSE OF THE STUDY

The purpose of this study was to explore and propose the implementation of artificial intelligence systems in the global electrical energy industry with the aim of preventing or reducing power outages.

Eskom, in order to avoid nationwide blackouts, employs a method called load-shedding. This involves temporarily and strategically reducing the load on specific locations within the grid or network to maintain stability and prevent system collapse (Laghari, et al., 2013).

The focus of this study is to investigate how artificial intelligence can be integrated into Eskom's power grid. By leveraging AI technologies, Eskom can optimize energy flow, utilize smart grids for efficient energy management, detect and mitigate cable and power theft, employ predictive analytics for improved production, and effectively plan for future energy demand. These insights will enable Eskom to enhance overall power grid operations and ensure a reliable and sustainable energy supply.

1.2. CONTEXT OF THE STUDY

- **Brief description of the field of study**

Coal plays a vital role in the South African energy sector, thanks to its affordability and ample availability. A significant portion, approximately 69%, of the country's electricity is generated from coal, while the remaining power comes from biomass, renewable, and nuclear sources (Pretorius, 2022).

- **Importance of why this field is important.**

Energy is crucial for the development of a country. It powers businesses across various sectors, households, etc. Therefore, energy has the greatest impact on the growth and stability of the economy of a nation (Inglesi & Pouris, 2010).

- **Current trending hot topics in this field**

Many African countries have long been grappling with the persistent challenge of energy outages, a problem that has persisted for decades. As the world increasingly shifts towards greener energy sources, there is a notable rise in the application of artificial intelligence within the renewable energy industry.

However, the potential of leveraging artificial intelligence to enhance South Africa's existing electrical power systems remains largely overlooked, presenting an untapped opportunity for advancement and optimization.

- **Proposed research base in the field to identify the gaps**

Legacy power stations and generators have been plagued by poor performance, frequent breakdowns, and unpredictability, which has resulted in limited research attention being given to these power systems. While the transition to greener energy is a gradual process that cannot happen overnight, it is essential to take immediate measures to ensure a consistent and stable energy supply. This is crucial to prevent any potential collapse of South Africa's economy and maintain uninterrupted business operations.

1.3. PROBLEM STATEMENT

Loadshedding poses a risk to South Africa's economic stability. Despite some evidence that artificial intelligence could be a feasible solution in reducing loadshedding, its complexity and high cost have hindered a lot of research attempts to understand and implement it within the South African context.

1.4. SIGNIFICANCE OF THE STUDY

- **Benefits or advantages of the study based on problem statement (to the science field)**

Artificial intelligence is a new topic and has been garnering relevance in various sectors. However, there are still few AI research studies that have been undertaken within the energy industry, especially within the electrical power sector.

In the South African context, the talks of shifting towards green energy have made industry experts as well as researchers shy away or abandon finding practical solutions to salvage the legacy infrastructure of Eskom, based on several reasons including poor performance, lagging maintenance programs, and collapsing infrastructure, Consequently, management faces a difficult decision regarding how to proceed in this situation.

Therefore, it is considered a "waste of time and resources" to invest in and focus on integrating AI with ageing infrastructure, as it is believed that integrating AI with renewable energy sources would be more effective.

However, this study will explore the relevance of the implementation of AI in the electrical sector (power generation) and the impact it will have on Eskom and the energy sector in South Africa.

1.5. DELIMITATIONS

- Other challenges are experienced in the power sector. However, this study is only limited to load-shedding and power generation-focused AI applications. Power transmission and power distribution will be excluded.
- To further narrow the research scope, focus will be placed on infrastructure and machinery failures at Eskom.

1.6. DEFINITION OF TERMS

- **Artificial intelligence:** the ability of machines following scripted logic to execute tasks usually performed by humans.
- **Load shedding**: is the process of reducing and relieving load stress by switching off certain parts of the grid to avoid country-wide blackouts.
- **Eskom:** A South African state-owned utility.

1.7. ASSUMPTIONS

- Respondents are assumed to have a basic understanding of artificial intelligence concepts and how they are being implemented in South Africa at present.

1.8. OBJECTIVES AND AIMS

Given the above, the objectives and the aim of the study are:

- To explore the technical possibilities for AI to mitigate electricity load-shedding in South Africa within the power generation sector.
- To investigate cost-benefit factors and comparisons in using Artificial intelligence to mitigate load-shedding in SA.

1.9. RESEARCH QUESTIONS

Given the above, the research questions to be uncovered are:

- What are the AI technical possibilities that can be implemented within the power generation in Eskom?
- What are the cost-benefit factors and considerations?

2. LITERATURE REVIEW

2.1. Introduction

This chapter offers a brief overview of Eskom, highlighting the organization's significance and the common challenges it encounters. In addition, it emphasises the crucial role of digitized power systems in today's business landscape. Subsequently, the chapter explores the diverse range of AI research initiatives implemented by organizations and countries worldwide. Through a critical analysis, this study highlights the practicality and economic feasibility of these AI applications. By examining real-world examples and evaluating their potential, Eskom can gain valuable insights into the practicality and economic viability of incorporating AI technologies into their own power systems.

2.2. Eskom Background

South Africa relies on Eskom for more than 90% of its energy supply (Booysen & Rix, 2021). However, the request to construct a power station in 2004 was rejected, despite a significant 50% increase in electricity demand from 1994 to 2007. These circumstances played a role in the country's first-ever severe power outages experienced in 2008. As a consequence, the GDP experienced a decline of 5.7% compared to previous years (Inglesi & Pouris, 2010).

To better understand the operations of Eskom, it is important to explore its organizational structure, which consists of three distinct entities. These entities will be discussed in detail in the subsequent sections, shedding light on their roles and responsibilities within the overall functioning of Eskom.

2.2.1. Power Generation

The electricity generation process is a crucial aspect of providing power to meet the demand. Eskom, as a key player in South Africa's energy sector, operates a range of electricity-generating plants. Notable examples of newly constructed power stations include Kusile and Medupi (Booysen and Rix, 2021). These power stations, along with others, play a vital role in generating electricity throughout the year.

Eskom's Generation Group is responsible for operating various types of power plants, including nuclear, gas turbines, and hydroelectric units. The company maintains and operates hydroelectric, pumped storage, and gas turbine power plants (Pretorius, 2022). It's noteworthy that a significant portion of Eskom's generation capacity, specifically 38 GW out of 44 GW, is derived from 13 coal-fired stations. These stations contribute significantly to meeting the electricity needs of South Africa's businesses and industries.

2.2.2. Power Transmission

A transmission line, also known as a high-voltage line, is like a highway for electricity, carrying power to communities at high voltage levels. These remarkable lines stretch across vast distances, covering at least 30,000 kilometres, connecting cities and towns and delivering electricity to businesses and homes (Pretorius, 2022). Just like how roads connect different destinations, transmission lines connect power sources to areas where electricity is needed the most. They play a vital role in ensuring a reliable and efficient flow of electricity, enabling businesses to operate smoothly and keeping our homes powered up. These high-voltage lines form the backbone of our electrical infrastructure, contributing to the growth and development of our communities.

2.2.3. Power Distribution

Transmission and distribution lines play a crucial role in establishing a seamless connection between power plants and end-users. These lines form a comprehensive system that ensures the smooth flow of electricity at a standard frequency of 50Hz, enabling businesses and consumers to access reliable power supply. By efficiently transmitting electrical energy from the generation sources to various locations, these lines serve as the backbone of our power infrastructure, supporting the uninterrupted operation of industries and facilitating the delivery of electricity to homes and businesses alike.

2.3. Power outages

Power blackout refers to the temporary disruption of electricity supply within a specific timeframe. Such outages can occur due to various factors, including sudden increases in power demand or technical issues(Nghia, et al., 2020). To ensure the stability of the power grid, control solutions are swiftly implemented before resorting to load shedding measures(Nghia, et al., 2020).

Power outages can be caused by natural disasters and technical problems. Common natural causes include animals coming into contact with live wires, vehicle accidents, and severe weather conditions that damage transmission line vegetation. Transmission and distribution outages can result from damaged infrastructure, faulty lines, system instability, overloaded wires, or equipment malfunctions. Energy shortages can also contribute to blackouts. Some incidents, like faults, may trigger contingencies, while others can cause a chain reaction leading to widespread outages. It is crucial to address these factors to minimize the impact of power blackouts on businesses and communities (Laghari et al., 2013).

2.4. Common issues

Voltage instability is a significant factor that contributes to power blackouts, specifically when the transmission system becomes overloaded (El-Sadek, 1998). Improper load shedding, whether excessive or insufficient, has been a common cause of power blackouts, raising concerns about the effectiveness of current load shedding techniques. Given the complexity and size of modern power systems, there is a need for alternative methods to enhance reliability and minimise the occurrence of blackouts (Laghari et al., 2013). Businesses must recognize the importance of addressing voltage instability and implementing effective load shedding strategies to mitigate the risks associated with power outages.(Laghari, et al., 2013).

2.5. Stability threats

When there is an imbalance between electricity demand and supply, it puts the stability of the power grid at risk. Eskom, the power utility in South Africa, faces challenges due to both maintenance issues with older plants and mismanagement during the construction of new ones. The result is a loss of generation capacity of up to 20 GW from plants that are, on average, 40 years old. To avoid a grid collapse when demand exceeds supply, Eskom's National Control Centre in Johannesburg closely monitors and controls the grid frequency. As part of their demand management strategy, the company implements scheduled power outages known as load-shedding (Booysen and Rix, 2021). This allows Eskom to maintain grid stability and ensure reliable electricity supply to customers.

2.6. Management Theory : Decision-Making

One of the management theories that this study discusses a great deal is decision-making theory, which is an integral part of this research study.

As part of this framework, which examines the processes by which managers make choices and make decisions within the context of an organisation, there are various models and approaches that provide guidance for effective decision making. In Edwards (1954) report, the decision-making process is explored in depth. The report discusses rational decision-making, subjective expected utility, and probability theory, among other models and theories. In addition, it offers insight into the field of decision science by discussing cognitive and psychological factors that affect decision making.

Similarly, AI is able to analyse historical data on electricity demand, supply and infrastructure conditions by using algorithms. As previously mentioned, AI combines data and analytical models to support decision-making, by integrating real-time data, such as forecasts and grid performance. The system can predict and optimise the overall power system to minimise and eliminate loadshedding. AI will act as a decision making model (Brynjolfsson & McAfee, 2011), that can be used by Eskom.

2.7. AI literature

2.7.1. AI Definition

According to McCarthy (2004), artificial intelligence is the process of making machines intelligent by making computers capable of understanding and executing human actions.

There has been extensive research and advancements in artificial intelligence since the early 1950s. AI is currently reaching a level of sophistication that was unimaginable to the early pioneers of the field (Wooldridge, 2018).

Among the most exciting fields of science is artificial intelligence. While it has the potential to achieve great things, many people around the world remain sceptical of its capabilities. There have been several instances in the history of AI where researchers have overstated its capabilities. As a result of the enthusiasm and optimism that often accompany AI research, unrealistic expectations are often made regarding its potential (Wooldridge, 2018).

2.7.2. Preventive & predictive maintenance

Eskom has been facing significant challenges due to a long-standing backlog of maintenance, which has adversely affected the performance of its power plants. The delay in implementing an old maintenance plan, specifically aimed at refurbishing control and instrumentation systems, has impacted the majority of the 11 power plants. Additionally, factors such as the failure to rehabilitate cooling towers, a backlog of boiler tube leak repairs, and plant shutdowns due to inefficient operation have contributed to high load losses (News24Wire, 2022, p1).

These issues have resulted in rapid deterioration and reduced operational efficiency of the plants (Paton, 2022).

