




A comparative analysis of OEM and local service provider maintenance in South African wind farms

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DECLARATION

I, Sefularo Brenda Sidaki, hereby declare that this research dissertation, titled: Comparative analysis of OEM and local service provider maintenance in South African wind farms, is my original work. It has not been submitted for any degree or examination at any other university. All sources consulted or quoted have been acknowledged using complete references.

I understand that plagiarism is a serious academic offence, and I affirm that this dissertation is the result of my independent effort and critical engagement with the research subject. The information provided herein is accurate to the best of my knowledge and was conducted ethically, adhering to the guidelines set forth by North-West University.

Sefularo Brenda Sidaki.

A handwritten signature in black ink, appearing to read 'Sefularo Brenda Sidaki', with a large, stylized flourish above the name.

October 2025

DEDICATION

This mini dissertation dedication extends to all the participants in the South African wind energy space who contributed their time, insights and expertise to this study. Your dedication to advancing renewable energy and your willingness to assist in this research were instrumental and deeply appreciated. To my immediate manager who supported my studies since the first day of my studies.

This dissertation is also dedicated to my cherished family and friends, whose unwavering love, support, and belief have been the bedrock of this academic journey. A special dedication goes to my immediate family, affectionately known as the Blue team. Your constant understanding, patience, and encouragement have been invaluable, providing the strength and motivation needed to navigate the complexities of this research. This work would truly not have been possible without your unwavering presence in my life.

PREFACE

This dissertation is the culmination of my academic journey toward understanding the critical dynamics of wind farm maintenance in South Africa. The inspiration for this research arose from the slowly growing emergence of local service providers in the wind energy sector, contrasting with the long-standing predominant reliance on Original Equipment Manufacturers (OEMs) for wind farm maintenance. As South Africa deepens its commitment to renewable energy, the efficiency and cost-effectiveness of maintaining its burgeoning wind fleet have become paramount. It became clear that a detailed comparison of maintenance outcomes between OEMs and local service providers was essential, yet often underrepresented in both academic literature and strategic discussions. This research aims to contribute to filling that gap by providing a comprehensive evaluation of their respective approaches, challenges, and potential long-term impacts on the sustainability of wind energy in the country.

Throughout this study, I have had the privilege of engaging with key stakeholders and participants across the wind energy value chain, learning first-hand about their operational realities, maintenance strategies, and perspectives on the OEM vs. Local Service Provider (LSP) debate. Their insights have immeasurably enriched this research and provided a deeper understanding of the technical-, economic-, and strategic considerations involved. I hope that this dissertation will not only contribute to academic discourse, but also serve as a valuable resource for wind farm operators, policymakers, industry associations, and local enterprises keen on strengthening South Africa's renewable energy self-sufficiency.

I would like to acknowledge the invaluable support I received from my supervisor, Dr. Prinsloo, whose guidance, expertise and encouragement have been crucial in shaping the direction and depth of this research. His input has been instrumental. I also extend my sincere gratitude to all the participants in the wind energy space who generously shared their time, knowledge, and data with me; your dedication to the industry and willingness to assist were deeply appreciated. It is my sincere hope that this work can spark meaningful discussions and actions aimed at optimising wind farm maintenance outcomes and fostering a robust local service provider ecosystem in South Africa.

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I am immensely grateful to the organisations and individuals within the South African wind energy sector who generously participated in this study. Your openness, willingness to share your invaluable experiences, and trust in this research were fundamental to its success. Without your insights into the complex dynamics of wind farm maintenance, this comparative evaluation would not have been possible.

A special thank you goes to my family and friends, especially my immediate family, affectionately known as the Blue team. Your continuous encouragement, understanding, and patience provided the strength and perseverance needed during the most challenging moments of this academic journey. Your unwavering belief in me made all the difference.

Lastly, I wish to acknowledge North-West University for providing the conducive academic environment and resources that facilitated this research. To everyone who has played a role in the completion of this dissertation, I am forever grateful.

ABSTRACT

South Africa's commitment to a sustainable energy future has led to a significant increase in the development and operation of wind farms, which are crucial in contributing to national energy security, reducing carbon emissions, and promoting economic development. These large-scale renewable energy projects, particularly under the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), are not only vital for electricity generation but also for job creation and local economic stability. However, the long-term viability and efficiency of these wind farms are heavily dependent on effective and sustainable maintenance strategies.

This study explores and comparatively evaluates the maintenance outcomes of wind farms in South Africa, focusing on the performance differences between Original Equipment Manufacturers (OEMs) and Local Service Providers (LSPs). The research aims to identify the opportunities and challenges of each service model and their implications for operational efficiency, cost management, and local economic impact.

The findings reveal that maintenance strategies are central to wind farm performance. OEMs are indispensable during the warranty period due to their technical expertise and proprietary access, while LSPs offer significant post-warranty benefits through cost-effectiveness and rapid, localised response. The study concludes that these two service models are complementary rather than competing, and the most sustainable and efficient strategy is a hybrid maintenance model that combines OEM expertise with LSP agility. This model optimises operational efficiency and aligns with national development objectives.

Managerial implications include the need for wind farm operators to strategically plan their post-warranty maintenance, facilitating data-sharing and collaborative partnerships between OEMs and LSPs. Stakeholders must also invest in capacity-building to address skills gaps, which will empower LSPs and contribute to a more robust, competitive, and localised wind energy sector in South Africa.

Key terms: Original Equipment Manufacturers (OEMs), Local Service Providers (LSPs), Wind Farm Maintenance, Maintenance Outcomes, Comparative Evaluation, South Africa, hybrid maintenance model.

LIST OF ABBREVIATIONS AND ACRONYMS

AWEA	: American Wind Energy Association
CAGR	: Compound Annual Growth Rate
CAQDAS	: Computer-Assisted Qualitative Data Analysis Software
CSI	: Corporate Social Investment
CSIR	: Council for Scientific and Industrial Research
EMS-REC	: Economic and Management Sciences Research Ethics Committee
EWEA	: European Wind Energy Association
GW	: GigaWatt
IEEE	: Institute of Electrical and Electronics Engineers
IRENA	: International Renewable Energy Agency
ISP	: Independent service provider
KPI	: Key Performance Indicator
LSP	: Local Service Provider
MS Teams	: Microsoft Teams
MW	: Megawatt
O&M	: Operations and Maintenance
OEM	: Original Equipment Manufacturer
OGRM	: Opportunistic Group Replacement Maintenance
POPIA	: Protection of Personal Information Act
REIPPPP	: Renewable Energy Independent Power Producer Procurement Programme
SANEDI	: South African National Energy Development Institute

SAREM : South African Renewable Energy Masterplan
SCom : Scientific Committee
SCADA : Supervisory Control and Data Acquisition
SMT : Strategic Maintenance Theory

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CHAPTER ONE: OVERVIEW OF STUDY

1.1 Introduction

South Africa's energy transition has increasingly emphasised the need to diversify its generation mix beyond coal, with a growing portfolio of alternative energy sources contributing to the national electricity supply. As of 2024, solar photovoltaic (PV) is the fastest-growing renewable energy source, accounting for over 11 GW of installed capacity, followed by wind energy (Department of Mineral Resources and Energy, 2024; Section 1.2). Hydropower, although geographically limited, contributes over 1.5 GW through both large-scale and small embedded schemes (CSIR, 2025). Natural gas is primarily being explored for peaking power and industrial use. However, infrastructure and supply constraints persist (SANEDI, 2023:30). Nuclear energy remains a key component of South Africa's long-term low-carbon strategy, with the Koeberg plant contributing approximately 1.8 GW to the national grid (Department of Mineral Resources and Energy, 2023). Biomass and biogas are increasingly promoted through municipal and agricultural waste-to-energy projects, though their current share remains below 1% of total generation capacity (Poorun & Radmore, 2023:32–34). These alternative energy sources complement wind power, which remains a key pillar of South Africa's Integrated Resource Plan (Department of Mineral Resources and Energy, 2024) and future energy security strategy.

South Africa's energy transition increasingly emphasises diversification of the energy mix to lessen dependence on fossil fuels. Wind power has become a central pillar in advancing energy security and sustainability, yet maintaining consistent performance depends heavily on efficient operations and maintenance (O&M), a field often limited by high costs, reliance on foreign original equipment manufacturers (OEMs), and insufficient local technical expertise (Creamer Media's Engineering News, 2023).

Wind farm maintenance ensures not only equipment reliability but also economic viability and energy availability. This study responds to South Africa's growing need to localise and optimise wind farm maintenance practices through a comparative evaluation of OEM and local service provider (LSP) maintenance models.

The growing global demand for clean and sustainable energy has driven the expansion of wind power generation (Konstantinidis & Botsaris, 2016:2). Wind farms located in regions with abundant wind resources play a central role in this shift. However, ensuring the long-term reliability and effectiveness of these installations requires robust maintenance strategies

and capabilities.

This research aligns with the global transition to low-carbon energy systems, particularly the development of wind power as a key renewable source. Wind farms are especially relevant in countries like South Africa, where wind resources are plentiful. Local generation of clean electricity not only supports global sustainability goals but also enhances national energy security (IRENA, 2019:70; Konstantinidis & Botsaris, 2016:6). For wind farms to meet these objectives, they must operate reliably, efficiently, and economically throughout their entire lifecycle.

Historically, the development of wind energy dates back to the late 19th century. James Blyth, a Scottish engineer, constructed the first electricity-generating wind turbine in 1887 (Blyth cited by Wu *et al.*, 2023:518). Shortly thereafter, Charles F. Brush created similar systems in the U.S. (Gipe & Möllerström, 2022:1976). Following World War II, technological advancements accelerated, particularly in the U.S., as interest in alternative energy sources grew (Mulder, 2021:18).

Modern wind turbines have become reliable and efficient due to significant progress in materials and engineering (Ullah *et al.*, 2024:16). A wind farm, which may comprise dozens or hundreds of turbines, generates electricity across a designated geographic area (Gipe & Möllerström, 2022:1991). These installations may be onshore or offshore, depending on wind availability, environmental considerations, and land use (Desalegn *et al.*, 2023:3).

Wind turbines operate by converting the kinetic energy of wind into electrical power (Volker *et al.*, 2017:1). The blade length directly impacts energy output, with longer blades capturing more wind. Advances in tower height and blade design have significantly increased energy generation (Chen, 2023:546). Factors such as average wind speed, site layout, and local environmental and social conditions influence wind farm configuration (Bashir, 2020:7892).

In South Africa, wind energy expansion has been driven by the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), launched in 2011 by the Department of Mineral Resources and Energy (Merem *et al.*, 2022:10; Department of Mineral Resources and Energy, 2021). South Africa's wind energy infrastructure is predominantly situated in rural and semi-rural regions (see further on). According to the Department of Mineral Resources and Energy (Department of Mineral Resources and Energy, 2021), approximately 86% of operational wind farms under the Renewable Energy Independent Power Producer Procurement Programme are located in sparsely populated provinces such

as the Eastern Cape, Northern Cape, and Western Cape. These regions are prioritised for wind energy development due to their consistent wind profiles, availability of undeveloped land, low population density, and compatibility with environmental and grid integration requirements (Labuschagne, 2023).

South Africa's wind energy sector remains heavily reliant on foreign OEMs for both turbine supply and technical expertise (SAWEA, 2024). Leading international firms Siemens Gamesa (Spain/Germany), Nordex Acciona (Germany/Spain), Vestas (Denmark), and Goldwind (China), have supplied turbines across multiple Renewable Energy Independent Power Producer Procurement Programme projects (Rivett-Carnac, 2022:10). Chinese OEMs, particularly Goldwind, have expanded their market presence by offering competitively priced technology and integrated financing packages.