While there is often a trade-off between preventive and unplanned maintenance, predictive maintenance (PdM) offers a solution by maximizing the useful life and availability of components. By employing an automatic monitoring system, the condition of equipment in service can be continuously monitored, enabling the prediction of potential malfunctions (Carvalho et al., 2019). Implementing PdM can help Eskom mitigate the maintenance trade-off and improve the longevity and reliability of its equipment.

Unplanned downtime can be caused by unexpected failures resulting from inadequate approaches. To prevent equipment breakdowns, scheduled maintenance plays a crucial role. One of the most effective ways to achieve this is through frequent component replacements. Prolonged idle periods of machines can lead to increased maintenance costs.

In recent years, the emergence of the Fourth Industrial Revolution (4IR) and smart systems has brought the concept of predictive maintenance (PdM) into the spotlight. Predictive maintenance utilizes technology and practices that reduce downtime costs and improve production efficiency, thereby enhancing manufacturing equipment productivity. Moreover, by maximizing the lifespan of components, predictive maintenance also fosters sustainability in manufacturing operations.

Among the commonly employed machinery maintenance methods, preventive maintenance involves regular inspections and maintenance of each component. Implementing regular maintenance intervals helps prevent machine breakdowns and is considered a sound practice (Lee et al., 2019).

2.7.3. Fault detection

Eskom has implemented a generation recovery plan aimed at enhancing the performance and availability of the generation phase, as stated by Pretorius (2022).

Recent advancements in the field of Machine Learning have played a significant role in achieving the desired objectives, particularly in addressing the complexity of nonlinear tasks. Ma et al. (2019) conducted a study focusing on the application of machine learning in forecasting power system faults and estimating load forecasts.

To predict system failures, a specific AI algorithm has been developed by Patton (2022), utilizing historical data on previous system failures.

2.7.4. Cable or power theft detection

Cable theft poses a significant challenge for Eskom, impacting service delivery and imposing a considerable financial burden on the company, according to Eskom's own data. Despite increased protection and security measures taken by Eskom's business operating units, cable theft remains a persistent issue in various sectors, including telecoms and power (Govender & Ras, 2017).

Similarly, power theft is a pressing concern in Nigeria's power sector. This illicit practice allows users to illegally extract energy from utilities, leading to financial losses for utility companies. Omijeh et al. (2012) highlight the detrimental effects of electrical theft and its impact on the Nigerian power industry.

The misappropriation of funds within the power sector can manifest in various forms, including meter tampering, theft (such as through illegal connections), billing irregularities, and unpaid bills. These illegal activities have resulted in significant revenue losses for Nigerian power utilities (Nwaoko, 2006).

Ensuring the reliability and protection of electricity grids is crucial for the smooth functioning of any economy. Distributor system operators (DSOs) face a critical challenge in detecting instances of illegal electricity consumption. Minimizing non-technical losses is essential for maintaining a reliable power grid. The rising popularity of smart meters allows for extensive data collection on electricity consumption, and the integration of new artificial intelligence technologies can provide more efficient solutions to combat power theft. By leveraging these technologies, researchers aim to address this issue more effectively (Blazakis et al., 2020).

To address this issue, researchers have conducted numerous studies in this area.

Blazakis et al. (2020) conducted a study focusing on the detection of power thefts using an adaptive neuro-fuzzy inference system (ANFIS) based on artificial intelligence. The study discusses the algorithm and its application in improving the detection of power thefts. Examples of illegal activities related to unlawful energy use demonstrate the potential of the proposed technique to achieve high success rates when appropriately implemented.

Depuru, et al., (2011) examined the detection of non-technical losses (NTL), which are energy theft and irregularities committed by big power end-users in Malaysia. They highlighted the seriousness of dishonesty among power consumers and proposed a model of theft control that incorporates various detection techniques to enhance fraud detection.

A novel method for detecting streetlamp power cable theft was presented by Xilinx (2003). The authors introduced a unique approach specifically designed to identify streetlamp power cable theft incidents.

As reported by Nagi, et al., (2011), the authors explored using Support Vector Machines to recognize Non-Technical Loss Detection in Power Distribution for metered customers. Using an artificial intelligence algorithm, a supportive vector machine (SVM), they were able to develop an automated and non-technical system to detect loss, based on non-technical approaches.

2.7.5. Load forecast/predictions or intelligent load shedding

A study conducted by Mortaji et al. (2017) introduced an algorithm called smart-direct load control (S-DLC) to mitigate peak-to-average ratio issues by implementing load shedding during sudden grid load fluctuations. The algorithm incorporates forecasting methods, shedding techniques, and S-DLC. Additionally, the platform offers a real-time load control system that utilizes the Internet of Things (IoT) and stream-based analytics to create customized daily schedules for IoT-connected electronic devices, considering customer demands, thermal comfort, and forecasted load.

The research findings indicate that combining load shedding techniques using an autoregressive integrated moving average time-series prediction model with S-DLC implementation and leveraging IoT can significantly reduce power outages for customers (Mortaji et al., 2017).

As the power grid expands to accommodate new energy installations and the electrification of power grid equipment, the failure rate of power systems has increased, leading to decreased stability. Consequently, clearing power system faults has become challenging (Langhari et al., 2013).

To achieve voltage stability, Sallam and Khafaga (2013) utilized fuzzy logic control, an artificial intelligence technique, for load shedding. The simulation results demonstrated successful implementation of load shedding with a fuzzy logic controller, effectively stabilizing the system and restoring voltage to normal levels.

Haidar et al. (2010) proposed an intelligent control strategy for load shedding using deep reinforcement learning. This strategy enables autonomous voltage control through deep reinforcement learning, where a continuously trained network develops a load shedding strategy for emergency scenarios requiring grid voltage control. The proposed strategy is incorporated into the Pypower module for simulation verification and enables joint simulation and data analysis.

Implementing a complete load shedding optimization model poses computational challenges and is difficult to solve in a timely manner, especially considering the increasing energy sources and demand-side behavior. Sensitivity-based methods may compromise control accuracy and fail to ensure global optimality (Liu et al., 2021).

2.7.6. Smart Grids

This study introduces a groundbreaking framework called "Grid Mind" that enables autonomous control in the operation of electric grids. Duan et al. (2020) propose an innovative approach that combines artificial intelligence (AI) techniques with advanced networks to ensure secure grid operation.

By harnessing deep reinforcement learning (DRL) algorithms, this platform incorporates an agent system that utilizes a model-free, data-driven, and closed-loop control scheme. Through interactions with extensive simulations and real-time grid environments, the agent is trained solely based on data to effectively control voltage in a power grid.

The application of an Autonomous Voltage Control (AVC) system equips grid operators with efficient and timely control strategies for real-time voltage management (Duan et al., 2020).

2.7.7. Enablement of Big Data in power systems

In their study, Barla-Martinez et al. (2021) provide a comprehensive analysis of Artificial Intelligence (AI) applications specifically tailored for distribution networks. The research covers various aspects such as maintenance, monitoring, and operation, highlighting the emerging AI techniques and data sources available for power system usage.

The study examines a range of data-driven services designed for distribution networks, including energy management systems, observability, fraud detection, non-technical loss detection, predictive maintenance, forecasting, and on-demand trading. A thorough review is conducted to explore the AI methods employed in each of these services, shedding light on their implementation and effectiveness (Barla-Martinez et al., 2021).

2.7.8. Disadvantages of AI in Power systems

- Cyber attacks

Artificial intelligence (AI) in power systems has shown vulnerabilities to security attacks, as highlighted in studies conducted by Chen et al. (2018). However, Tian et al. (2019) have also demonstrated solutions to overcome these vulnerabilities, ensuring the security of AI algorithms in power systems.

- High costs of implementation

While AI offers significant benefits, its implementation comes with high costs, including substantial capital investment and expenses for repairs and maintenance, as noted by Das (2022).

- Complexity

Moreover, integrating AI into existing power systems with non-existent data systems and deteriorating infrastructure in South Africa poses additional challenges. The complexity of merging AI technology with outdated infrastructure requires careful planning and expertise. It is crucial for businesses in the power sector to assess these factors and adopt appropriate strategies to effectively and securely integrate AI into their operations.

2.8. Cost-benefit

An excessive amount of attention has been focused on the technical details of the study. There is no evidence of knowledge regarding the cost-benefit factors, particularly in South Africa. Therefore, there is a gap in the South African literature, which this study intends to fill. Accordingly, the research question pertaining to this element is:

- What are the cost-benefit factors and considerations?

2.9. Summary

The literature review indicates that numerous studies have explored the use of Artificial Intelligence (AI) in electrical or power systems worldwide. However, these research projects have mostly been limited in scope. In order to gain a comprehensive understanding of the AI landscape in this field, further investigation is warranted. The aim of conducting additional research is to identify the specific AI technical possibilities and assess their potential adoption in both the short and long term. Moreover, the study seeks to uncover the cost-benefit factors and considerations associated with these AI applications. By addressing these research objectives, businesses can gain valuable insights into the feasibility and advantages of implementing AI in their power systems, enabling informed decision-making and maximizing their operational efficiency and financial returns.

3. RESEARCH METHODOLOGY

This chapter will present a framework necessary to achieve the objectives and aims of this study. The primary purpose of this paper is to identify which Artificial Intelligence prospects can be implemented or adopted in the power generation division to manage and or reduce load shedding. It will also be beneficial to investigate what the cost implications are.

Therefore, this chapter will also outline the questionnaire design, population, sampling, and collection method. The chosen methodology will indicate the data required, chosen methods, and the reasoning behind the decision.

3.1. Research Methodology

A quantitative methodology was employed in the research. When addressing questions that require quantitative information, researchers typically follow a statistical method (Williams, 2007).

Research that uses numerical or statistical data as the basis for its design can be referred to as quantitative research. Quantitative research methodology adheres to the assumption of the empiricist paradigm, which is at the heart of the study (Creswell, 2003).

3.2. Research Design

A quantitative methodological approach was adopted in this research study. This approach consists of using an experimental or survey approach in order to collect data thus resulting in statistical data as stated by Creswell (2003).

Digital platforms such as LinkedIn, WhatsApp were used to disseminate the survey questionnaire to a variety of industry professionals.

3.3. Population and Sample

3.3.1. Population

For this study, the population was confined to professionals (Majid, 2018), working in the energy and technology industries mostly situated in South Africa.

3.3.2. Sample

When planning a research study, it is imperative to consider the sample size (Burmeister, 2012). An association of energy and technology professionals was selected through a snowball method that relies on the social network of participants sharing common traits and recommending others (Handcock and Gile, 2011).

A minimum of 50 industry professionals were selected to participate in the survey. Confidentiality was maintained (Boruch, 1971), and all respondents remained anonymous (Wildman,1977) for the duration of the survey.

The characteristics of the respondents were as follows

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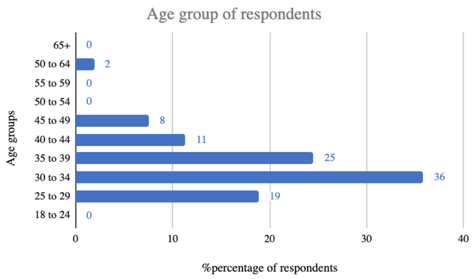
Figure 1: Age of respondents



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80% of the respondents are between the ages 25 and 49 as shown on Figure 1.

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Figure 2: The professional industries

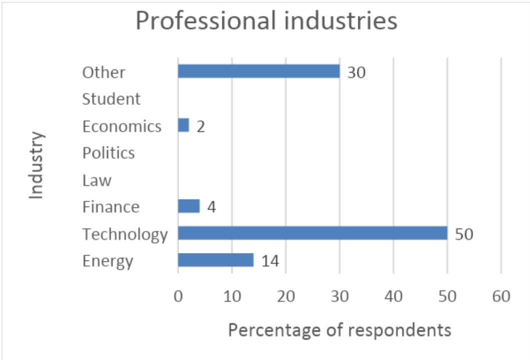

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Figure 2 shows that more than 60% of the same respondents work in the energy and technology industries.

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Figure 3: Location

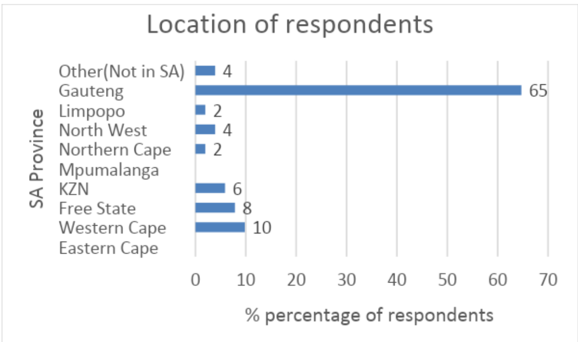

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Figure 3 shows that 65% of the respondents live in Gauteng province, considered one of South Africa's largest business hubs.

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Figure 4: Years of work experience

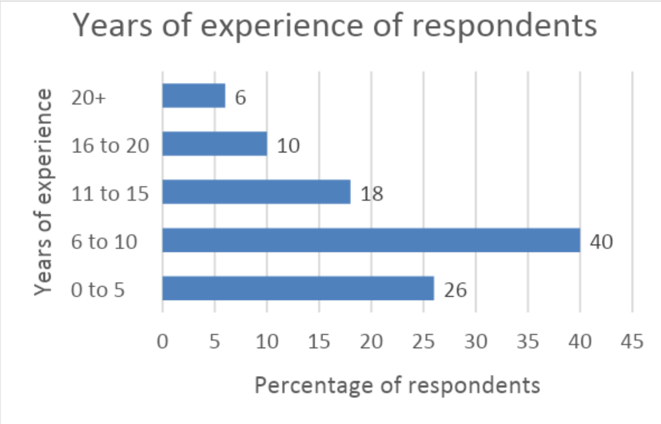


Figure 4 shows that 84% of the respondents have experience from zero to fifteen years.

Figure 5: Respondents' level of education

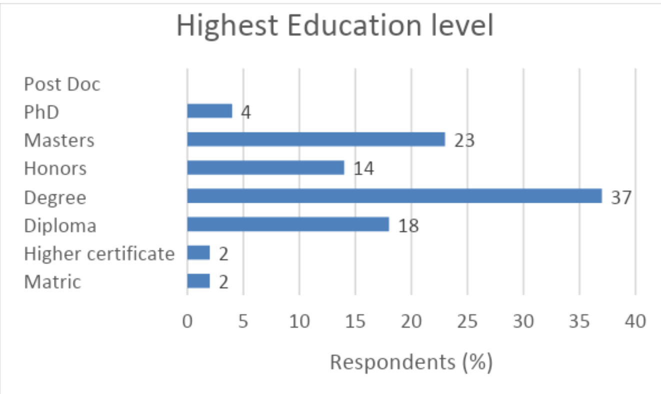
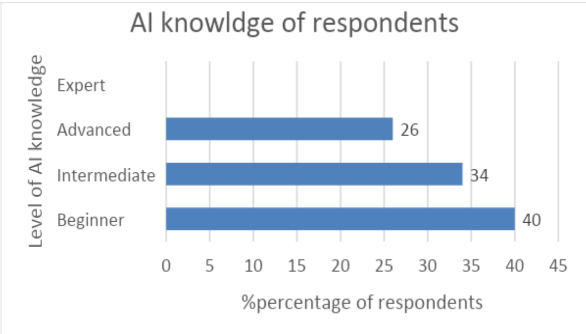


Figure 5 illustrates that 92% of respondents held certificates ranging from diplomas to master's degrees

Figure 6: AI level knowledge of the respondents  	Figure 6 shows that, there was a significant proportion of respondents with more than six to ten years of experience in terms of AI knowledge, 26% of the respondents had advanced knowledge, while 34% and 40% of the respondents had intermediate and beginner knowledge, respectively.

3.4. Research Instrument

A survey questionnaire was chosen as the instrument for this research report. The following sections were compiled:

3.4.1. Demographics

It was required that respondents complete this section by providing their age, their location (one of the nine provinces in South Africa), their highest level of education, professional industry, and their years of work experience.

3.4.2. Load-shedding issues at Eskom

The respondents were asked to rate the severity of load-shedding, to identify the power division that was responsible for load-shedding, to determine the causes of load-shedding, and to identify the reasons for load-shedding.

The information gathered from this section helped narrow down the technical challenges Eskom faces, especially in the power generation utility.

3.4.3. Artificial Intelligence:

The purpose of this section was to evaluate respondents' understanding of artificial intelligence, determine whether artificial intelligence is required to move from renewable energy to the electrical sector, and determine whether SA has the infrastructure capability, financial resources, or skills to support it. Additionally, they were asked to rank the proposed artificial intelligence implementations within Eskom's three divisions from lowest to highest.

The insights generated from this section assisted in identifying the AI prospects that could ultimately be implemented at Eskom, to alleviate or manage load-shedding.

3.4.4. AI enablers - Data:

Respondents were surveyed to assess the importance of data as the basis for the proposed artificial intelligence models/prospects, whether Eskom had enough data, whether a data centre was required, and the degree to which these AI models were difficult to construct.

The purpose of this section is to determine the importance of data and to determine whether Eskom has an adequate amount of data available for exploitation.

3.4.5. AI Prospects:

In this section, respondents were required to determine whether it is important for supply and demand data to be collected, to determine the likelihood of the installation of smart grids & the proposed AI prospects, their ability to curb loadshedding, and to measure respondents' level of confidence when it comes to the feasibility of implementing AI in SA.

It is intended that this section will serve as a tool for determining the practicality of implementing the proposed AI system within Eskom.

In summary, considering the survey responses, a number of conclusions will be drawn from the data - as follows:

- Eskom's main utility or the one that contributes most to load shedding.
- Several areas in which Eskom may be able to maximize the use of artificial intelligence.
- The probability of AI implementation varies depending on a variety of factors, including one's age, technical exposure, geography, etc.
- The challenges associated with implementing artificial intelligence.

3.5. Data collection Procedure

The data collection process involved the completion of a questionnaire as shown in Appendix A. The questionnaire was administered via WhatsApp, and the survey link (Fowler, 2013) was further circulated via WhatsApp through colleagues, friends, and acquaintances, as well as through LinkedIn.

It will be possible to collect responses and analyse them using a computer-based system.

3.6. Limitations of the study

The following limitations were encountered in this study:

- Selection of samples based on the snowball method can skew results by introducing bias into the process.
- There is a lack of transparency regarding current AI/Data projects being conducted by Eskom.
- There is a lack of previous research materials on AI in electrical studies, both locally and internationally.
- Current AI research studies are difficult to access.

3.7. Reliability and Validity

Heale & Twycross (2015) state that, when it comes to the assessment of validity, it can be defined as how well an idea has been measured quantitatively and to what extent. A reliable instrument is one that is accurate and reliable. An instrument's consistency is a measure of how consistently a particular research instrument produces the same results over a period.

Validity and reliability are important factors that affect correlation coefficients (Connelly, 2016) therefore, they must be considered. There is a theory that a correlational study aims to determine whether two or more variables may be related to each other, as explained by Leedy, & Ormrod (2001). In accordance with Gliem & Gliem (2003), it has been demonstrated that alpha-Cronbach's can be used to test the reliability of data.

3.8. Ethical Considerations

Neither the IP address, contact information, or location of respondents were recorded or collected. The results sought after were held in the strictest confidence, respect, and honesty (Breen, 2006).

CHAPTER 4: DATA ANALYSIS AND INTERPRETATION

4.1. Introduction

This chapter provides a summary of the survey results obtained from the questionnaire, focusing on potential Artificial Intelligence (AI) solutions that can help Eskom address and mitigate load shedding challenges. It also examines the feasibility of implementing these solutions considering Eskom's financial situation and the broader financial context of the South African government.

The survey results will be analyzed in relation to Eskom's load shedding issues, considering factors that deter AI adoption and factors that enable AI implementation, such as data availability, infrastructure readiness, and the availability of AI skills. Furthermore, the practicality of implementing AI in South Africa will be evaluated.

4.2. Issues at Eskom

A significant majority of respondents (94%) acknowledge that the severity of load shedding in South Africa has led to significant economic hardships for themselves and their families (Figure 7). Among the contributors to load shedding, power generation is considered to have the most significant impact (Figure 8). Lagging maintenance programs and an ageing infrastructure were identified as the primary reasons for load shedding in South Africa (Figure 9). Consequently, the South African government was primarily held responsible for load shedding, followed by Eskom management (Figure 10).

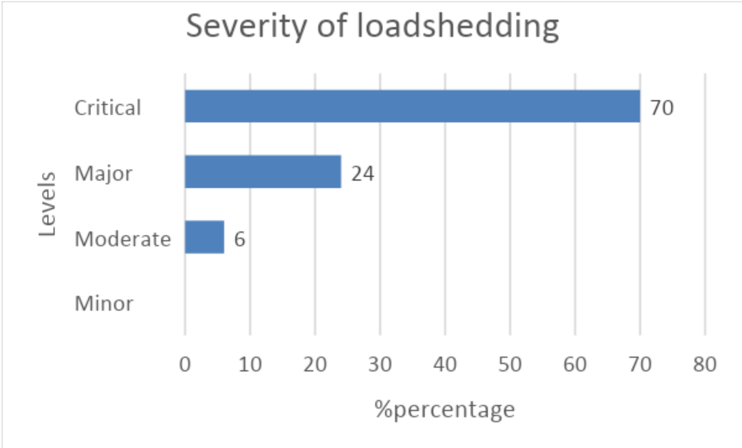


Figure 7: Severity of load-shedding in South Africa

Many of the respondents believe that the load shedding issues in South Africa are extremely severe as shown on figure 7.

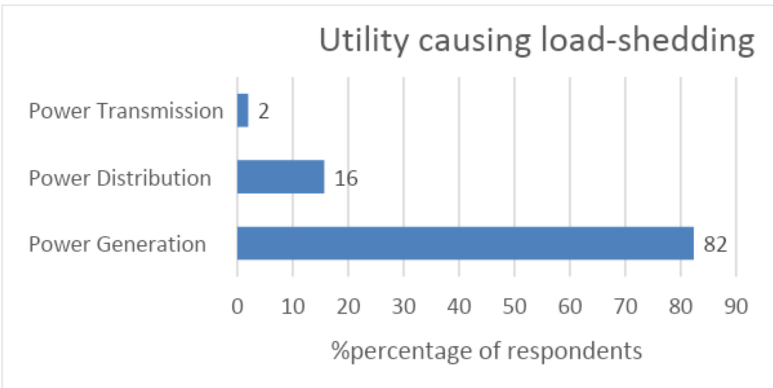


Figure 8: Eskom's division responsible for load-shedding

In terms of load shedding, 82% of respondents believe that the power generation utility is largely responsible, as opposed to the other two divisions as shown on figure 8.