Despite the REIPPPPO's local content requirements aimed at developing the domestic industry, the wind turbine supply chain continues to be dominated by imported components, especially for technically advanced parts such as nacelles, blades, and control systems. Local manufacturing is mainly limited to towers and civil works. This dependence increases vulnerability to logistical disruptions, with shipping delays and limited OEM technician availability often resulting in prolonged downtime and increased maintenance costs (Section 2.5; Ma *et al.*, 2020:3628; SKYSPECS, 2023:7).

To address these gaps, the South African Renewable Energy Masterplan (SAREM) proposes incentives for joint ventures between local companies and global OEMs (GreenCape, 2022:19). These initiatives aim to enhance skills transfer, build domestic capacity, and reduce reliance on imported technologies. Strategic localisation of high-value components and services could significantly improve long-term cost-efficiency and operational resilience.

Wind farm construction in South Africa has been dominated by Danish (Vestas), German (Nordex), and Chinese (Goldwind) OEMs, with substantial contributions also from Italian (Enel), French (EDF), Indian (Suzlon), and Spanish (Siemens) developers (African Energy Council, 2022; ENEL Green Power, 2021b, 2022, 2024; Suzlon, 2025; NS Energy, 2019).

Among local efforts, Sivunguvungu Wind Energy Converter (I-WEC) stands out as the only African manufacturer of 2.5 MW wind turbines. Although not yet active in utility-scale development, the company has successfully manufactured and installed components such as blades and turbines, for operational sites, notably at the Saldanha facility (Onsomu, 2022). Its tower production capabilities mark a step toward building a domestic manufacturing base.

Table 1.1 presents major wind farms in South Africa developed by OEMs (OEMs), highlighting their predominance in rural regions (Windpower, 2025).

Table 1.1: Major OEM-constructed wind farms in South Africa

OEM/Engineering, Procurement and Construction (EPC) Contractor	Wind Farm(s)	Province/Region
Vestas (Denmark)	Wesley, Ciskei (34.5 MW). EPC & turbines	Eastern Cape, Amathole District
	Karusa (147 MW). EPC & turbines	Western/Northern Cape (Karoo Hoogland)
	Soetwater (147 MW), Garob (~145 MW), Oyster Bay (140 MW), Nxuba (~139 MW). EPC by Vestas/Nordex partners with ENEL Green Power	Northern & Eastern Cape
	Brandvalley, Rietkloof, Wolf cluster (~373 MW). Turbines and service	Western/Eastern Cape
	Umsinde and Khangela Emoyeni (2 × 144 MW orders). Turbines and service	Western Cape
	Witberg (108 MW). Turbines and service	Western Cape
Nordex (Germany)	Roggeveld (147 MW). EPC & turbines	Western Cape (Matjiesfontein/Sutherland)
	Parts of Korosun 2 cluster (Umsobomvu & Hartebeesthoek). Turbines and service (set for 2026)	Eastern/Northern Cape border

OEM/Engineering, Procurement and Construction (EPC) Contractor	Wind Farm(s)	Province/Region
Goldwind (China)	Golden Valley (120 MW)	Eastern Cape, Amathole District
	Jeffreys Bay (138 MW) – Siemens SWT turbines	Eastern Cape, Kouga Municipality
Suzlon (India)	Cookhouse (138.6 MW). Suzlon S88 turbines	Eastern Cape, Blue Crane Route Municipality
	Multiple REIPPP Window 2 projects (~433 MW total)	Various in Western/Eastern Cape. Grahamstown, Grassridge, Chaba
Sinovel (China)	Dassiesklip (26 MW), Van Stadens (26 MW)	Western Cape (Caledon area), Eastern Cape
Acciona (Spain)	Gouda (135 MW). Acciona turbines	Western Cape

As wind farm numbers increase, the need for effective operations and maintenance becomes critical. Proper maintenance ensures turbines perform optimally and remain operational over their expected lifespan. OEM guidelines recommend routine inspections, timely repairs, and proactive tasks, such as oil changes and blade assessments (AWEA, 2017; Zappalá & Tavner, 2022:357). The scope and frequency of such tasks vary depending on turbine models, environmental conditions, and usage history.

OEMs have historically managed wind turbine maintenance, especially during warranty periods, offering technical expertise and proprietary tools (Baker, 2015:9). Typically, wind farm operators enter into full-service agreements with OEMs for the first few years. As these contracts expire, owners must decide whether to continue with OEMs or transition to LSPs.

This decision significantly impacts operational costs, turbine reliability, and long-term success (Section 2,1). LSPs are a subset of ISPs. ISPs are third-party companies that offer operations and maintenance services for wind turbines, independent from the OEM. ISPs

can be international, regional, or local. They often provide services such as inspections, repairs, blade maintenance, Supervisory Control and Data Acquisition (SCADA) diagnostics, and other related services. Examples include companies such as Deutsche Windtechnik and SkySpecs (Deutsche Windtechnik Internal, 2024; SKYSPECS, 2023:7).

LSPs are independent service providers that operate within a specific geographic region, such as South Africa. LSPs may be smaller in scale and might focus on servicing projects in their domestic markets. They are often part of localisation efforts, especially in countries with renewable energy procurement frameworks that prioritise local content (South Africa's REIPPPP).

In South Africa, LSPs often deliver maintenance that is more tailored to local conditions and more accessible in remote areas (Wind Systems Magazine, 2023; PSI Repair Services, 2022:1). Moreover, they contribute to local economic development through job creation and skill transfer (Arsenova & Wlokas, 2019:48; CSI Energy Group, 2023).

LSPs offer reduced service fees, lower component repair costs (often using refurbished parts), and increased responsiveness. Some reports estimate cost savings of 40-70% compared to OEMs (Wind Systems Magazine, 2023). These savings are crucial in a competitive energy market that focuses on reducing operational expenses (Green Building Africa, 2022).

Nonetheless, LSPs face challenges. Their service quality may be inconsistent, and they may lack access to proprietary diagnostic tools, which could potentially affect reliability. In contrast, OEMs provide original parts, technical consistency, and warranty-backed services (Windpower Engineering & Development, 2024).

While OEMs ensure high reliability, their services can be costly and slow, especially in rural locations. LSPs, on the other hand, provide flexible and locally informed support, often at lower costs (SKYSPECS, 2023:9). This creates an ongoing debate: should operators prioritise OEM reliability or LSP flexibility and affordability? Effective operations and maintenance strategies are crucial for achieving sustainable and profitable wind farm operations (Konstantakos *et al.*, 2019:112; Costa *et al.*, 2021:8).

The purpose of this study is to compare the maintenance approaches of OEMs and LSPs in South African wind farms, evaluating their cost-efficiency, operational effectiveness, and long-term sustainability. With the growing focus on renewable energy, particularly in rural areas, reliable and affordable maintenance practices are essential for the sector's continued success.

1.2 Background of the study

South Africa's wind energy industry has emerged as a crucial part of the country's long-term energy transition strategy, which aims to diversify the national energy mix, reduce dependence on coal, and fulfil climate obligations under the Paris Agreement (Presidential Climate Commission, 2022). Since the launch of the REIPPPP in 2011, the sector has seen rapid growth, with over 3.4 GW of installed capacity across more than 30 utility-scale wind farms as of 2024 (Department of Mineral Resources and Energy, 2024; Independent Power Producer Office, 2021:1). Most of these projects are concentrated in rural provinces such as the Eastern Cape, Western Cape, and Northern Cape, areas characterised by strong wind resources but limited infrastructure and economic activity (CSIR, 2025).

Globally, wind energy is playing a pivotal role in the low-carbon energy transition, contributing to reduced emissions and decentralised electricity generation. In South Africa, the REIPPPP has attracted over R200 billion in investments and created thousands of jobs (Independent Power Producer Office, 2023). Despite this progress, post-commissioning support, such as maintenance, remains largely outsourced to OEMs. These service contracts are often expensive, centralised and not responsive to localised needs, leading to increased downtime and limited localisation benefits (Hussain *et al.*, 2024:324).

Conversely, LSPs offer the potential for more affordable, flexible, and locally embedded maintenance solutions (SKYSPECS, 2023:7; Pragma, 2023). Yet, concerns remain around their access to proprietary knowledge, spare parts, and technical training (Pragma, 2023; SKYSPECS, 2023:7). This study seeks to explore the effectiveness, responsiveness, and cost-performance trade-offs between OEM and LSP maintenance providers in the South African wind energy sector.

The wind industry in South Africa is structured around Independent Power Producers (IPPs) who are awarded 20-year Power Purchase Agreements with Eskom (Africa Energy Portal, 2022). While turbines are sourced almost exclusively from global OEMs such as Siemens Gamesa, Nordex, Acciona, Vestas and Goldwind, the long-term operational and maintenance responsibilities vary (Rivett-Carnac, 2022:8, 23). During the initial two to five-year warranty period, OEMs typically provide full-scope maintenance services, leveraging their proprietary technology, diagnostic systems and global technical expertise (TIPS, 2022:37).

However, this OEM-dominated maintenance model is increasingly under scrutiny due to its long-term limitations in the South African context. Firstly, post-warranty maintenance through

OEMs is cost-intensive, often governed by premium long-term service agreements that escalate annually (El-Naggar *et al.*, 2023). Secondly, OEMs often have a limited local presence and rely on fly-in, fly-out service teams, which leads to delays in response times, particularly in remote areas (Wind Systems, 2018; Pragma, 2023). Thirdly, the OEM-centric approach constrains local skills development, as site-based employees are typically excluded from technical troubleshooting and repair tasks, thereby undermining workforce localisation and retention (HSRC, 2024).

The result is a growing disconnect between South Africa's policy goals, particularly economic empowerment, industrialisation, and local capacity-building, and the operational realities of wind farm maintenance (SAWEA, 2024). This is especially evident in the limited participation of South African companies in the post-construction phases, which has sparked debate about how the industry can better support the long-term localisation objectives outlined in the REIPPPP's Economic Development Requirements (HSRC, 2024).

The emergence of LSPs represents a partial response to these challenges. LSPs, which include local contractors, engineering firms, and joint ventures with foreign technical partners, are starting to offer more competitive alternatives in the operations and management space (Pragma, 2023). Their advantages include lower operational costs, shorter mobilisation times, a deeper understanding of site-specific challenges, and the ability to support local job creation and training programmes (EIMS Africa, 2019). However, LSPs also encounter systemic barriers, such as limited access to OEM-controlled diagnostic tools and training, the absence of a unified safety and technical certification framework, and resistance from financiers who prioritise operational risk mitigation (Pragma, 2023).

The problem is further magnified in organisations that are reaching the end of the OEM warranty phase. Senior management of wind farms is grappling with the question of how to maintain turbine performance and availability while simultaneously driving cost efficiency, operational flexibility, and socio-economic development (Lloyd's Register, 2018; Pragma, 2023). The current uncertainty around whether to renew OEM contracts, transition to LSPs, or adopt a hybrid model (Section 1.2) is compounded by the lack of empirical data on the performance, risk, and cost implications of these alternatives in the South African context (Konstantakos *et al.*, 2019:112; Costa *et al.*, 2021:8).