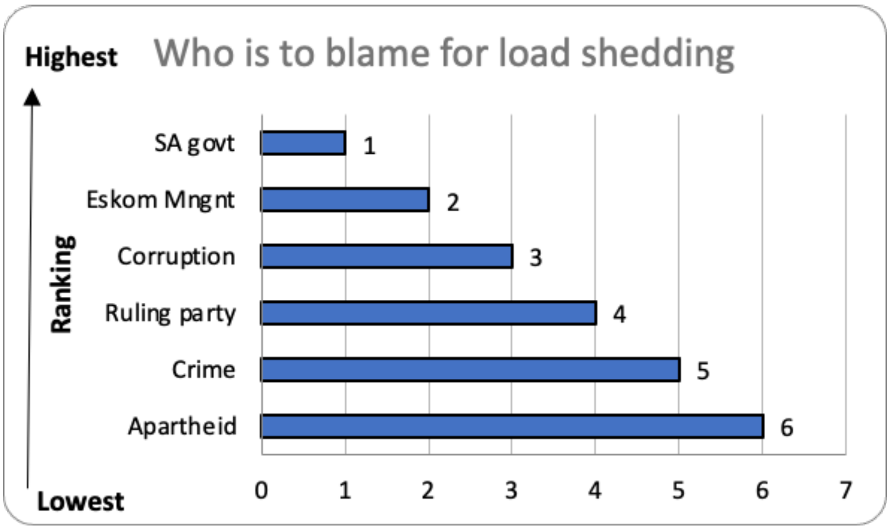


Figure 9: Ranked choices for who is to blame for load-shedding.

According to the results, the South African government was voted as the most likely cause of load shedding followed by Eskom Management. Crime was voted as the least likely cause of load shedding in South Africa.

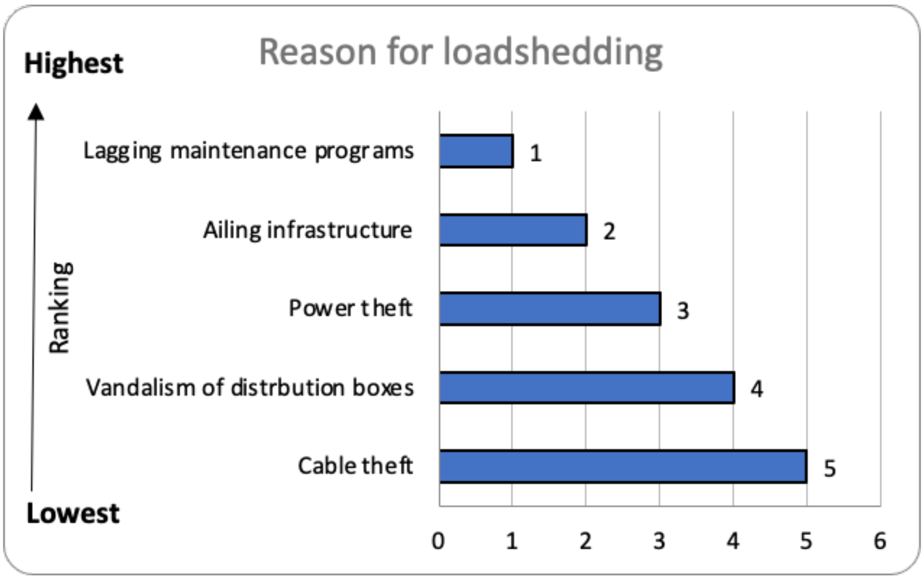


Figure 10: Reason for load-shedding rankings

It was reported that a lack of maintenance was the leading cause of load shedding, followed by an ageing infrastructure, and cable theft was the least likely cause of load shedding.

4.3. AI deterrents and AI enablers

In South Africa, artificial intelligence implementation can be enabled or hindered by several factors. Most respondents (40%) do not believe that South Africa has the infrastructure to facilitate AI implementation (Figure 11). Respondents believe that SA does not seem to possess the necessary AI skills (Figure 12).

As per the results, over 90% respondents strongly believe that data act as a building block for AI models (Figure 13). According to 75% of respondents (Figure 14), Eskom is said to have sufficient data to develop AI models (Figure 15) However, more than half of respondents believe Eskom will have difficulty building these models (Figure 16).

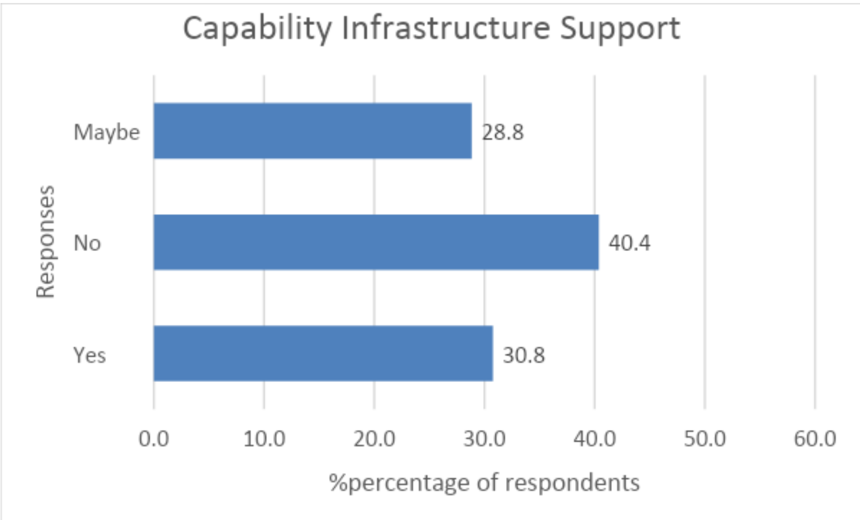


Figure 11: SA capability to support AI infrastructure.

SA is not considered capable of supporting AI by 40% of the respondents, while 31% believe that it is capable, while the remaining are uncertain as shown on figure 11.

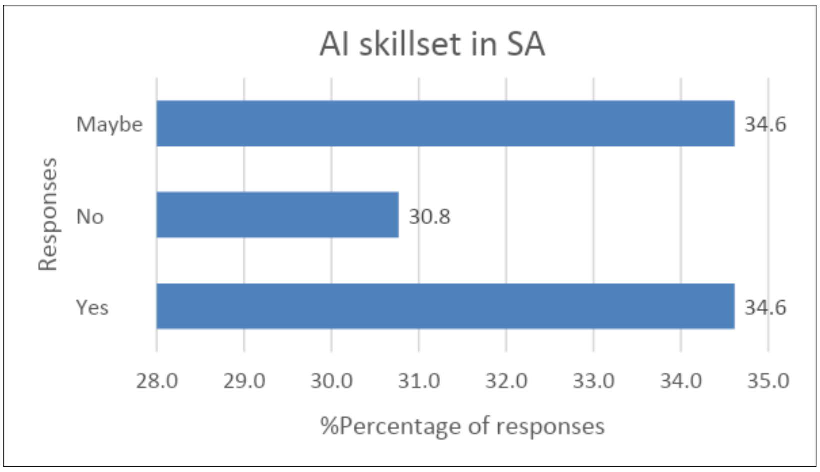


Figure 12: AI skillset in South Africa

SA was not found to be capable of possessing AI skill set by 31% of the respondents, while 34.6% were sure, and the remainder were unsure as illustrated on figure 12.

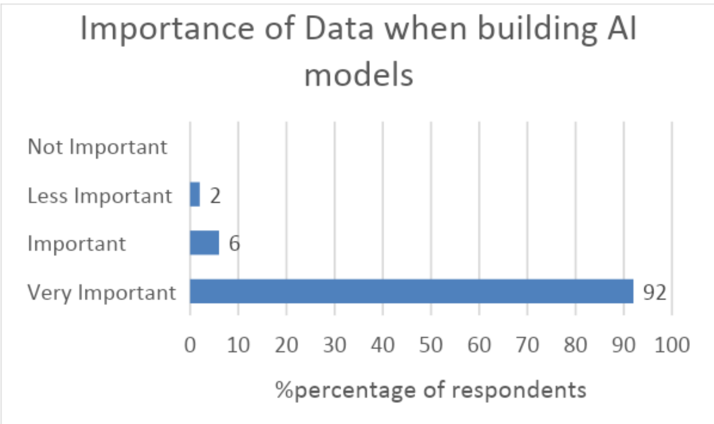


Figure 13: Importance of data as a building block of AI.

Figure 13 shows that data is an important component of AI model development.

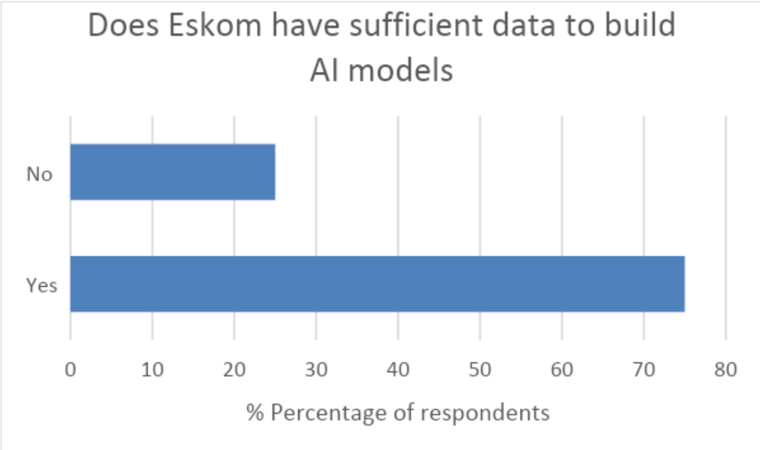


Figure 14: Sufficient data at Eskom

Figure 14 depicts that 75% of the respondents believe that Eskom has sufficient quality data to build the AI models.

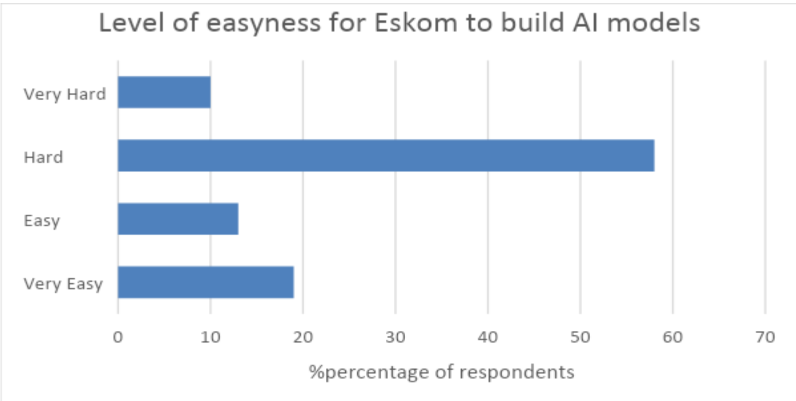


Figure 15: How easy will it be for Eskom to build AI models.

It won't be easy for Eskom to build AI models, according to over 70% of respondents as displayed on figure 15.

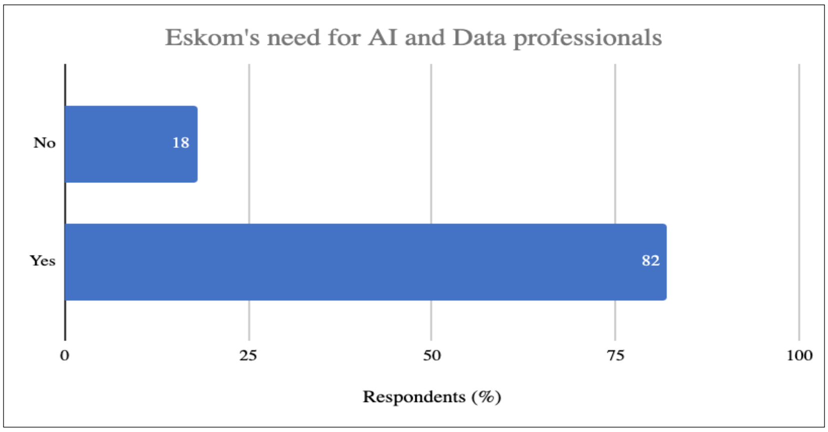


Figure 16: AI skillset required in Eskom.