This issue is no longer hypothetical; it is operationally urgent. When wind farm turbines approach their fifth year of operation, marking the expiry of full-scope OEM maintenance agreements, maintenance contracts would lock the organisation into high-cost, low-localisation

models for the next five to ten years. On the other hand, shifting too quickly to under-resourced LSPs may jeopardise safety, availability, and compliance with lender obligations. Addressing this misalignment between operational needs, employee aspirations, and policy goals now is critical to sustaining the organisation's long-term viability.

An emerging solution, already piloted in select projects such as the Cookhouse Wind Farm, involves adopting hybrid maintenance models (EIMS Africa, 2021). These models distribute maintenance responsibilities between OEMs and LSPs based on risk profiles, technical complexity, and localisation opportunities. For instance, OEMs may retain responsibility for major corrective tasks or updates to SCADA systems. At the same time, LSPs handle scheduled inspections, minor repairs, and balance-of-plant services. The Cookhouse example demonstrated a 99% energy-based availability rate following the transition, underscoring the viability of hybrid models when implemented with proper oversight (EIMS Africa, 2021).

Given the strategic importance of maintenance in determining asset longevity, cost efficiency, and socio-economic returns, a research study into the operational, organisational, and developmental implications of transitioning from OEM-led to hybrid or LSP-based models is both timely and necessary. Such research would provide decision-makers with practical insights into balancing performance, cost, and policy alignment in the evolving wind energy landscape. More importantly, it would help chart a path for how South Africa's wind industry can mature beyond construction-phase success towards long-term sustainability, resilience, and inclusivity.

In conclusion, the evolution of wind farm maintenance models in South Africa is no longer merely a technical concern; it is a multidimensional issue that intersects with economics, workforce development, policy alignment, and long-term sustainability. Addressing this issue through targeted research is essential. Empirical insights into the costs, performance, and localisation outcomes of different maintenance strategies will enable more informed decisions and help chart a sustainable future for the country's wind energy sector.

1.3 Problem Statement

South Africa's wind energy sector, expected to reach 11.5 GW by 2030, is vital to the country's decarbonisation and energy security efforts. Effective operations and maintenance are essential to ensure optimal turbine performance and long-term sustainability. Wind farm operators face a strategic dilemma: OEMs provide technically reliable but expensive services, while LSPs offer more affordable maintenance options that may raise concerns about service quality and reliability (IRENA, 2019:70; Wind Systems Magazine, 2018).

The sector is further challenged by rising operational costs, technician shortages, and logistical delays, especially when relying on international OEMs unfamiliar with local conditions (Creamer Media's Engineering News, 2023). Hybrid maintenance models and increased LSP involvement are proposed solutions, but these strategies remain underutilised due to a lack of empirical evidence regarding their effectiveness in the South African context (Konstantakos *et al.*, 2019:112; Costa *et al.*, 2021:8).

This knowledge gap limits informed strategic decisions by operators, investors, and policymakers, potentially undermining cost-efficiency, energy availability, and local economic benefits. Furthermore, no comprehensive research currently evaluates the impact of maintenance models on key operational outcomes in South Africa's rural wind farms.

According to the literature, the comparative effects of OEM and LSP maintenance on wind farm performance remain unclear (Pragma, 2023; EIMS Africa, 2019; HSRC, 2024; Fox *et al.*, 2021). While some studies have evaluated individual aspects, such as cost efficiency, response time, and the availability of local expertise, a gap remains in comprehensive, comparative analyses that consider long-term performance, downtime, and sustainability outcomes across different contexts, particularly in emerging markets like South Africa. The existing literature often lacks standardised metrics and tends to focus more on OEM performance, with limited empirical data available for LSPs, making it difficult to draw definitive conclusions.

Addressing this gap will contribute to both academic knowledge and industry best practices, enabling more effective and sustainable management of wind assets in South Africa.

The problem under investigation is the lack of empirical understanding regarding how OEM- and LSP maintenance strategies influence costs, performance, and sustainability of South African wind farms. This deficiency hinders strategic, technical, and socio-economic decision-making in a rapidly expanding energy sector.

1.4 Objectives

The primary objective of this study is to evaluate and compare the effectiveness, cost-efficiency, and operational performance of OEMs and LSPs in the maintenance of wind farms in South Africa. This study's main goal is to compare wind farm maintenance outcomes in South Africa, specifically looking at OEMs versus LSPs.

"Outcomes" are more than just technical performance. They also include decision-making factors, stakeholder perceptions, cost-efficiency, and long-term sustainability. To fully capture

this, the study uses several secondary objectives to provide a balanced and comprehensive comparison between the two service models.

The secondary objectives for the research are as follows:

- 1 To identify the key factors influencing the choice between OEMs and LSPs for wind farm maintenance in South Africa.
- 2 To analyse stakeholder perceptions (e.g. wind farm owners, technicians, and managers) of the reliability and responsiveness of OEMs versus LSPs.
- 3 To determine the role of data-driven maintenance practices (e.g., predictive maintenance) in enhancing cost-efficiency and operational performance.
- 4 To evaluate the long-term sustainability and localisation potential of relying on LSPs versus OEMs.

1.5 Research Questions

Drawing from the objectives, the following primary research question has been identified:

How do OEMs and LSPs compare in terms of effectiveness, cost-efficiency, and operational performance in the maintenance of wind farms in South Africa?

To further contextualise the above research objectives and bridge the gap identified in the problem statement, the following sub-research questions are also relevant:

- How do OEMs and LSPs use predictive- or data-driven maintenance practices, and what is their impact on cost-efficiency and performance?
- What are the long-term implications for sustainability and localisation when relying on OEMs as opposed to LSPs in wind farm maintenance?
- How do OEMs and LSPs compare in terms of operational performance indicators such as downtime, fault resolution rates, response times, parts availability, and logistical efficiency in wind farm maintenance?
- What impact does the provider type (OEM versus LSP) have on long-term asset reliability, including turbine lifespan, and how are these outcomes influenced by local presence, supply chain structures, and workforce skills?

- How do regulatory frameworks, contractual agreements, and workforce capabilities shape the comparative effectiveness of OEMs and LSPs in the South African wind energy sector?

1.6 Scope and limitations of the study

This study is situated within the renewable energy sector, focusing on operational efficiency and optimisation in wind energy production. It specifically investigates how maintenance practices influence energy output, intersecting with research domains such as engineering, operational management, and, to some extent, economics, depending on the research objectives.

The geographic focus is determined by the research aims, data availability, and practical constraints. In the South African context, rural wind farms provide an appropriate case study due to their extensive wind resources and significant wind farm development (Lombard & Ferreira, 2015:77). Focusing on a defined region enables more detailed analysis of local factors affecting maintenance practices and performance.

Although existing literature explores wind farm performance and general maintenance strategies, there remains a gap in comparative research on OEM and LSP maintenance within South Africa. This study seeks to address that gap; however, several limitations must be acknowledged:

- The study concentrates on OEMs and LSPs, potentially excluding insights from other relevant stakeholders such as wind farm operators, technicians, and regulatory bodies.
- Data was collected through qualitative interviews, relying on participants' experiences, perceptions, and honesty, which may introduce bias and limit objectivity.
- Quantitative performance indicators (downtime records, cost logs) were not included, restricting the ability to perform detailed operational- or cost-efficiency analysis.
- Due to its qualitative nature, the participant sample is small and not representative of all OEMs and LSPs in South Africa.
- Variations in the scope and terms of service contracts between OEMs and LSPs may limit the direct comparability of their performance outcomes.
- The findings are context-specific and may not be generalisable to wind farms in other regions or countries with different regulatory, economic, or infrastructural conditions.

- Permission constraints restricted the study to one OEM and one LSP, with six participants interviewed in each organisation. While these interviews provided rich and detailed insights, the limited organisational scope constrains generalisability to the broader South African wind energy sector. The findings should therefore be interpreted as illustrative case studies rather than definitive sector-wide conclusions. Trustworthiness and credibility were enhanced through systematic coding using CAQDAS (NYU Libraries, 2025) and by providing thick descriptions of the organisational contexts studied.

1.7 Significance of the study

This study is significant because it provides valuable insights into how different maintenance models—LSPs and OEMs—impact operational performance, long-term sustainability, and alignment with South Africa’s energy policy goals. It addresses a gap in empirical research, providing evidence that can inform both industry practices and policy development. As the country increasingly emphasises renewable energy, particularly in rural regions, the adoption of reliable and cost-effective maintenance strategies is crucial for ensuring the sector’s ongoing success.

1.8 Research Design and Methodology

Research design is a framework or structure for conducting a study, providing the plan for conducting research, how data is gathered, analysed, and interpreted to answer the research questions (Saunders *et al.*, 2019:163). It is the substrate level that underlies the entire research process, setting the grounds for which methods to use and the study direction. Research designs are crucial for organising research in line with the purpose, context, and method of the study, which determines whether a qualitative, quantitative, or mixed-method approach is appropriate (Creswell, 2009:11-14).

In other words, a research design is a plan of action that shows how the study should be conducted (Saunders *et al.*, 2019:161). In contrast, research methodology refers to the methods and techniques used to collect and analyse data (Bryman, 2016). According to Creswell (2009:5), selecting a proper methodology guarantees that the result of a study is valid and reliable.

This study employs a qualitative research design to investigate the impact of maintenance practices by OEMs and LSPs on electricity losses in wind farms. The methodology employed in this study primarily involves collecting data in words through interviews (Creswell, 2009:113). This qualitative approach is suitable for capturing an in-depth understanding of the challenges

and opportunities in wind farm maintenance.

Qualitative research provides a deeper understanding of the differences in the maintenance of OEM service providers versus LSPs at a South African wind farm. It enables the researcher to comprehend what happens, why, and how these differences emerge at the wind farm (Ugwu & Eze Val, 2023:20). The qualitative research questions are appropriate as they focus on a small group of experienced service providers, using semi-structured interviews to obtain in-depth insights into the differences between OEM and LSP maintenance practices. The emphasis is on understanding the personal experiences of these individuals, rather than making broad generalisations.

Although the researcher conducted the interviews using paraphrased questions, the semi-structured interview's nature allowed for flexibility (Ugwu & Eze Val, 2023:26; George, 2023). The researcher could adapt questions and probes based on the flow of the conversation, which led to more detailed and relevant responses. Qualitative research enables the exploration of diverse perspectives within a particular group or context (Ugwu & Eze Val, 2023:33). It highlights variations in individual experiences, providing a more comprehensive view of a topic.

The maintenance of onshore wind farms, especially those situated in rural and remote regions of South Africa, poses distinctive operational challenges that are well-suited to exploration through qualitative methods (El-Naggar *et al.*, 2023:2). Such an approach enables a deeper understanding of the human, logistical, and organisational factors that shape maintenance outcomes (Kiunke *et al.*, 2022:8-9). This is particularly important when assessing the roles and effectiveness of OEMs and LSPs. Qualitative research offers a robust framework to explore these complex, context-specific dynamics in depth (Lim, 2024:1). Through semi-structured interviews, qualitative methods provide information on the following key perceptual indicators:

- Technician and stakeholder perspectives on the advantages and limitations of OEM versus LSP delivery.
- Experiential knowledge of delays, miscommunications, or procedural inefficiencies not captured in SCADA data.
- Comparisons between OEMs and LSPs, focusing on responsiveness, adaptability, and cost-effectiveness
- Insights into how remote location affects service logistics, workforce mobilisation, and part availability

Rural wind farms often face prolonged response times and limited local technical support, factors that influence turbine downtime and site-level decision-making. These experiences are best captured through qualitative inquiry, which allows for flexibility, depth, and nuanced understanding of context-specific challenges.

By engaging on-site personnel, maintenance planners, and service providers through interviews, qualitative research can reveal practical barriers and identify opportunities for optimising service strategies through revised contracts, hybrid service models, or improved communication protocols.

Ultimately, such insights are crucial for informing more resilient, locally responsive maintenance practices, particularly in South Africa's expanding wind energy sector, which emphasises localisation and sustainable infrastructure development.

1.9 Research Strategy

A research strategy is a structured plan that outlines the approach a researcher will take to investigate a specific question or issue (Saunders *et al.*, 2019:112). It serves as a roadmap for the entire research process, guiding decisions on data collection, analysis, and interpretation. The study remains focused, logically organised, and methodologically robust by establishing a clear research strategy.

As part of the energy transition, wind energy plays a vital role in South Africa. Maintenance is a key factor in wind farm profitability (Hippe *et al.*, 2024:2). While service providers can cater for professional expertise, the ultimate impact of these service providers on maintenance remains to be studied. This study conducts a comparative analysis of OEM and LSP maintenance practices in South African wind farms, with a specific focus on preventive, predictive, and corrective maintenance activities. Specifically, the research aims to contribute to the existing literature by determining whether significant differences exist in maintenance and service provider outcomes between OEM service providers and LSPs, while also identifying contributing factors for each case.

1.10 Outlined strategy for the study

Research Objectives and Questions: The study is guided by clear and focused objectives and research questions examining the comparative outcomes of maintenance practices by OEMs and LSPs in South African wind farms, considering the opportunities and challenges they face.

Scope and Focus: The study evaluates and compares the effectiveness, cost-efficiency,

operational performance, and long-term sustainability of OEMs and LSPs in the maintenance of wind farms in South Africa, with attention to technical outcomes, stakeholder perceptions, data-driven practices, and localisation potential.

Data Collection Methods: An interview guide was systematically designed to ensure alignment with the research objectives and was employed to elicit detailed, context-specific insights from key personnel at targeted service providers engaged in wind farm maintenance in South Africa. The guide emphasised simplicity and was tailored to capture their experiences, perspectives, and insights.

Sampling Strategy: The sampling approach was delineated, detailing the criteria by which participants were selected for their direct relevance to the research questions, forming the qualitative component of this study. Explicit exclusion criteria were also established to ensure appropriate participant inclusion.

Ethical Considerations: The study adheres to stringent ethical guidelines, encompassing the procurement of informed consent from all participants, safeguarding their privacy and confidentiality, and ensuring their equitable treatment throughout the research process. These ethical protocols were formally approved during the ethics clearance application.

1.11 Conceptual framework

This study is grounded in the Strategic Maintenance Theory (SMT), which frames wind farm maintenance as a strategic management function rather than a purely technical task, linking reliability, cost-efficiency, and sustainability to broader organisational goals. Evolving from reactive and preventive approaches, SMT integrates corrective, preventive, and predictive models, with growing use of hybrid and optimisation frameworks to minimise downtime and costs. While globally advanced, South Africa's wind sector faces unique challenges, including skills localisation, supply chain delays, uneven adoption of predictive maintenance, and the dispersion of assets in rural areas.

These theoretical lenses helped explain why OEMs often dominate early operational phases, primarily due to warranty obligations, technical exclusivity, and risk mitigation. However, as turbines age and localisation pressures increase, LSPs may emerge as viable alternatives if they can meet performance, compliance, and cost-efficiency expectations (Zhou & Xu, 2023:229). Within this framework, the OEM–LSP comparison is positioned in a value-risk matrix where factors such as cost, reliability, response time, availability, and skills transfer guide strategic decision-making for wind farm maintenance, while also shaping the structure of data

collection, thematic analysis, and interpretation throughout the study.

1.12 Summation and Thematic Analysis

In this study, the most appropriate method was qualitative, and the data analysis techniques applied were summation and the thematic method, which are suitable for a qualitative study of this nature. The summation method is utilised to summarise qualitative information.

In the thematic method or process of data analysis, as used in qualitative research, the starting point is identifying, analysing, and reporting patterns (themes) within the data. The themes reflect something significant within the data in relation to the research question and aim to capture an average meaning in the data set (Braun & Clarke, 2006). This process involves reading and re-reading the data, generating initial codes, searching for themes, reviewing these themes, defining and naming them, and producing a report (Braun & Clarke, 2006).

This places thematic analysis at an advantage over mere frequency of words, and allows for a deeper meaning and understanding, as it involves interpretation around the different meanings (themes) and not just counting how frequently terms appear. The steps followed in this study were:

Step 1: Data collection:

Interviews were used as a researcher's tool to acquire pertinent, experience-based insights for the study concerning the impact of maintenance practices by OEMs and LSPs on electricity losses in wind farms. The recruitment process involved formulating an interview schedule to elicit relevant information from participants with diverse technical and managerial roles. Semi-structured group interviews were conducted, ensuring flexibility for emerging themes. All interviews adhered to ethical guidelines, including obtaining informed consent, assuring confidentiality, and securely storing anonymised data. The aim was to achieve thematic saturation, providing sufficient depth and diversity to address the study's objectives.

Step 2: Summation:

Data was then gathered by the researcher as part of the summation process, which involved reviewing and condensing the collected information to its essential elements, facts, and discoveries. This process provided a synopsis of the content without delving into a profound analysis, involving the distillation of information into a concise format.

Step 3: Thematic analysis:

During the phase of thematic examination, the summarised content was meticulously scrutinised to identify recurring themes, patterns, and underlying interpretations. This stage extended beyond mere summarisation, aiming to extract profound insights and meanings embedded within the data.

In line with the Protection of Personal Information Act (POPIA), particularly its provisions on informed consent, participants provided their consent before any interviews or observations took place. This process involved a clear explanation of the study's purpose, the voluntary nature of their participation, and how their data would be securely stored and utilised for the research.

1.13 Statistical analysis

For the context-specific opportunities and challenges associated with wind farm maintenance outcomes by OEMs versus LSPs in South Africa, this study employed Thematic Analysis to analyse the qualitative interview data. This method is highly beneficial for studies of this nature, providing the tools to uncover the real experiences, operational realities, challenges, and opportunities related to wind farm maintenance.

Thematic Analysis is a widely endorsed method for systematically identifying, analysing, and reporting patterns (themes) within qualitative datasets. Its adaptability has made it a cornerstone in diverse disciplines such as health, education, and the social sciences (Christou, 2023:6-15; George, 2023).

This study was conducted through a qualitative approach combining semi-structured interviews with key stakeholders and a supporting literature review to explore the operational, cost, and strategic differences between OEMs and LSPs. The interviews offered first-hand perspectives on reliability and responsiveness.

By following the systematic thematic phases outlined in Section 12.1, the researcher will generate insights that enhance understanding of the participants' operational contexts. This process will capture their experiences to aid understanding that will inform more effective and targeted maintenance strategies and policies on wind farm operations in South Africa. The ultimate aim is to extract rich, meaningful patterns from participants' responses, providing both descriptive and interpretive insights that align with the research objectives.

Thematic Analysis is particularly suited for this study given its flexibility and emphasis on researcher engagement, which will be critical in interpreting the complex, context-dependent

views of stakeholders.

1.14 Contribution of the study

Theoretical contribution:

- The proposed research will advance the Strategic Maintenance Theory (SMT) by investigating the unique setting of wind energy and OEMs versus LSPs, examining how longer-term performance and lifecycle costing pertaining to OEM versus LSP involvement may affect maintenance strategies. Such research could shed light on differences from traditional industries. The proposed research will have findings, which may be exploratory, on the outsourcing debate in a capital-intensive and technologically advanced industry. This is tied to more general theories on using specialised knowledge within complicated projects (Gambal *et al.*, 2022:1).
- The proposed research will examine maintenance practices in real-world settings, thus bridging the gap between theory and practice in the maintenance field. Evidence to support or refute existing frameworks related to maintenance, outsourcing, and OEM involvement will be produced (Zhang *et al.*, 2019:401).
- The proposed research aims to identify potential risks associated with implementing the two types of maintenance (OEM versus LSP) for wind farms and the impact of these decisions on operations, thereby enhancing wind farms' risk management capabilities in delivering renewable energy (AWEA, 2017).

Industry contribution

- Practical guidelines to optimise maintenance strategies may reduce downtime, lower costs, and increase energy production (El-Naggar *et al.*, 2023:3-6).
- Evidence-based information regarding OEM service providers versus LSP impacts assists in evaluating and comparing the effectiveness, cost-efficiency, and operational impact of OEMs versus LSPs in maintaining wind farms in South Africa.
- The findings will contribute to cost-effective maintenance strategies for wind energy, rendering its technology more competitive (Zhang *et al.*, 2019:401).
- The implementation of best maintenance practices will contribute to increased reliability and availability, thereby enhancing the stability of the energy supply (AWEA, 2017).

- The findings of this research may be considered in local job and skills development related to the maintenance of wind farms. This would benefit regions where wind farms are located (Muñoz Cabré, 2020:13).
- Wind farm maintenance findings will inform policy advice on renewable energy, maintenance standards, and the role of OEM service providers versus LSPs (Rivett-Carnac, 2022:19).
- Research will contribute to identifying benchmarks for wind farm maintenance, which operators can use to compare and identify improvements and best practices in maintenance and OEM/LSP engagement (AWEA, 2017).

1.15 Chapter summary

This study was aimed at comparatively evaluating the maintenance outcomes of wind farms in South Africa, specifically focusing on the performance differences between OEMs and LSPs. The rapid expansion of wind energy in South Africa is crucial for national energy security and sustainable development. Despite the significant contribution of wind farms to electricity generation and economic growth, their long-term viability is heavily dependent on effective maintenance strategies. The choice between OEMs, with their specialised knowledge, and LSPs, offering localised expertise and economic empowerment, presents a complex operational landscape.

The background of the study highlights the increasing role of wind energy in South Africa's energy mix, particularly post-REIPPPP, aimed at fostering a more robust and localised renewable energy sector. However, challenges such as optimising operational efficiency, managing costs, and ensuring local content development persist. The disparities in maintenance outcomes between different service provider types remain a critical barrier to achieving full potential and are context-specific to the South African environment. While government commitment and programs promote localisation and sustainable infrastructure, the uptake of opportunities for enhanced performance and efficiency through optimal maintenance models remains a key area for investigation. Consequently, this study looks at the operational environment for wind farm maintenance, the challenges faced by both OEMs and LSPs, and the opportunities available to them, to offer management strategies that can help optimise maintenance outcomes in the context of South Africa's wind energy sector.

One of the key features is in the research design and methodology section, which indicates that a structured framework is needed to perform studies of this kind. Research design acts as a

scope that determines what data to ask for, how to analyse, interpret, and, ultimately, what conclusions a researcher can or cannot reach. This is an exploratory study focusing on the opportunities and limitations of maintenance practices by OEMs versus LSPs in South African wind farms. Through qualitative methods such as semi-structured interviews and thematic analysis, the research seeks to reveal trends and rich understandings from the lived experiences of wind farm personnel and stakeholders. Ethical considerations, including informed consent and data confidentiality in line with POPIA, were integral to the data collection process.