According to Figure 16, it is assumed by 82% individuals that Eskom's need for AI and data professional is high.

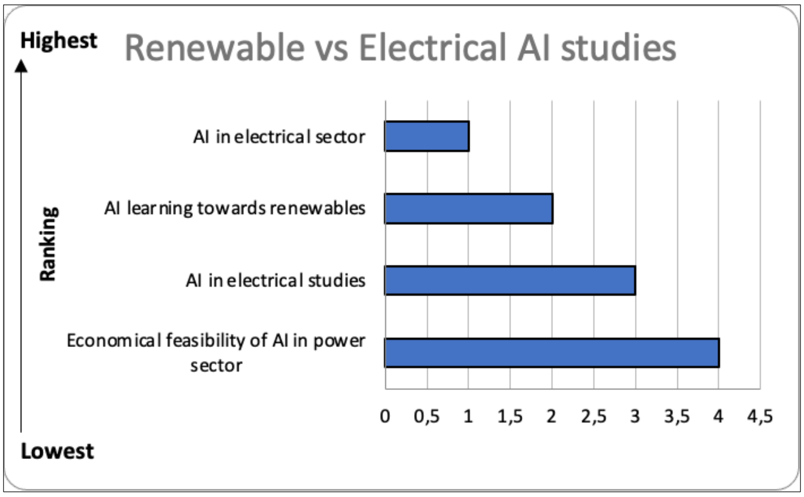


Figure 17: AI studies in SA in renewables vs electrical

In the SA context, respondents believe that AI studies should also lean towards the power sector as opposed to renewables as shown on figure 17.

4.4. AI prospects

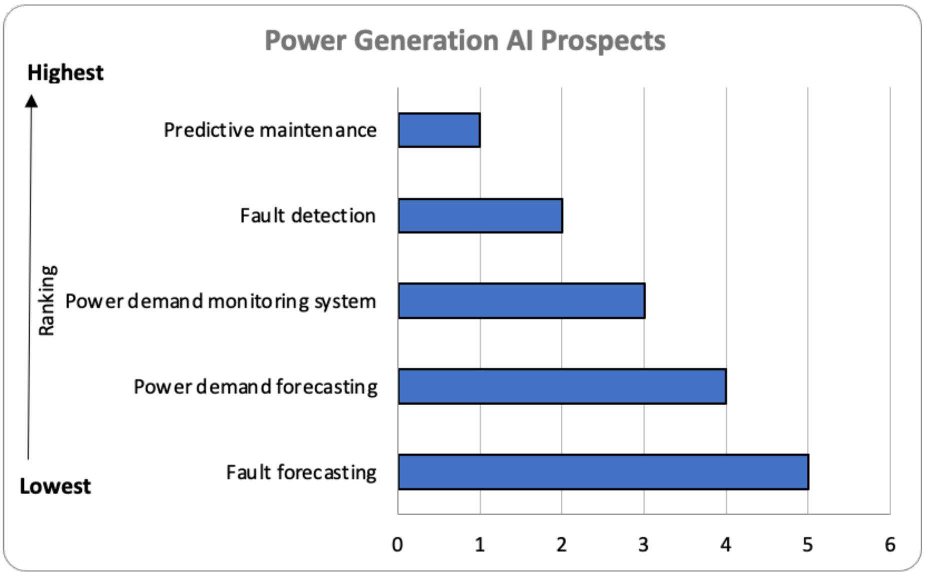


Figure 18: Proposed AI prospects in the power generation division

As displayed on figure 18, the respondents ranked the following AI solutions in order of highest to lowest, namely predictive maintenance, fault detection, and power demand monitoring, as possible AI solutions to be implemented within the power generation division.

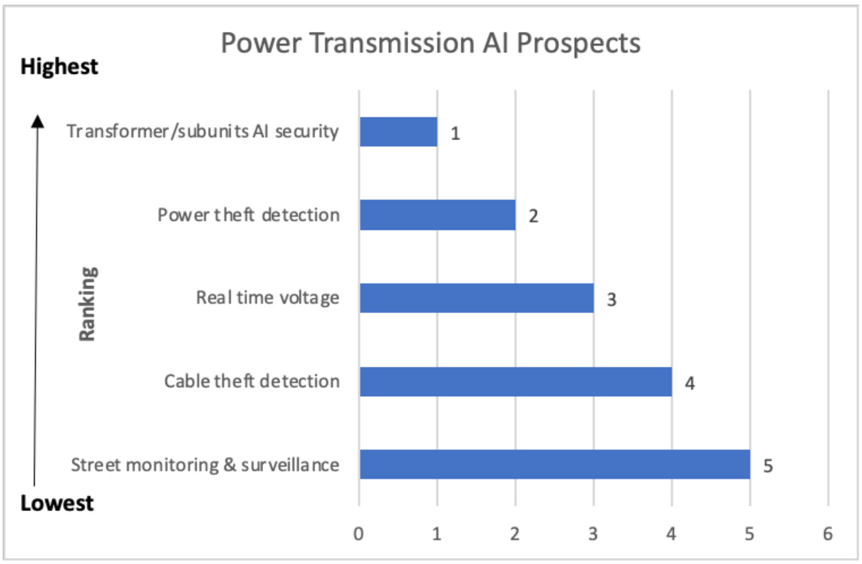


Figure 19: Proposed AI prospects in the power transmission division

Figure 19 indicates that transformer security, power theft detection, and real-time voltage monitoring are the top three AI solutions selected by respondents in the power transmission division.

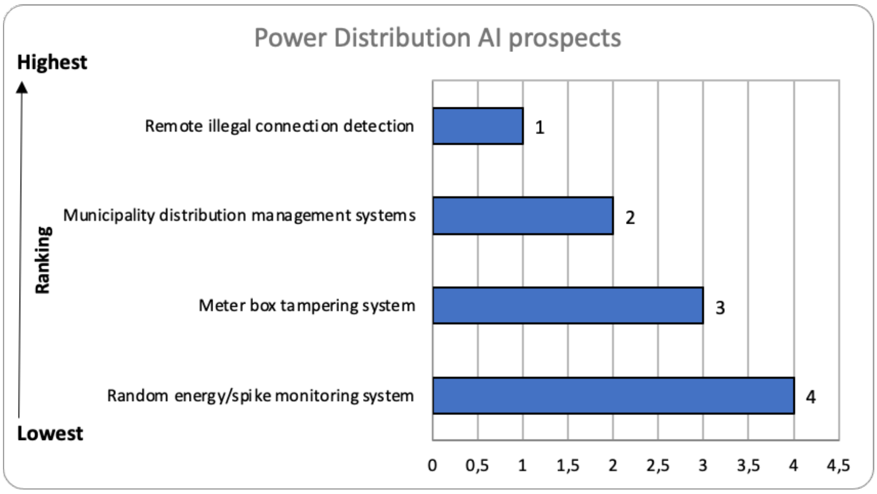


Figure 20: Proposed AI prospects in the power distribution division

Within the power distribution division remote illegal connection detection was ranked as the highest possible AI solution by respondents as illustrated on figure 20.

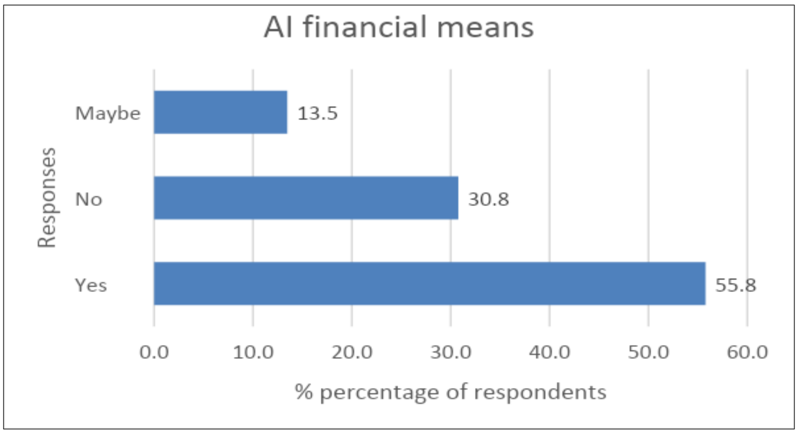


Figure 21: Does SA have the finance to support AI?

There is an opinion that SA has the financial capability to implement artificial intelligence (AI) among a little over fifty percent of the population.

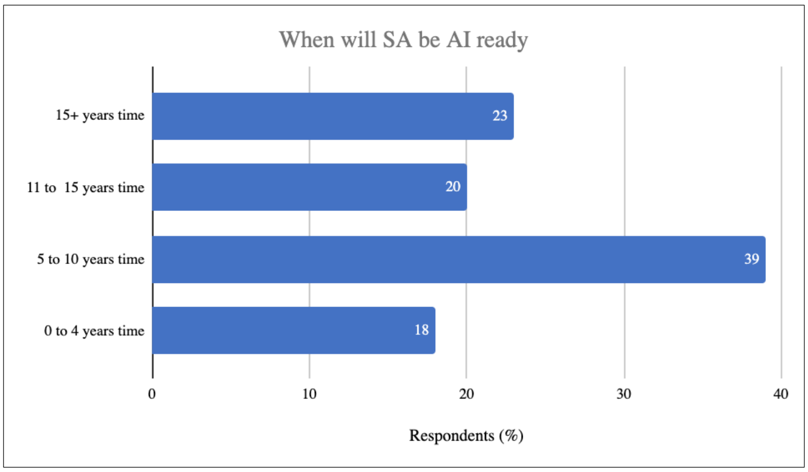


Figure 22: SA's timeline to be AI ready.

On figure 22, 39% of respondents state that SA is likely to be AI-ready within the next 5 to 10 years, at the earliest.

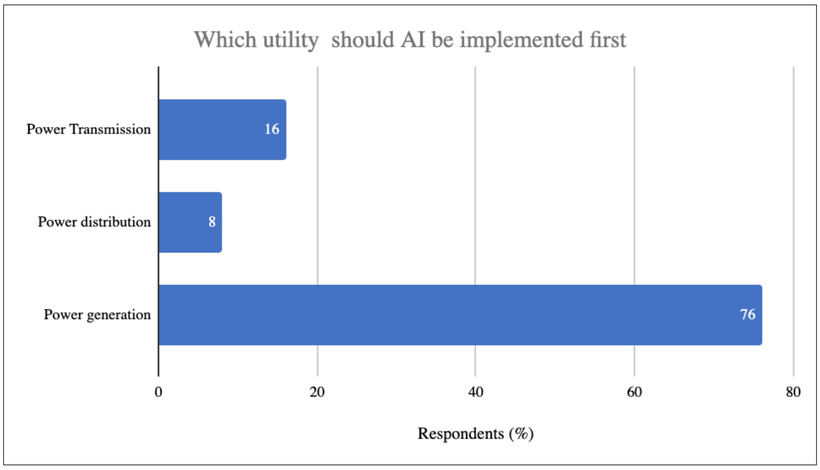


Figure 23: Utility likely to implement AI first

According to the survey as displayed on figure 23, 76% of respondents believe that the power generation sector is an appropriate place to begin implementing AI.