The study's contributions span theoretical and industry realms. Theoretically, it enhances the understanding of maintenance paradigms within the wind energy sector and how the choice of service provider impacts operational performance and economic outcomes in a developing market context. Industry contributions suggest that this research will offer a better understanding of what wind farms require from their maintenance providers and suggest possible improvements in policies, support systems, and operational practices that enhance productivity and sustainability in the South African wind energy sector.

The need for this study is addressed through issues specific to wind farm maintenance in South Africa, which can potentially empower stakeholders to overcome challenges and leverage opportunities for improved operational efficiency. Optimised maintenance practices will ultimately benefit electricity supply stability, reduce losses, and contribute to the overall economic growth and sustainability of the renewable energy sector. The results could be useful in informing policy-making and supporting mechanisms, while contributing to the goals of sustainable development and energy security. This is in addition to the role the study will play towards ensuring that maintenance services and support mechanisms are more effective and visible in enhancing wind farm productivity and reliability in the market.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Wind energy has become a pivotal component of global renewable energy strategies, offering a low-emission alternative to fossil fuels and playing a crucial role in achieving decarbonisation goals. However, the efficiency and reliability of wind energy systems do not merely depend on turbine design or wind resource availability; they also rely on the effectiveness of operational and maintenance strategies. As wind energy infrastructure increases in complexity and scale, particularly with the expansion of offshore projects and ageing onshore assets, the focus on performance optimisation and minimising downtime has become increasingly urgent.

2.2 Wind energy context: Onshore- and offshore turbines

Onshore and offshore wind turbines differ in several essential ways, including installation, size, maintenance, environmental impact, and cost (Desalegn *et al.*, 2023:3). Compared to offshore turbines, onshore turbines are easier and cheaper to install and maintain because they are located on land-based sites; however, they are generally smaller with lower power outputs (Reuters, 2024a). Conversely, offshore turbines are larger, more powerful, and harness stronger winds, producing more energy overall (Desalegn *et al.*, 2023:1). They require a more expensive installation and maintenance cost due to the marine working environment, which also necessitates special vessels and equipment to work in (Larsen & Nielsen, 2018:73).

Key performance indicators (KPIs) in wind O&M include availability, Mean Time to Repair (MTTR), response time, and cost per MW (Pfaffel *et al.*, 2019:15). Downtime due to delayed repairs or spare part shortages can reduce availability by up to 20%, particularly in emerging markets with limited-service infrastructure (Zhou & Xu, 2023:225).

The environmental impacts vary, with onshore turbines potentially harming land habitats. Conversely, offshore turbines may adversely affect marine life (Volker *et al.*, 2019:6). Onshore wind farms tend to be more affordable, whereas offshore wind farms can generate more energy but at a higher cost (Desalegn *et al.*, 2023:1).

2.3 Comparison of South African wind farms with international wind farms

In comparison to established international wind markets, such as those in Germany, Denmark, the United States, and Spain, South Africa's wind energy sector remains in a relatively early stage of development (Merem *et al.*, 2022:10). In countries with decades of experience, wind

farms benefit from:

- Highly developed operations and maintenance frameworks, often blending OEM oversight with sophisticated local maintenance networks (Hansen *et al.*, 2021:17).
- Extensive local training pipelines, producing skilled technicians through national energy and vocational programs (IEA, 2025:39).
- Integrated digital asset management tools and predictive maintenance systems that optimise turbine performance in real-time (Global Wind Energy Council, 2025).
- Robust policy and funding mechanisms that incentivise research, innovation, and domestic capability development (IEA, 2025).

Despite this growth, the sector remains heavily reliant on foreign OEMs for operations and maintenance services beyond the initial two to five-year warranty periods. This dependence is attributed to limited local technical training, underdeveloped supply chains for replacement parts and tooling, and challenges in scaling local providers to handle complex or large-scale operations and maintenance tasks (Morris *et al.*, 2020:8).

The wind energy sector has experienced significant global growth. In 2024, global wind power installations reached a record 117 GW, bringing the total operational capacity to approximately 1,136 GW. China led the way, contributing nearly 80 GW of new capacity, accounting for 68.2% of global additions (Global Wind Energy Council, 2025). This expansion illustrates the growing maturity of maintenance markets and the increasing role of digitalised operations in extending turbine life cycles.

OEMs offer specialised engineering support and warranty-backed repairs, which enhance reliability, but at higher costs (Pattison *et al.*, 2016:573). LSPs, in contrast, provide cost-effective alternatives due to lower labour costs and local logistics, but may face challenges accessing diagnostic tools and proprietary parts (Zhou & Xu, 2023:223).

In South Africa, LSPs have the potential to lower annual maintenance costs by as much as 25%; however, concerns persist regarding their quality assurance and technical expertise (Rivett-Carnac, 2022:19). To address this, hybrid models that integrate OEM technical supervision with LSP implementation are increasingly being recommended to achieve a balance between cost efficiency and service quality (Hippe *et al.*, 2024:2; Li *et al.*, 2024:2; SKYSPECS, 2023:10).

In contrast, South Africa has been a slower adopter, as most of its wind farm infrastructure was built only in the past decade, creating both a learning curve and an opportunity for strategic policy alignment (IRENA, 2020:34; SAWEA, 2024; Ukoba *et al.*, 2025:4). Over 70% of operations and maintenance contracts in South Africa are still managed by foreign OEMs, reflecting the country's limited access to skilled technical personnel, inadequate local tooling and spare part supply chains, and the nascent state of independent service providers (ISPs) (SAWEA, 2024). This reliance is compounded by the absence of accredited local training centres focused specifically on wind energy technology.

In Denmark, for example, a significant portion of operators have shifted from OEM-led contracts to ISPs to reduce costs and regain control of asset management decisions (Windpower Monthly, 2015). A well-developed service ecosystem, robust technical training pipelines, and regulatory frameworks that support competition in the aftermarket has facilitated this shift (Hansen *et al.*, 2021:11). In contrast, emerging wind energy markets, such as South Africa, continue to rely predominantly on OEM-led service models due to an underdeveloped local supplier base, limited technical expertise, and insufficient policy incentives to localise maintenance capabilities (Hansen *et al.*, 2021:11). The contrast underscores the need for South Africa to accelerate skills development and strengthen its domestic wind energy value chain.

South African operators face a stronger imperative to develop hybrid service strategies that can reduce reliance on expensive OEM contracts while simultaneously fostering a local maintenance ecosystem.

South African wind farms are compared with those of more experienced international counterparts in Table 2.1.

Table 2.1: Comparison of South African versus International Wind Farms

Aspect	South African wind farms	Experienced international wind farms
Installed Capacity	3.36 GW (2022) (SAWEA, 2024:4)	China: 79.8 GW added in 2024; US: 153 GW total (AP News, 2024)
Number of Wind Farms	34-37, estimated capacity 3442 MW (Statista Research Department, 2025; HSRC, 2024; Biznews, 2023; Independent Power Producer Office, 2021)	Thousands across China, US, and Europe (Global Wind Energy Council, 2025)

Largest Project	Roggeveld Wind Farm (147 MW) (Roggeveld Wind Farm, 2022)	Hornsea Wind Farm (UK): 1.8 GW (Maqbool <i>et al.</i> , 2025:3)
Growth Projection	Targeting 17.7 GW by 2030 (SAWEA, 2024:11)	Global target: 320 GW annual additions by 2030 (Global Wind Energy Council, 2025)
Development Programs	REIPPPP	Various national and regional initiatives (Ørsted, 2025:6)
Operational Experience	Relatively new. 97% built post-2010 under REIPPPP (HSRC, 2024)	Mature industry with 20– 30+ years of operation (e.g., Germany, Denmark, Spain) (Global Wind Energy Council, 2025)
Operations and maintenance Strategy	Reliance on OEMs during and beyond warranty; LSP use emerging (Morris <i>et al.</i> , 2020:28)	Balanced hybrid models; mature operations and maintenance service markets with in-house, OEM, and 3rd-party integration (Hansen <i>et al.</i> , 2021:17)
Skilled Workforce	Growing, but limited in rural regions; ongoing training needs (OECD ,2017:14)	Strong domestic pipelines via technical schools, universities, and national programs (IEA, 2025:39)
Technology Access	Limited access to proprietary tools, analytics, and advanced diagnostics. (SSACI, 2024:26)	Widespread use of SCADA, predictive maintenance, and AI-driven diagnostics (Global Wind Energy Council, 2025)
Policy & Regulatory Framework	Strong REIPPPP framework, but less focus on post-construction performance monitoring (Department of Mineral Resources and Energy, 2021:A4)	Well-developed incentive systems for performance optimisation, local content, and innovation (IEA, 2025)
Community Involvement	Good social programs (especially via REIPPPP), but may lack long-term technical integration (Mukonza & Nhamo, 2018:27)	Community ownership and long-term employment models are more embedded in some regions (e.g., Denmark) (Nordic Policy Centre, 2025)

Maintenance Cost Pressures	High post-warranty costs. OEMs may be unsustainable for long-term rural operations (Morris <i>et al.</i> , 2020:28)	Cost-efficient operations and maintenance due to competitive local markets and long-standing vendor relationships (Hansen <i>et al.</i> , 2021:24)
Site Knowledge & Responsiveness	OEMs often unfamiliar with rural terrain and logistics; LSPs offer local insights (Morris <i>et al.</i> , 2020:27)	Deep integration with local geography and climate through in-house and third-party expertise (Hansen <i>et al.</i> , 2021:24)

2.4 Comparison of South African and advanced-market wind farm maintenance practices

Operations and maintenance challenges at South African wind farms include logistical delays due to spare parts supply issues, a shortage of skilled technicians, and restricted access to OEM data, all of which contribute to extended downtimes, often lasting several weeks or even months (Pragma, 2023). The prevailing maintenance strategy remains largely corrective and preventive, with minimal uptake of predictive maintenance owing to underinvestment in condition-monitoring technologies (Pragma, 2023; Reddit, 2024a). By contrast, international benchmarks suggest that unplanned turbine downtime typically averages around 15 days per year (Reddit, 2024a).

Research on offshore wind farms underscores the importance of predictive- and opportunistic maintenance approaches in significantly reducing downtime (Hu *et al.*, 2024:16). Optimisation models further indicate that a strategic combination of preventive and corrective maintenance can reduce operations and maintenance costs by approximately 40% and improve turbine availability by about 1.8 percentage points (Yu & Strömberg, 2021:1).

In more developed countries, such as Germany, Denmark, the United States, and the United Kingdom, there is a growing transition toward predictive maintenance, driven by the integration of real-time analytics and SCADA-based monitoring systems (Hu *et al.*, 2024:15; Gigoni *et al.*, 2019). These regions benefit from well-established logistics networks, a highly skilled technical workforce, and service redundancy through multiple LSPs. In the post-warranty phase, many wind farms transition to independent or LSPs to reduce operational costs and enhance flexibility (Deutsche Windtechnik Internal, 2024). Furthermore, there is widespread deployment of artificial

intelligence and machine learning technologies to support performance optimisation and early failure detection (Chatterjee & Dethlefs, 2022:2).

Localisation is central to South Africa's REIPPPP, which mandates local job creation and skills transfer. However, foreign OEM dominance limits meaningful technology transfer, slowing the development of local maintenance ecosystems (IPP Projects, 2024). Stronger policy enforcement and technical training partnerships are needed to equip LSPs with the skills to manage wind farms independently (Eberhard & Naude, 2016:8).

In contrast, South Africa's limited local technical capacity and slow uptake of LSPs have resulted in less efficient operations and maintenance performance, as well as prolonged downtimes (Pragma, 2023). Mature markets in Europe and the UK benefit from independent service providers with certified multi-brand capabilities, robust digital infrastructure, and advanced analytics (Deutsche Windtechnik Internal, 2024).

2.5 Global trends in wind farm operations and maintenance

Global trends in wind farm operations and maintenance reflect significant regional variation and technological progression. China has emerged as a global leader in wind energy deployment, particularly in the operations and maintenance market. Between 2017 and 2021, China's wind farm operations and maintenance sector experienced a compound annual growth rate (CAGR) of approximately 13%, expanding from USD 2.7 billion in 2016 to nearly USD 5 billion by 2021, representing 25% of the global market share at the time (Research and Markets, 2023). In 2022, China commissioned 37 GW in new wind capacity and was responsible for 66% of the ~117 GW installed globally in 2023 (IEA, 2025; Reddit, 2024c). Notably, in 2021, China added 16.9 GW of offshore capacity, nearly equalling the global offshore wind capacity added over the preceding five years (Enerdata, 2022).

Developed countries have seen a strategic shift in operations and maintenance practices, moving from traditional routine and corrective maintenance approaches, previously accounting for over 45% of maintenance activities, toward predictive and condition-based maintenance (Costa *et al.*, 2021:20). This shift is particularly evident in the Asia-Pacific (APAC) region, where China remains the dominant force. In 2022, APAC held a 32% share of the global operations and maintenance (Global Growth Insights, 2025). The adoption of predictive maintenance systems in the region has reportedly resulted in a 40% reduction in turbine failure rates (Costa *et al.*, 2021:20; Global Growth Insights, 2025).

2.6 Global growth and forecasts

The global wind energy market continues to expand rapidly. In 2023, approximately 117 GW of new capacity was installed globally, representing a 50% year-on-year increase from 78 GW in 2022 (AP News, 2024; Reddit, 2024b). The operations and maintenance segment is projected to grow from USD 17.9 billion in 2020 to USD 27.6 billion by 2027, reflecting a compound annual growth rate of around 6.4% (REGLOBAL, 2023). Separate forecasts anticipate that the operations and maintenance market will reach USD 26.61 billion by 2029, up from USD 11.92 billion in 2022, indicating a compound annual growth rate of approximately 12% (Global Growth Insights, 2025).

Offshore operations and maintenance are growing at an even faster rate (around 17.6% compound annual growth rate) driven by increased complexity, higher risks, and evolving technology platforms.

2.7 Wind energy trends in Africa and South Africa

While the African continent contributes modestly to global wind energy capacity, it is experiencing rapid growth in this sector. In 2023, Africa and the Middle East added approximately 1 GW of new wind capacity, tripling the figure recorded in 2022, with projections suggesting a fivefold increase by 2028 (AP News, 2024). Wind energy currently accounts for approximately 8% of total electricity generation in the Middle East and Africa region (Enerdata, 2023).

South Africa distinguishes itself in the regional landscape, representing an estimated 40% of the continent's wind operations and maintenance capacity (Global Market Insights, 2024). As of 2023, the country had an installed wind capacity of around 3.7 GW (~0.3% of global capacity) across 19 utility-scale projects, exceeding that of Morocco (1 788 MW; ~0.16% of global capacity) and Egypt (1 702 MW; ~0.15% of global capacity) (Creamer Media's Engineering News, 2025; Statistica Research Department, 2025). Independent Power Producers (IPPs), such as those operating the Garob (145 MW) and Soetwater (147 MW) projects, underscore South Africa's advancement (ENEL Green Power, 2021a; ENEL Green Power, 2019). However, no new capacity was introduced in 2022, signalling a stagnation in recent development.

It is concluded that, although Africa contributes less than 0.65% to global wind capacity, the sector is growing rapidly, adding approximately 1 GW in 2023, which is three times the figure for 2022. South Africa leads the continent in both installed capacity and operational infrastructure.

2.8 The adoption of advanced operations and maintenance technologies

Next-generation wind technologies are rapidly gaining traction worldwide, particularly in Europe, the United States, China, and the broader Asia-Pacific region. These innovations encompass the deployment of high-capacity offshore turbines, such as 15 MW+ models, and large-scale projects like China's 1 GW Hainan floating wind farm, along with the increasing adoption of direct-drive generator systems (Reuters, 2024b). In parallel to hardware advancements, the industry is undergoing a significant digital transformation through artificial intelligence (AI), machine learning (ML), drone-based inspections, digital twins, and Internet of Things (IoT) applications (Rasheed *et al.*, 2024). These technologies have demonstrated their value by reducing turbine failure rates by 35-40%, lowering operations and maintenance costs, and improving turbine availability by as much as 30-50% (Global Growth Insights, 2025). Companies such as GE and Vestas have led this shift, introducing models like the Haliade-X and V236-15.0 MW, which offer greater rotor diameters and efficiency gains (Global Wind Energy Council, 2025). Hybrid systems integrating wind with storage or solar are also gaining momentum in countries like India and China, while floating offshore wind projects are emerging in the UK, Norway, and Japan (IEA, 2025).

In contrast, South Africa's wind sector has seen limited uptake of such technologies. Most projects remain dependent on 2-3.5 MW onshore turbines, with little evidence of digital optimisation or post-warranty innovation since the initial REIPPPP's rollouts (CSIR, 2025). The lack of an offshore wind policy, combined with insufficient investment in digital infrastructure and skills development, has hindered the adoption of global best practices (Department of Mineral Resources and Energy, 2023). Furthermore, South Africa's policy focus has historically centred on expanding generation capacity rather than fostering innovation, while local content requirements and manufacturing capabilities remain underdeveloped (GreenCape, 2022:73; HSRC, 2024). Bridging these gaps will be essential if South Africa is to transition from a capacity-focused to a technology-driven wind energy landscape and to align with the global movement toward smarter, more resilient renewable energy systems (World Economic Forum, 2025:4). Such insights are vital for developing policy and programming interventions to advance gender equity and increase agricultural productivity.

2.9 Lifecycle analysis of wind turbines: South Africa versus global averages

Lifecycle analysis offers a comprehensive view of the environmental impacts associated with wind turbines, from cradle to grave, encompassing raw material extraction, manufacturing, transportation, operation, maintenance, and eventual decommissioning (Oblakovic *et al.*,

2023:1). Globally, wind energy is recognised for its relatively low lifecycle carbon emissions, particularly when compared to fossil fuel-based electricity generation (Mello *et al.*, 2020:215). Onshore wind turbines typically produce between 5 and 12g CO₂-eq per kWh of electricity generated over their lifespan, which averages 20 to 25 years (Farina & Anctil, 2022:2). These emissions are mainly concentrated in the manufacturing and installation phases, where materials such as steel, concrete, and fibreglass are used extensively. Nonetheless, wind remains one of the cleanest utility-scale technologies over its lifecycle.

In South Africa, lifecycle emissions during the manufacturing phase are generally aligned with global norms, mainly due to the extensive importation of standardised turbine components from Europe and Asia (El-Naggar *et al.*, 2023:3). However, operational lifecycle emissions may be slightly higher than the global average (Ibrahim & Thopil, 2025:13). This is largely due to inefficiencies in the local supply chain, prolonged logistics routes from global OEMs, and continued reliance on imported spare parts, which heighten emissions associated with transport and maintenance (Ibrahim & Thopil, 2025:13). Moreover, the insufficient localisation of service infrastructure leads to longer repair times and less efficient servicing, thereby further compounding the environmental burden during the operational phase.

A critical gap in South Africa's wind energy lifecycle management is the lack of a structured framework for decommissioning and recycling, particularly regarding turbine blades. These blades are often composed of non-biodegradable composite materials, such as epoxy resin and fibreglass, which are challenging to recycle and typically end up in landfills (Gonzalez *et al.*, 2017:567). In contrast, leading global OEMs like Siemens Gamesa and Vestas are increasingly investing in circular economy approaches, including the development of recyclable blades and programmes that support the refurbishment or repurposing of turbine components (Vestas Mediterranean, 2023; Siemens Gamesa, 2025). These innovations not only reduce lifecycle emissions but also align with broader sustainability and resource efficiency goals.

South Africa also lacks regulatory incentives or standards to encourage end-of-life planning and extended producer responsibility, both of which are emerging priorities in mature wind energy markets (Bishoge *et al.*, 2020:12). This regulatory shortfall may lead to an accumulation of wind waste as the first wave of turbines installed under the REIPPPP reaches the end of its operational life in the 2030s.

Importantly, maintenance practices play a pivotal role in shaping the overall lifecycle performance of wind turbines. Devenish (2021:35) highlights that extending turbine longevity through effective maintenance can reduce lifecycle emissions by 15-20%, as it delays the need

for component replacement and new installations. The adoption of predictive maintenance, facilitated by data-driven monitoring systems and digital diagnostics, has the potential to minimise unplanned downtime, enhance turbine performance, and reduce the frequency of high-emission maintenance activities (Devenish, 2021:34-35). However, the uptake of such technologies remains limited in South Africa, particularly among LSPs, due to cost, skills, and infrastructure constraints.

In conclusion, while South Africa's lifecycle emissions in the wind sector align with international norms, inefficiencies in operations, logistics, and end-of-life management indicate a potentially higher environmental footprint over the turbine's full lifespan. Closing this gap will require coordinated efforts to integrate predictive maintenance, develop recycling infrastructure, and align national regulations with circular economy principles observed in leading global markets.

2.10 Importance of wind farms in South Africa

Wind energy plays a crucial role in South Africa's transition away from coal-fired power, which continues to dominate the national energy mix. Amid persistent electricity shortages, grid instability, and increasing international pressure to reduce carbon emissions, wind farms have become ever more significant to the country's energy strategy.

Wind farms play a crucial role in diversifying the grid, enhancing energy security, and promoting regional economic development, especially in rural and underdeveloped provinces such as the Eastern Cape, Western Cape, and Northern Cape.

In addition to providing clean energy, wind farms also create local employment opportunities, support community development projects, and enhance technical capacity. As the industry matures, optimising operations and maintenance (O&M) will be crucial for ensuring sustained output and financial viability, reducing downtime, and promoting long-term asset performance.

However, compared to more experienced international operators, South African wind farms are still refining their governance structures, data-driven maintenance regimes, and local training programmes, which are essential for achieving operational excellence.

2.11 Wind farm performance and availability

Maximising a wind farm's performance is vital for boosting energy output and ensuring returns on investment. Numerous studies have highlighted the significance of maintenance strategies in shaping key performance indicators (KPIs), including availability, capacity factor, and overall

energy production (Ma *et al.*, 2020:3628; Cevasco *et al.*, 2021:18; Pragma, 2023). Availability denotes the percentage of time a wind turbine can generate electricity, excluding scheduled maintenance, repairs, or external disruptions such as grid outages (DNV GL, 2017:4). Conversely, capacity factor signifies the actual energy output of a wind farm over a specific period as a proportion of its maximum potential output if operating at full capacity continuously (Wilkie & Galasso, 2021:1; NYSERDA:2020:4).

The study by Ma *et al.* (2020:3628) proposes an improved opportunistic group replacement maintenance (OGRM) strategy that optimises maintenance costs and enhances turbine reliability by individually adjusting reliability thresholds for each subassembly. It is useful to understand the baseline performance and availability of a wind farm before examining specific maintenance activities or items completed by the OEM. Downtime analysis provides key context for understanding performance, which requires separating downtime by cause (e.g., unplanned repairs, scheduled repairs, component failures) and examining both the frequency and duration of each category (Hussain *et al.*, 2024:323). Identifying downtime enables the emergence of a strategy for predictable performance, allowing for a more consistent identification of maintenance practices that can be improved to reduce downtime and capture energy.