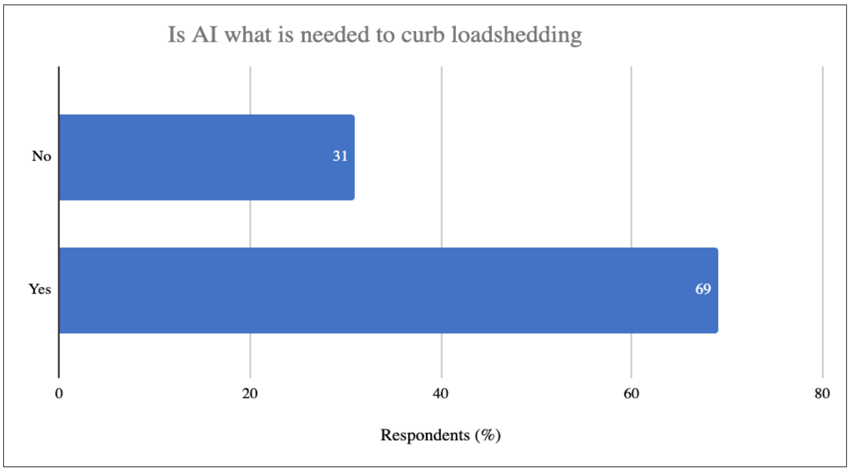


Figure 24a: Is AI a possible solution?

Figure 24a illustrates the perception of most respondents that artificial intelligence might be a viable solution to load shedding in South Africa.

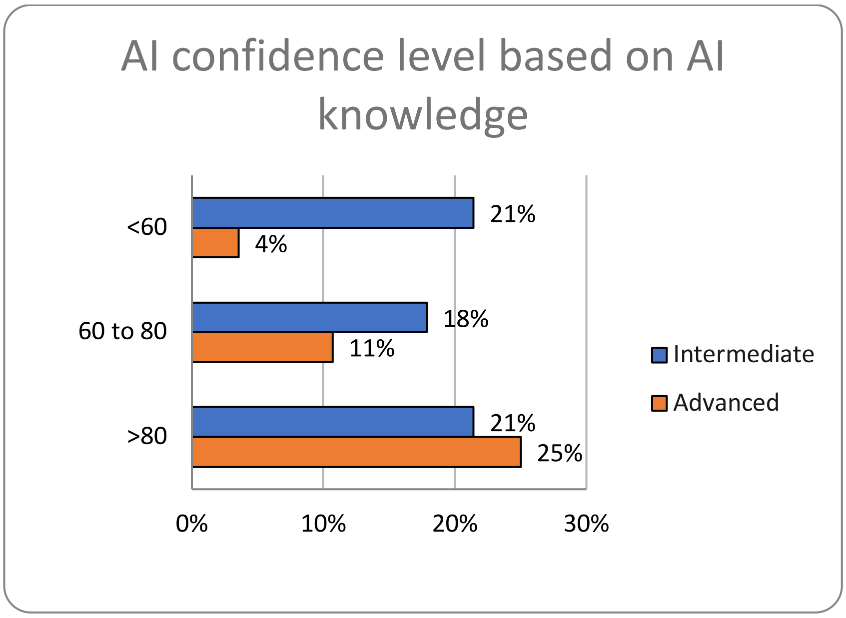


Figure 24b: Confidence level based on AI knowledge.

Figure 24b shows that 75% of the respondents have intermediate or advanced knowledge of AI, among the 69% who believe AI can reduce load-shedding as displayed on figure 24a.

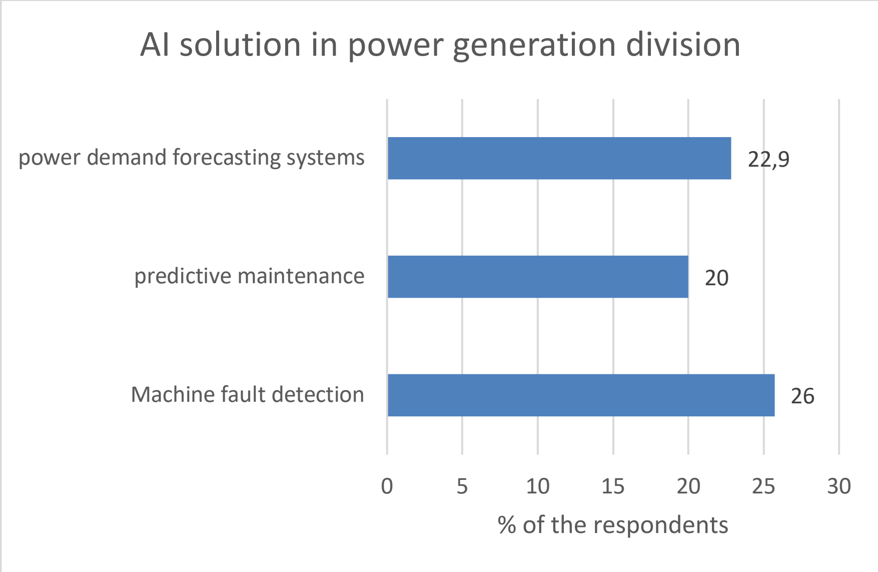


Figure 24c: Top 3 AI solutions

As illustrated in Figure 24c, the top three AI solutions were selected by those who believe AI can manage load shedding in the power generation sector.

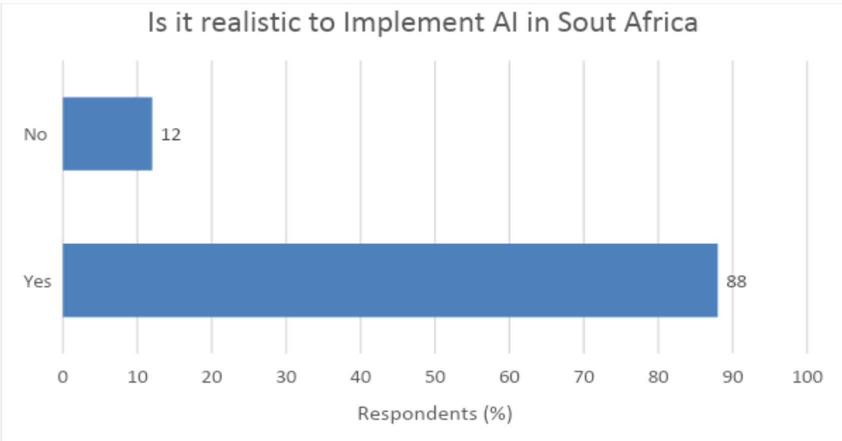


Figure 25: Confidence on AI implementation

Figure 25 illustrates respondents' confidence level or realistic expectations regarding the implementation of AI.

CHAPTER 5: DISCUSSION OF RESULTS

5.1. Introduction

This section provides an analysis of the results presented in chapter 4. The study aims to evaluate the existing AI infrastructure in South Africa and within Eskom, the national power utility. It will also assess the availability of AI enablers in the electrical sector, specifically within Eskom, and determine the level of AI skills in South Africa. Furthermore, the analysis will examine the presence of AI data centers, available datasets, and the quality of data, while considering the factors that influence data quality. The financial implications of implementing AI and its potential prospects will also be discussed. Overall, this assessment aims to determine the feasibility of implementing artificial intelligence and compile the cost-benefit factors associated with its implementation.

5.2. Load shedding severity

Is load-shedding a significant issue in South Africa? According to Figure 7, a majority of respondents (94%) confirmed that South Africa experiences a high level of load shedding. This indicates that power outages pose a significant economic challenge and result in severe financial difficulties for individuals. To illustrate this, the EskomSePush application provides a graph comparing the total number of load-shedding hours from 2015 to 2022. To corroborate this, see figure 26.

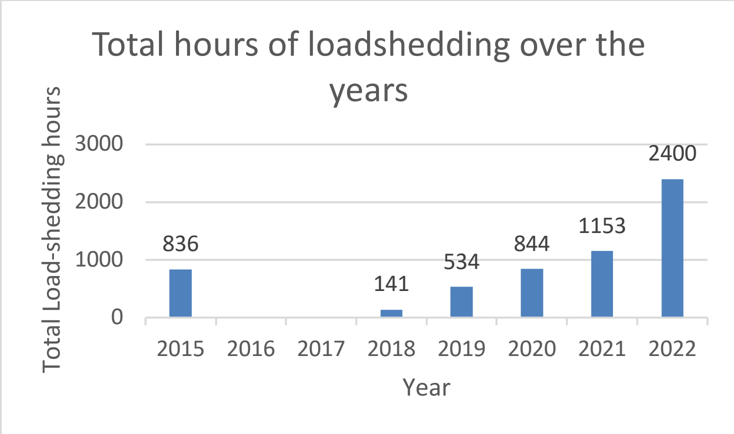


Figure 26: The total number of load shedding in South Africa over the past seven years

Based on Figure 26, South Africa has encountered more than 2,400 hours of load-shedding in 2022, nearly double the hours compared to 2021. With only two months remaining until the year-end, it is evident that the severity of load-shedding stages in 2022 surpasses that of previous years, and this trend is expected to persist throughout the year (Labuschagne, 2022).

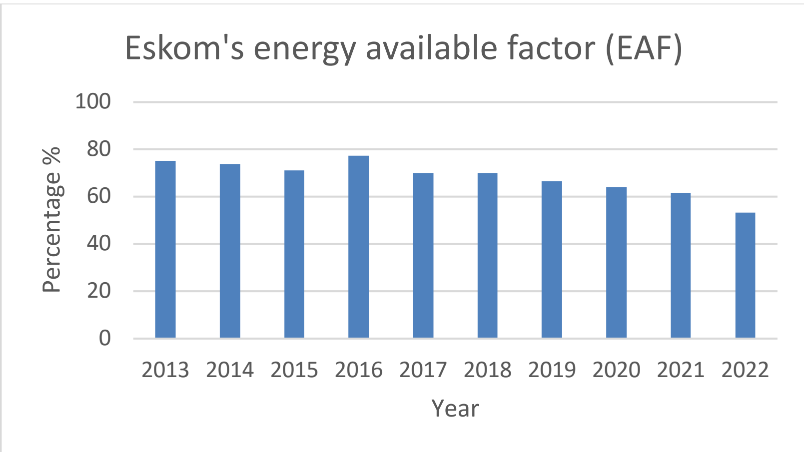


Figure 27: The availability of energy at Eskom over the past few years

Due to recent declines in Eskom's energy availability, by the end of October 2022, only 53 percent of the installed capacity of 50,000MW, equivalent to 26,486MW, was accessible. The consequences of load-shedding are far-reaching, including substantial financial losses estimated at R150 million to R250 million per day in foreign investments alone. Moreover, the impacts extend to job losses, emigration of skilled workers, increased debt relief, and the overall shrinkage of the South African economy by an estimated 8% to 10% (Business Tech, 2022).

5.3. Load-shedding causes

What is the primary cause of load shedding? According to Figure 10, survey respondents identify lagging maintenance programs as the main cause, followed by dilapidated infrastructure and power theft. To ensure a reliable and sustainable power generation system, prioritizing maintenance is crucial, refer to Figure 28 for reference. By doing so, load shedding and its frequency can be minimized. Eskom recognizes the importance of planned maintenance and has launched an accelerated program to address the maintenance backlog that has accumulated over time (Madubela, 2022).