2.12 Maintenance strategies at wind farms

Wind turbine maintenance can take various forms, including, but not limited to, preventive maintenance, corrective maintenance, and predictive maintenance (Yan *et al.*, 2023:3). Preventive maintenance involves regularly scheduled inspections and servicing to minimise the risk of failure and extend the operational lifespan of key components. In contrast, corrective maintenance is typically carried out after a fault has occurred, aiming to restore equipment functionality through repair or replacement (TWI, 2024). Predictive maintenance also involves condition monitoring and the use of data science and analytical techniques, considering the prediction of failure along with a pre-emptive maintenance schedule (Devenish, 2021:34-35).

In many circumstances, the OEM will be the primary resource or provider of service to the wind farm for maintenance, either during the warranty period or when specialised service is sought (SKYSPECS, 2023:6). OEM service is required for maintaining complex turbine components. However, relying on OEM service in some cases may introduce additional costs and logistics (SKYSPECS, 2023:6).

The type of maintenance strategies adopted for renewable assets, such as wind farms, will be a key driver contributing to the performance and availability of wind energy production (Devenish,

2021:11). A good maintenance strategy will aim to balance the costs of maintaining the wind asset while increasing the benefits, including minimised downtime and improved energy production (El-Naggar, *et al.*, 2023:2-3). Understanding wind farm maintenance strategies and the role of the OEM will be key to assessing how maintainers contribute to electricity shortages.

2.13 Impact of maintenance on key performance indicators

Both planned (preventive or scheduled) and unplanned (corrective or breakdown) maintenance activities are closely linked to the performance of wind farms, particularly in terms of key performance indicators such as availability, capacity factor, reliability, and energy yield (Electric Power Research Institute, 2023:2; AWEA, 2017). Downtime resulting from these maintenance activities, whether routine inspections, component replacements, or unexpected equipment failures, directly affects the availability of wind turbines (AWEA, 2017). Reduced availability translates into lost operational hours, and consequently, lower energy production, which undermines both revenue and long-term project performance. The magnitude of this impact depends on two primary variables: the frequency of maintenance interventions and the duration of each event (Ozturk & Fthenakis, 2020:2). Frequent or prolonged downtime not only reduces the turbine's productive output but also escalates operational costs and disrupts grid integration plans.

In many South African wind farms, OEMs are contractually responsible for specific maintenance activities during the warranty or early post-commissioning phases. While OEMs offer advanced technical expertise and standardised procedures, this arrangement often introduces delays due to limited local presence, slow response mobilisation, and resource scheduling constraints, especially in remote locations such as the Northern Cape or Eastern Cape. This is exacerbated when spare parts or specialist tools need to be imported, extending downtime even further. As a result, reliance on OEMs can unintentionally compromise KPIs related to turbine availability and overall system efficiency.

Understanding the direct correlation between maintenance regimes and performance indicators is therefore crucial in optimising wind farm operations. A data-driven maintenance strategy, one that considers historical fault data, real-time monitoring outputs, and turbine-specific performance trends, can help develop a proactive maintenance schedule. Such a schedule aims to balance reliability and operational continuity, reducing the likelihood of catastrophic failures while minimising unnecessary shutdowns. Ultimately, improving maintenance planning not only safeguards energy output but also extends asset life and enhances the financial viability of wind energy investments (Gonzalez *et al.*, 2017:567).

2.14 Post-warranty operations, maintenance models and service providers

As wind farms transition beyond the OEM warranty period, typically occurring within 2 to 5 years of commissioning, asset owners must re-evaluate their operations and maintenance strategies to ensure continued performance and cost efficiency (IRENA, 2020:54). During the warranty period, OEMs are contractually obligated to provide comprehensive maintenance and guarantee turbine availability, often with performance assurances and limited operator control over service timelines (IRENA, 2020:54). Once this period concludes, operators face a strategic decision: extend the OEM service agreement, engage independent service providers, or develop in-house maintenance capabilities.

Each post-warranty option presents unique advantages, limitations, and implications for long-term operational resilience.

Many wind farm owners opt to renew or renegotiate service agreements with the OEM. These agreements typically offer continued access to proprietary components, expert technicians, remote diagnostics, and performance guarantees. OEMs such as Siemens Gamesa, Vestas, and GE Renewable Energy maintain centralised service infrastructures that can ensure consistent quality and reliability (TIPS, 2022:7-8). However, extended OEM contracts often come at a premium and are perceived to offer less flexibility in cost structures and service customisation (IRENA, 2020:26).

In the South African context, reliance on OEMs is often necessitated by limited local technical expertise, regulatory hurdles, and logistical challenges associated with operating in remote locations, such as the Northern Cape. These regions suffer from prolonged response times due to spare part lead times, import delays, and a limited pool of qualified service personnel (Poorun & Radmore, 2023:2).

Globally, the market for ISPs is expanding rapidly, offering a competitive alternative to OEM services. Independent service providers offer customised, modular maintenance services, such as blade repair, gearbox maintenance, condition monitoring, or SCADA analytics, typically at lower costs than those of OEMs. These providers are increasingly supported by digital tools, which enable real-time diagnostics, predictive maintenance planning, and asset-specific performance optimisation (Clifton *et al.*, 2023:949; Spain & Ahearne, 2022:56-58).

In mature wind markets, such as Germany, Spain, and the U.S., ISPs have carved out a substantial market share, driven by deregulated maintenance environments, the growth of digital platforms, and the ageing of first-generation wind farms (Global Wind Energy Council,

2024). In South Africa, however, ISPs remain underutilised (Mukonza & Nhamo, 2018:23). This is mainly due to regulatory inertia, a lack of certified local technicians, and operator concerns about losing access to original equipment manufacturer-specific data and parts (Mukonza & Nhamo, 2018:22). Despite these challenges, interest in ISP engagement is increasing, particularly among IPPs looking to localise services and reduce long-term operations and maintenance costs.

A third option for post-warranty service is to develop in-house maintenance teams. This model is more prevalent among large utilities or operators with multiple assets located in proximity. The benefits include cost control, operational flexibility, local job creation, and improved response times. Internal teams can also foster knowledge retention and skills development in emerging markets such as South Africa, which aligns with the localisation objectives of the REIPPPP (IPP Projects, 2024).

However, in-house maintenance requires substantial investment in training, tools, software systems, and safety compliance. Certification for working on high-voltage and high-altitude equipment is particularly demanding. Operators must invest in workforce development over several years (Mukonza & Nhamo, 2018:27). As a result, this model remains relatively rare in South Africa. However, some IPPs have begun exploring hybrid approaches that combine in-house core teams with specialist support from independent service providers or OEMs.

Choosing the most appropriate post-warranty service model involves weighing factors such as turbine age and technology, cost structures, performance history, site location, and workforce availability. Increasingly, predictive maintenance tools, SCADA analytics, and digital twins are shaping service strategies by enabling condition-based and data-driven interventions, rather than relying solely on time-based maintenance schedules (Gigoni *et al.*, 2019).

Globally, the trend is shifting towards flexible, performance-based contracts that align incentives with turbine availability and energy output rather than fixed maintenance schedules. These models are being adopted by both OEMs and ISPs, with growing attention to cost transparency, performance guarantees, and uptime assurance (IRENA, 2020:60).

For South Africa, fostering a competitive post-warranty operations and maintenance landscape will require not only greater participation from ISPs and internal teams but also targeted policy support to build local technical capacity, streamline certification pathways, and incentivise digital adoption.

As wind farms exit the OEM warranty period, typically within two to five years, operators must

choose between extending OEM service agreements, contracting LSPs, or developing in-house maintenance capacity. Globally, there is a clear shift toward flexible post-warranty service models that incorporate predictive maintenance, cost transparency, and performance guarantees (Hussain *et al.*, 2024:324). In South Africa, OEMs continue to dominate post-warranty services due to limited local capacity and regulatory inertia, although interest in LSPs is growing. Understanding the implications of these service choices is crucial for assessing long-term cost efficiency and operational resilience.

2.15 Digitalisation and industry 4.0 in wind operations and management

The global wind industry is rapidly embracing Industry 4.0 technologies. Innovations such as SCADA systems, Internet of Things (IoT) sensors, drones, digital twins, and artificial intelligence (AI) are transforming operations and maintenance (Spain & Ahearne, 2022:56-58). These technologies enable real-time condition monitoring, proactive diagnostics, and automated maintenance scheduling. In South Africa, digital adoption is slower and often limited to the OEMs' installed systems. The gap in digital infrastructure and analytics capabilities hinders the transition toward predictive maintenance and limits performance optimisation.

2.16 Localisation and skills development in wind operations and maintenance

South Africa's REIPPPP mandates localisation targets for skills development, job creation, and enterprise development (Eberhard & Naude, 2016:8). However, the presence of foreign OEMs has constrained technology transfer and limited the development of domestic maintenance capabilities. Literature highlights the need for stronger policy frameworks and capacity-building initiatives to support LSPs (IPP Projects, 2024). Bridging the skills gap is crucial to reducing reliance on foreign expertise and enhancing long-term sector sustainability.

2.17 Environmental and social impacts of maintenance practices

While wind energy is widely regarded as environmentally friendly, maintenance activities, particularly those conducted offshore or in sensitive habitats, can raise environmental and social concerns. Onshore maintenance may disturb local wildlife, while offshore servicing can affect marine ecosystems (Volker *et al.*, 2019). Furthermore, community engagement in maintenance planning and local job creation can impact a project's social licence to operate. Understanding these dynamics is essential for aligning wind farm operations with broader sustainability and community development goals.

2.18 Comparative downtime analysis: global vs South Africa

Downtime is one of the most critical indicators of wind farm performance. Globally, advanced operations and maintenance systems in Europe, China, and North America report significantly reduced unplanned downtime due to mature service ecosystems and rapid-response infrastructure (DNV GL, 2020; Hussain *et al.*, 2024:324). In contrast, South African wind farms often face extended downtimes due to delays in OEM response, long lead times for spare parts, and limited technical support in remote regions. A comparative downtime analysis highlights the importance of optimised logistics, local repair capacity, and decentralised service teams for performance improvement.

2.19 Cost comparisons of OEM and LSP maintenance services

Maintenance cost structures across OEMs and LSPs vary significantly, impacting wind farm operators' budget control and long-term sustainability. OEM service agreements typically include specialised engineering expertise, proprietary spare parts, and warranty-backed repairs, albeit at premium prices (SKYSPECS, 2023:6). Their intimate knowledge of design specifications and dedicated training programs allows them to offer preventive maintenance strategies that, while expensive upfront, reduce unplanned outages and catastrophic failures (Schelling, 2021).

LSPs, on the other hand, often offer lower maintenance costs due to cheaper labour and flexibility in sourcing spare parts—including refurbished or non-OEM components (Zhou & Xu, 2023:223). However, these cost savings may be offset by longer repair lead times and reduced reliability caused by unfamiliarity with specific turbine models and restricted access to proprietary diagnostic technologies (Pattison *et al.*, 2016:578).