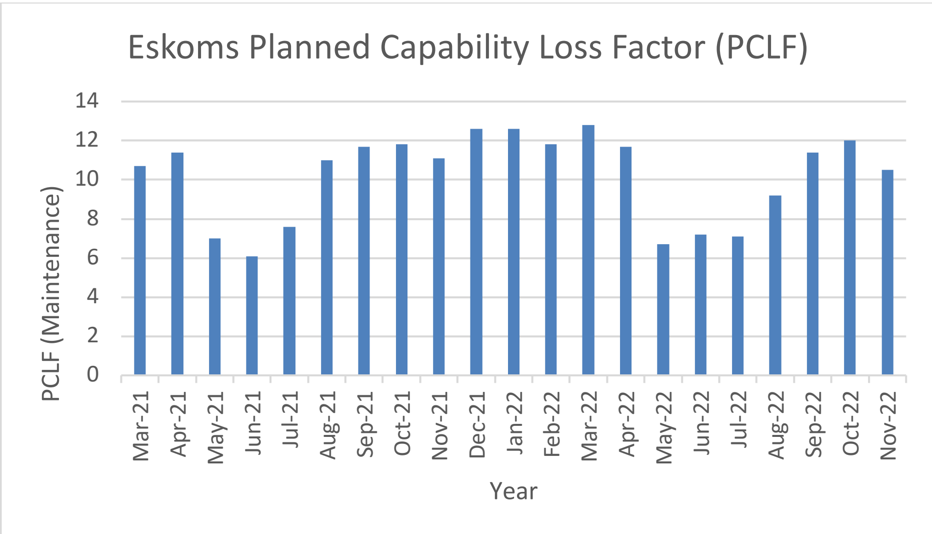


Figure 28: Diagram illustrating how long generator units were offline for planned maintenance or repair as recorded by Eskom.

Currently, Eskom is conducting an intensified maintenance program to enhance the reliability of its ageing coal-fired power plants. Although this may result in temporary increases in load shedding, it is a necessary step to improve the long-term efficiency of the generation plants (McLeod, 2021). Consequently, South Africa finds itself caught in a cycle of load shedding, driven by the lack of maintenance and the need to implement necessary repairs and upgrades.

5.4. The worst-hit utility

Eskom's power generation division plays a crucial role in the company's operations, with 82% of respondents indicating it as the primary cause of load shedding, as shown in Figure 8.

The generation side of Eskom's business faces significant challenges in terms of plant reliability and predictability (Madubela, 2022). A senior Eskom official once acknowledged in a press conference that load shedding mainly stems from faulty and neglected systems that require maintenance and attention (Retief, 2019).

Load shedding is a strategy employed when there is a deficit between electricity demand and the available generating capacity, often due to resource shortages. It serves as an effective measure to reduce capacity during periods of resource scarcity, preventing the depletion of reserves and the potential collapse of the entire power grid (SA News, 2022).

5.5. Who is to blame?

Load shedding is commonly attributed to factors such as poor management within Eskom, corruption, inadequate governance by the SA government, and ineffective leadership by the ruling party, as depicted in Figure 9.

There has been a tendency to engage in finger-pointing to find responsible parties. Are former Eskom CEOs Allen Morgan or Thulani Gcabashe, Minister of Mineral Resources and Energy Gwede Mantashe, or former South African President Jacob Zuma accountable? Despite identifying various contributing factors, the blame game has failed to yield more precise answers.

Before 2004, less than 40% of the country's population had access to electricity (The World Bank, 2022). Since the early 1990s, this figure has increased to 84%. As South Africa's population has grown from 40 million to 60 million, the demand for electricity has also surged. However, during the early 2000s, the government declined to provide Eskom with a loan to expand its capacity. Consequently, it may appear that a thorough root cause analysis will struggle to pinpoint the underlying issues fueling Eskom's mounting problems.

5.6. Artificial Intelligence

5.6.1. Is AI necessary in the electrical sector?

In times of crisis, innovative approaches emerge to address the challenges at hand. The scale and complexity of the current energy crisis contribute to its intricacy.The combination of increasing grid demand and longstanding issues in ageing energy systems introduces a multitude of complex variables. Merely investing in infrastructure alone is insufficient, and traditional human approaches may prove ineffective. The complexity of these challenges surpasses the capabilities of current methods. However, artificial intelligence (AI) holds promise in tackling large-scale, intricate problems (Nasila, 2021).

According to the feedback received, there is a clear call for the South African government and Eskom to embrace AI in the electrical industry. Given the energy crisis currently faced by South Africa, it begs the question: Could AI offer a viable solution for Eskom, particularly in the power generation division, where accumulated complex issues persist? The following section aims to provide a comprehensive exploration of these pressing issues.

5.6.2. AI Infrastructure

Figure 11 illustrates a range of perspectives among participants regarding the adequacy of South Africa's infrastructure to support widespread implementation of artificial intelligence. The increasing prevalence of AI across various domains has demonstrated its potential to enhance and safeguard existing infrastructure (Robbins & van Wynsberghe, 2022).

Given the well-documented challenges faced by Eskom, it is understandable that confidence in artificial intelligence within South Africa may be lacking. The question arises: Can AI effectively carry out its tasks while accommodating the high electricity consumption required for its operation? According to Violini (2021), organisations must establish their enterprise AI strategies and develop the necessary infrastructure before embarking on AI implementation. Supporting AI applications and workloads entails several factors, such as having a data storage environment capable of handling data-intensive AI workloads and scalable storage capabilities to accommodate growing data volumes.

Eskom manages the Eskom data portal through its data centre, making the data accessible to the public for analysis, research, and personal use. This comprehensive database includes various categories of data gathered over time, covering areas like lockdown tracking, demand and supply, outage performance, renewable energy, emissions, and the use of open cycle gas turbines.

Contrary to the findings presented in Figure 14, it remains to be determined whether Eskom possesses sufficient data to construct AI models. Nevertheless, as the sole and largest electricity provider in South Africa and other African countries, Eskom generates vast amounts of raw data that should be intelligently recorded and analyzed. Moreover, their ongoing efforts in building a data portal represent a crucial step in the implementation of artificial intelligence.

5.6.3. AI Skillset

According to Figure 12, South Africa is witnessing a growing pool of skilled professionals with expertise in artificial intelligence. The Data Science Academy and the South African Institute for Machine Learning and Applied Artificial Intelligence (SAIML) are actively promoting the development of AI and machine learning skills in the country. These organizations offer training and educational programs to equip individuals with the necessary skills and knowledge for working in artificial intelligence.

In addition to establishing the appropriate infrastructure, having a capable team is vital for any AI infrastructure development initiative (Violini, 2021). While Figure 12 indicates that most respondents believe South Africa possesses the necessary AI skillset, it's important to note that the country ranked poorly in retaining skilled and talented workers, as highlighted in the 2020 Global Talent Competitiveness Index published by Insead Business School.

Upon closer examination, it becomes evident that many of these talented individuals eventually leave South Africa for better opportunities elsewhere, resulting in a skills gap and high demand for skilled workers. Addressing this challenge and retaining top talent will be crucial in ensuring the long-term success of AI initiatives in the country.

5.6.4. AI Data in SA

The field of artificial intelligence (AI) has gained significant momentum in recent years, despite its initial discovery in the 1950s. Figure 13 reveals that 92% of respondents recognize the importance of data in AI technology, as it serves as a driving force behind its development. Data plays a vital role in the creation of AI models, as highlighted by Tennison & Bogataj-Jancic (2020). The availability of data influences how AI systems are constructed and the effectiveness of AI techniques employed. Access to large volumes of high-quality data is crucial for delivering a final product of exceptional quality.

In the case of Eskom, the organization has taken steps to enhance its data capabilities by expanding its own data portal. This initiative enables Eskom to gather data for various purposes, such as equipment fault management, network planning, and telecommunications (Tech, Central, 2015). Access to and availability of data are therefore pivotal factors in the development of AI products (Tennison & Bogataj-Jancic, 2020).

5.6.5. AI Data Quality at Eskom

Figure 14 indicates that the majority of respondents believe that Eskom possesses sufficient data due to its extensive history and its position as South Africa's primary energy provider. However, it is important to distinguish between data quantity and data quality, as emphasized in Choi et al.'s research (2003). Data quality encompasses more than just the volume of data collected; it also includes factors such as data cleanliness, accuracy, and reliability. Many organizations, regardless of their size, often struggle with low-quality data due to various reasons, including timeliness, biases, and other factors.

In the case of Eskom, several variables impact the quality of their data. These variables include issues such as meter tampering, illegal connections, corruption, unreliable supply chains, and political interference, among others. While Eskom is a state-owned enterprise, their data projects are rarely publicized, making it unclear how much data they have collected and from which sources they are drawing upon.

To address transparency and provide timely information, Eskom has introduced the Eskom Data Portal, which offers the public access to up-to-date information on Eskom's operations, including generation performance, demand and supply histories, and more. Just like any other form of data, AI processes heavily rely on data quality. However, this should not serve as a reason to postpone the adoption of AI (Younanzadeh, 2022).

5.6.6. AI Prospects

The primary objective of this study is to highlight the relatively lower focus on AI research in the field of electrical energy. In comparison to other areas, such as renewable energy sources, there has been a significant shift away from traditional energy sources like coal, oil, and nuclear power. Consequently, fewer resources are allocated to artificial intelligence initiatives within the electrical energy sector. This limitation in funding has resulted in fewer studies being conducted, which hampers our understanding of how AI can effectively address industry challenges.

To provide some insights into AI implementations worldwide and their societal impact, as well as how Eskom could potentially benefit from them, the following list is presented. The rankings are based on the recommendations of respondents, as depicted in Figure 18, which contrasts with the results shown in Figure 24c.

Table 1: Ranking of probable AI solutions to be implemented in the power generation division in Eskom.

Ranking	AI solution
1	Predictive maintenance
2	Fault detection
3	Power load or demand monitoring and forecasting systems
4	Fault forecasting

5.6.6.1. Predictive Maintenance

Preventative maintenance is a top priority for Eskom, considering the urgent need to address maintenance requirements for its power generation assets. While performing maintenance may lead to temporary load shedding, it is crucial for ensuring the reliability and efficiency of the assets. A case study by Alsheryani et al. (2019) highlights the numerous benefits of predictive maintenance, including assessing asset health, managing capacity constraints, scheduling maintenance operations, and addressing asset ageing.

R&D Nester (2020a) is currently conducting a study on power management using artificial intelligence and energy analytics. Their focus is on implementing condition-based monitoring strategies to evaluate circuit breaker operations and finding solutions for asset management challenges through predictive maintenance and optimised maintenance plans. The aim is to develop predictive models that can extend asset life and reduce operation and maintenance costs.

5.6.6.2. Fault detection

Enel Green Power, a leading company in the wind energy sector, has developed an advanced system that utilizes artificial intelligence to analyze and monitor data from wind turbines. This system is designed to predict equipment failures by detecting anomalies in the power generation process (Bosatelli et al., 2021).

In the power sector, various institutions, such as the State Grid Corporation of China, Pacific Gas and Electric (PG&E) in California, and Korea Electric Power Corporation, have successfully implemented similar fault detection AI systems in transmission and distribution to proactively address equipment failures.

The application of this type of AI technology could have potentially mitigated the frequent equipment failures experienced by Eskom in 2022.

5.6.6.3. Power load or demand monitoring & forecasting systems.

Artificial intelligence (AI) is essential for developing algorithms that assess and predict system behavior, including load patterns to prevent load shedding. Gathering data on power demand and supply is crucial for building AI models, as recognized by 75% of respondents.

R&D Nester conducted a pilot study using machine learning techniques like support vector machines, deep learning, and random forests, leveraging historical consumption data for load forecasting. However, Eskom faces challenges in relying on extensive historical data, as external factors like illegal power demand and remote disconnected locations can distort the quality of demand data, impacting prediction accuracy. By continuously collecting up-to-date data, the load forecasting engine generates periodic forecasts for time horizons of 2 hours and 36 hours ahead with 15-minute time steps, enhancing accuracy for intra-day and day-ahead operational planning (*R&D Nester*, 2020b).

Imagine reducing load shedding to mere seconds. An integrated sensor-enabled AI system autonomously selects the most efficient power supply route, revolutionizing outage resolution. According to Papadopoulos (2022), a Chinese government-owned power grid company has successfully resolved outages within three seconds, a significant improvement from the previous six to ten hours. While currently limited to a pilot study involving 200 families in Xinjiang, China, this AI system holds promising potential.

5.6.6.4. Fault forecasting

In 2009, PA Consulting and San Diego & Electric Company experts developed the world's first artificial intelligence system capable of predicting power outages weeks in advance. This breakthrough technology offers utility companies the opportunity to significantly reduce maintenance costs, overhead, and power outages by identifying assets that are likely to fail within two weeks and proactively addressing the issues before an outage occurs. The system has demonstrated impressive accuracy, with equipment failure predictions reaching 80% accuracy one week in advance and 90% accuracy three days in advance (iPredictTM for Electricity Distribution, 2022). While initially designed for distribution systems, the same AI concept can also be applied to power generation systems.

By leveraging iPredict, utility companies can effectively forecast and plan repairs, minimizing disruptions to customer service and providing advance notice to customers regarding planned outages and infrastructure improvements. This proactive approach helps to mitigate the high costs and time associated with emergency repairs during unplanned outages, which includes installing new equipment, dispatching crews, managing traffic, and coordinating logistics.

5.6.6.5. Additional AI prospects in other divisions

a. AI Prospects in Power Transmission: Transformer security

Figure 19 presents the potential of artificial intelligence (AI) in power distribution. Experts have highlighted the significant impact that coordinated attacks on high-voltage transformers across a wide area can have on the reliability of an electric grid. The resulting widespread blackouts can lead to severe economic and social consequences (Bowen et al., 2018).

In the distribution sector, the detection of remote illegal connections emerged as the top priority according to survey respondents. This prioritization is not surprising given the pressing issue of illegal connections in South Africa. Recent reports by Seleka (2022) and Mkhabela (2022) confirm the recovery of illegally connected power cables worth millions of rands.

To address this challenge, the city has formed partnerships with law enforcement agencies, as highlighted by Thusi (2022) and Majola (2022). Funds are being allocated to enhance infrastructure security, deploy security patrols in high-risk areas, and establish permanent security measures at critical infrastructure sites. Illegal connections not only result in significant financial losses for municipalities but also pose a serious threat to families and children. In some cases, funds allocated for infrastructure maintenance are redirected to address cable theft (Sibiya, 2022).

Although efforts have been made by authorities and City Power to combat illegal connections, municipal governments continue to suffer substantial financial losses. Considering this, it may be beneficial for Eskom and the broader energy sector to explore the use of artificial intelligence in detecting power and cable line anomalies, among other applications. AI has the potential to enhance monitoring capabilities and mitigate the impact of illegal connections on the power distribution network.

5.7. AI Financial feasibility

Figure 21 highlights that approximately 56% of the respondents believe that Eskom has the financial capacity to implement AI technologies. However, it is important to acknowledge that Eskom has faced challenges in recent years, including rising operating expenses, corruption, mismanagement of funds, and high overhead costs (Investor, 2022). As a result, Eskom's debt and liabilities have significantly increased and are projected to continue rising. In 2022, Eskom received a cash bailout of $8 billion (Cotterill, 2022). This raises the question of whether AI implementations are cost-effective.

To finance the implementation of AI technologies, Eskom can explore assistance from various sources, including:

1. **Government support** (Naidoo, 2022): Eskom, being a state-owned company, may receive support from government agencies or development banks to facilitate the adoption of AI technologies.

2. **International organizations**: Institutions such as the World Bank and the International Monetary Fund (IMF) could potentially provide assistance to Eskom in its AI implementation efforts.

3. **Collaboration with private sector organizations** (Erasmus, 2022): Establishing partnerships with AI-specialized companies that possess the necessary financial resources can help support Eskom's AI implementation.

4. **Investors**: Engaging with venture capital firms interested in supporting the adoption of AI technologies can provide additional funding avenues.

While it is evident that implementing artificial intelligence incurs significant costs, it is essential to consider various factors, such as:

- Expertise: AI implementation requires skilled specialists such as data engineers, AI architects, and data scientists, whose high salaries should be factored into the cost analysis.
- Infrastructure: State-of-the-art infrastructure is necessary for installations, repairs, and ongoing maintenance of AI systems.
- Storage and server costs: Expenses related to data storage, backup code, and leasing remote servers need to be considered.

Additionally, costs associated with research and development, data preparation and collection, training and testing, and deployment should be included in the overall budget (Crawford, 2021). It is crucial to carefully evaluate the costs and benefits of any AI implementation and develop a clear budget and plan to ensure its successful integration into Eskom's operations.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. INTRODUCTION

A summary of the findings will be presented in this chapter, as will a presentation of the conclusions, recommendations, and future research regarding AI in the power generation industry.

6.2. CONCLUSIONS

This research aimed to explore the potential adoption of artificial intelligence (AI) solutions within Eskom to address load-shedding and improve operations across all divisions and the value chain. The top three AI prospects identified are predictive maintenance, fault detection, and power demand/load forecasts.

Predictive maintenance can help extend the lifespan of equipment by providing maintenance predictions, reducing operational and maintenance costs. Fault detection enables early identification of potential faults, allowing for proactive measures to prevent breakdowns and unplanned load shedding. Power demand and load forecasts rely on historical data to enhance power supply planning and minimize interruptions.

However, implementing AI at Eskom faces challenges such as corruption, vandalism, theft, lack of quality data, and a shortage of AI skills. The study also highlighted a gap in AI research focusing on renewable energy.

Securing funding from the government or institutions like the IMF or World Bank would likely be necessary for AI projects at Eskom. Financial constraints, time limitations, and a shortage of skilled labor may be encountered during implementation, considering the complex and resource-intensive nature of AI projects.

Despite the potential benefits, widespread adoption of AI to address load shedding is still in the early stages globally. Eskom faces urgent issues that demand attention, especially after experiencing a record number of machine failures in 2022 and starting the new year with load shedding.

Careful consideration of costs and risks is essential when evaluating AI implementation at Eskom, as it can bring significant benefits but requires thorough planning and mitigation of challenges.

6.3. RECOMMENDATIONS AND FUTURE RESEARCH

6.3.1. Recommendations for Practitioners

- **Foster Transparency:** To advance AI development across industries, it is crucial to provide public access to successful projects, research findings, and project details. This transparency enables knowledge sharing and facilitates further research and innovation.
- **Disclosure of Eskom's Initiatives:** Currently, there is limited information available regarding the artificial intelligence initiatives undertaken by Eskom. As a government-owned enterprise, it is advisable to make this information public to promote transparency and encourage collaboration and potential improvements in the field.

6.3.2. Recommendations for Researchers

- **African Datasets:** There is a significant shortage of African datasets, including South African datasets, for AI research. It is essential to focus on building and expanding such datasets specific to the African context. This effort will enhance the relevance and effectiveness of AI applications in Africa.

- **Scaling AI Studies:** Many AI studies in the electrical industry are limited to smaller populations or have not been implemented at scale. Conducting pilot studies that examine the impact of AI on larger populations is necessary to determine the broader societal implications and the extent of AI's effectiveness in the field.

By following these recommendations, practitioners can contribute to the growth of AI, foster transparency, and ensure the applicability of AI in the electrical industry. Researchers can enhance the availability of relevant datasets and expand the scope of AI studies to drive meaningful impact on a larger scale.

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APPENDIX A: SURVEY QUESTIONNAIRE

NO.	**QUESTIONS**
1	How old are you?
2	In which province are you located?
3	What is your highest level of education?
4	What is your area of expertise?
5	How many years of experience do you have in total?
6	What is the severity of load shedding in South Africa?
7	**Ranking**: In your opinion, who is to blame? Please rank all choices in the following order: 1 = Lowest; 6 = Highest
	Ruling party, SA govt, Eskom Management, Corruption, Apartheid, Crime
8	**Ranking**: What do you attribute SA's electrical problems to? Rank all choices. 1 = Lowest ; 5= Highest
	Cable theft, power theft, DB vandalism, ailing infrastructure, lagging maintenance
9	Rate your Artificial Intelligence knowledge : Beginner, intermediate, Advanced, Expert
10	Why do you think the AI boom is only taking place now?
11	Do you think SA has the infrastructure to support AI implementations on a larger scale?
12	Do you think SA has the financial means to support AI implementations on a larger scale
13	Do you think SA has the necessary skill-set or competent professionals to carry out the AI implementations?
14	How important is it to implement the following: Not important, Less important, Important, very important
a	To use AI in electrical industries ?
b	AI leaning towards electrical studies in the SA context?
c	AI leaning towards renewable energy studies?
d	Eskom and SA govt adopting AI in the power sector

e	Is it economically feasible to adopt AI in the power sector
15	**Ranking:** Which of the following AI solutions do you think Eskom should implement in the power generation
	Machine fault detection, Predictive failure events systems , Fault forecasting ,Predictive maintenance systems ,Power Demand monitoring systems , Power Demand forecasting systems
16	**Ranking**: Which of the following AI solutions do you think Eskom should implement in the Power Transmission division - Rank all choices. 1 = Lowest ; 5= Highest
	Cable theft detection, Street light monitoring & surveillance , Power theft detection , Real-time voltage management ,Transformer /subunits AI security systems
17	**Ranking**: Which of the following AI solutions do you think Eskom should implement in the Power Distribution division - Rank all choices. 1 = Lowest ; 4= Highest
	Meter box tampering detection systems , Random energy spike/demand emergence monitoring system , Remote illegal-connection detection , Municipality energy distribution management system
18	Which of the following division carries more issues that have led towards load shedding (Select ONE)
	power generation, power distribution, power transmission
19	How important is data when building AI models ? Very important, Important, less important, not important
20	Do you think SA or Eskom has sufficient data to build AI models? (yes/no)
21	Does Eskom need AI & data professionals to solve load shedding ? (yes/no)
22	Should Eskom build their own cloud data center?(yes/no)
23	How easy will it be for Eskom to build Data centers to enable them to build AI electrical models (Easy/hard)
24	Is it possible to build AI models in the absence of data (yes/no)?
25	How important of a factor is electrical consumption in load shedding? Very important, Important, less important, not important
26	How important of a factor is electrical supply in load shedding? Very important, Important, less important, not important
27	Economical Factors that affect load shedding (rank all from 1=lowest, 5=highest)
	Inflation ,Lower GDP per capita, Increasing Unemployment rate, OverpopulationShrinking sponsorship from govt

28	How important is it to collect power generation (supply) & power consumption(demand) data , in order build forecasting models? Very important, Important, less important, not important
29	Would implementing AI for power consumption & generation forecasts, help curb load-shedding ?(yes/maybe/no)
30	Do you think Smart grids can be implemented in SA? (yes/no/maybe)
31	Do you think smart grids have the capability to reduce outages in SA? (yes/no/maybe)
32	Financial impact - select one (yes/no/maybe)
a	Will the SA government/Eskom afford to implement any of the above mentioned AI solutions in the sector?
b	Given the financial status of Eskom, are these solutions cost-viable?
c	Is it worth employing AI techniques on aging infrastructure?
d	Do you think Eskom should invest in AI?
e	Do you think SA govt should invest in AI dedicated to electrical energy
33	Unintended consequences
34	Do you think its realistic to implement AI in SA (yes/no)
35	In how many years time, do you think SA will be AI ready
36	Which utility should AI be implemented first? Power generation, power distribution, power transmission
37	Do you think Artificial intelligence is what South Africa's power system needs to manage Load Shedding (yes/no)?
38	What is your confidence level on the above . Rate between 0%= lowest , 100%=high confidence level