In emerging economies, LSPs have been shown to reduce maintenance costs by 15-25% due to lower workforce and logistical expenses, although they must adhere to strict technical performance criteria to be effective (Rivett-Carnac, 2022:19; SKYSPECS, 2023:8). While short-term cost savings of around 20% have been documented, they may be accompanied by increased downtime due to slower response times and inventory constraints (Zhou and Xu, 2023:226). Conversely, OEM contracts, although more costly, tend to offer financial predictability through fixed or capped maintenance pricing models, mitigating the risk of unexpected failures and large repair expenses (Pattison *et al.*, 2016:582).

These cost differentials are primarily shaped by local workforce competence, supply chain maturity, and logistical infrastructure. In regions with weaker technical capacity or infrastructure, the hidden costs of delays, subpar repairs, and extended outages can quickly outweigh the

initial cost benefits of choosing LSPs (Rivett-Carnac, 2022:19). The selection between OEM and LSP services thus presents a trade-off between operational reliability and upfront cost reduction, requiring strong performance monitoring and innovative contracting strategies to ensure value for money (Zhou and Xu, 2023:229; Spain & Ahearne, 2022:56).

2.20 Impact of maintenance practices on turbine lifespan and availability

The quality and type of maintenance practices applied to wind turbines have a direct impact on both availability and service life. Preventive and predictive maintenance approaches help mitigate wear and prevent severe breakdowns, thereby extending equipment lifespan (Pattison *et al.*, 2016:579). Predictive maintenance using condition monitoring systems can increase turbine availability by 5-10% over traditional reactive models, thereby enhancing energy output and revenue (Yan *et al.*, 2023:3).

In less developed wind energy markets, such as South Africa, issues like delayed fault detection, limited on-site expertise, and infrequent maintenance cause component deterioration and early turbine retirement (Zhou & Xu, 2023:225). These issues are further worsened by low investment in advanced diagnostics, long lead times for spare part procurement, and restricted access to OEM technologies, all of which led to increased Mean Time to Repair (MTTR) and, ultimately, higher downtime rates compared to global benchmarks (Pattison *et al.*, 2016:585).

Industry best practices call for a proactive maintenance culture, using AI-driven analytics, real-time SCADA data integration, and cross-functional technician training to enhance both availability and lifespan of turbines (Yan *et al.* 2023:2). As a result, hybrid models that combine OEM expertise with locally trained service teams equipped with advanced diagnostic tools present a viable strategy to improve operational outcomes in countries like South Africa (Zhou & Xu, 2023:230). Prioritising proactive issue detection and system health monitoring can reduce long-term costs and extend turbine lifespans.

2.21 Summary of literature gaps and research justification

Despite the significance of wind turbine maintenance, few comparative studies evaluate the performance of OEMs versus LSPs, particularly in emerging markets like South Africa. While most existing research focuses on quantitative metrics, such as downtime rates, failure frequencies, and lifecycle costs, less attention is given to qualitative factors, including operational realities and stakeholder insights (Pattison *et al.*, 2016:576).

The views of operations managers, service technicians, and maintenance planners remain

underexplored, yet they are crucial for understanding key differences in technical responsiveness, skills adequacy, and cost-effectiveness between OEM and LSP models (SKYSPECS, 2023). These qualitative insights provide the necessary context that purely numerical evaluations often overlook. In this regard, qualitative research can bridge the gap between performance data and practical implementation by informing collaboration models and capability transfer between OEMs and local service entities.

The South African wind industry faces unique logistical, economic, and workforce-related challenges that are not adequately reflected in current global literature. Policymakers, developers, and project financiers need empirically grounded, locally relevant research to inform strategic decisions (Zhou & Xu, 2023:231). Maintenance policy frameworks must be adapted to support LSP integration while also ensuring quality and reliability. This study addresses this gap by focusing on South African wind farm operations and offering context-specific insights that support national renewable energy goals and inclusive economic development.

2.22 Strategic Maintenance Theory in Wind Energy

A maintenance strategy is a critical determinant of operational uptime, cost efficiency, and asset longevity in wind farms. The Strategic Maintenance Theory (SMT) provides a holistic perspective by elevating maintenance from a purely technical task to a strategic management function aligned with organisational objectives such as reliability improvement, lifecycle cost reduction, and optimised operational performance.

2.22.1 Evolution and foundations of SMT

SMT evolved as organisations recognised that traditional maintenance approaches, largely reactive and cost-driven, were insufficient for increasingly complex, high-value assets such as wind turbines. It draws conceptually from strategic asset management principles, integrating operational decision-making with long-term business goals. SMT emphasises maintenance as a value-creating activity, aligning resource allocation, risk management, and technology adoption with the overarching strategic objectives of an organisation (Papadopoulos *et al.*, 2022:835-846).

Although related frameworks, such as Reliability-Centred Maintenance (RCM) and Total Productive Maintenance (TPM), have informed industry practice, SMT extends beyond their scope by explicitly linking maintenance to corporate strategy and operational resilience. RCM focuses primarily on identifying the most effective maintenance tasks to preserve system function, while TPM emphasises operator involvement and continuous improvement. SMT, by

contrast, provides a broader decision-making lens that incorporates RCM's failure-mode focus and TPM's participatory ethos, situating them within a lifecycle cost and business value context. This makes SMT particularly relevant for industries, such as wind energy, where operational downtime has direct revenue implications and maintenance contracts significantly shape profitability.

2.22.2 SMT categories and comparative perspective

Under the SMT framework, maintenance is typically classified into three principal models:

- **Corrective maintenance (reactive):** Conducted after equipment failure. While simple and low-cost initially, it often results in extended downtime, higher repair costs, and collateral component damage over time (Tusar & Sarker, 2021:8).
- **Preventive maintenance (time- or usage-based):** Scheduled interventions aimed at pre-empting failures. Effective when well-optimised, but may result in unnecessary interventions if condition monitoring data is limited (Tusar & Sarker, 2021:3).
- **Predictive maintenance (condition-based):** Leverages sensors, SCADA systems, and analytics to predict component degradation and schedule maintenance at optimal intervals. This approach has been shown to minimise unplanned outages and extend asset lifespans (Frederiksen *et al.*, 2024:4).

Recent studies highlight the increasing adoption of hybrid or opportunistic maintenance models, which blend preventive and predictive elements. Scenario-based stochastic models report reductions in production loss and transport costs by up to 32% (Tusar & Sarker, 2021:21), while mixed-integer optimisation frameworks (e.g., STOCHOS) demonstrate measurable improvements in downtime reduction and resource allocation (Papadopoulos *et al.*, 2022:835–846). Probabilistic cost models now allow decision-theoretic optimisation under uncertainty, aligning component-level and farm-level strategies (Farhan *et al.*, 2025:468–471).

2.22.3 Relevance of SMT to this study

Despite these global advancements, there remains limited empirical analysis of how maintenance strategies are implemented in the South African wind sector, particularly when comparing OEMs and LSPs. The South African wind industry operates under unique constraints:

- Skills localisation policies shape maintenance contracts and staffing requirements.

- Supply chain challenges and longer lead times for imported components increase the cost of downtime.
- Predictive maintenance adoption is uneven, with some operators lacking access to advanced condition-monitoring infrastructure.
- Geographical dispersion of wind farms (often in rural areas) complicates logistics and increases maintenance costs.

SMT was selected as the theoretical lens for this study because it allows a structured comparison of OEM and LSP maintenance strategies beyond cost analysis alone. It provides a framework for evaluating:

- **Reliability:** Minimising unplanned outages and their impact on revenue.
- **Cost-efficiency:** Balancing immediate maintenance costs with long-term lifecycle savings.
- **Capability development:** Assessing local versus imported expertise, tools, and data systems.
- **Alignment with national objectives:** Including skills development, renewable energy policy compliance, and sustainability initiatives.

Alternative frameworks such as RCM or TPM offer valuable tools for asset-level decision-making but do not fully account for the contractual, economic, and policy-driven dynamics of South Africa's wind energy landscape. SMT, with its broader strategic orientation, is therefore the most suitable to frame this dissertation's aim: to analyse and compare the strategic maintenance approaches of OEMs and LSPs in the South African wind energy sector.

2.22.4 Synthesis and link to research gap

By applying SMT, this study moves beyond descriptive maintenance categorisation to critically analyse how different service providers structure and implement their strategies. This theoretical framing supports the dissertation's objective of evaluating which approach, OEM or LSP, offers more sustainable, reliable, and cost-effective maintenance under South African conditions. It also highlights potential trade-offs: while predictive maintenance may deliver higher uptime, its capital requirements and technological dependencies may not be readily met by all local providers; conversely, preventive or hybrid approaches may be more accessible but risk

inefficiencies if poorly scheduled.

In summary, SMT provides a decision-oriented framework that enables this research to:

- Identify the strategic rationale behind maintenance choices.
- Contextualise them within South African operational realities.
- Generate findings that can inform policy, contracting, and localisation strategies in the renewable energy sector.

2.23 Chapter summary

Performance is vital for maximising energy production and returns on investment in wind farms, with key performance indicators such as availability, capacity factor, and energy production serving as essential metrics. Availability is influenced by wind resources, turbine technology, and maintenance strategy, making downtime analysis key to improving performance. Effective preventive, corrective, and predictive maintenance is crucial, with predictive maintenance leveraging data science to forecast failures and schedule pre-emptive actions. While OEM services are often necessary for complex components, their reliance can lead to increased costs and logistical challenges.

Maintenance, both planned and unplanned, has a direct impact on key performance indicators, particularly availability and energy generation, with downtime events and their duration being critical. OEM-related delays can further exacerbate downtime. In the case of a qualitative interview schedule, thematic analysis facilitates the identification and interpretation of patterns or themes within the collected data.

CHAPTER THREE: RESEARCH METHODOLOGY AND METHOD

3.1 Introduction

While chapter one provides an overview of this study and chapter two presents the literature review, this chapter focuses on the methodology, design, and specific methods employed for conducting this research. The chapter commences with the rationale behind the selected methods, emphasising ethical considerations and potential limitations encountered during the study. This study seeks to explore the comparative outcomes, opportunities, and challenges encountered by OEMs and LSPs in wind farm maintenance in South Africa.

3.2 Empirical study

3.2.1 Research paradigm

This study adopted an interpretivist paradigm that focused on understanding phenomena through the lived experiences and perceptions of participants (Bryman *et al.*, 2017:384). Interpretivism holds that reality is socially constructed and is best comprehended through the study of human interactions, and the meanings individuals ascribe to them (Thanh & Thanh, 2015:24). This paradigm enabled the researcher to explore how OEMs and LSPs manage maintenance challenges in actual wind farm settings.

3.2.2 Research design

This study adopted a qualitative, exploratory research design, which is well-suited for investigating complex phenomena in contexts where limited empirical research is available, such as the South African wind energy sector. As Rangarajan and Shields (2020:1703) note, exploratory research, unlike descriptive or explanatory approaches, aims to uncover underlying meanings and relationships rather than testing predefined hypotheses. This is particularly relevant here, as the study seeks to compare the maintenance outcomes of OEMs and LSPs.

The qualitative inquiry allowed for the collection of rich, nuanced data on how stakeholders experience and perceive maintenance practices. Creswell and Poth (2018:45) support this by stating that qualitative designs are highly effective for exploring lived experiences and gaining in-depth insights into social or organisational processes. Aspers and Corte (2019:139) further explain that this type of research is an iterative process that builds contextual understanding through continuous engagement with participants and data.

The design is particularly suited to the South African context, where skill shortages and limited empirical evidence pose unique challenges. Direct engagement with stakeholders provided insights that would likely have been overlooked by quantitative methods alone.

Data collection (Section 3.4) focused on in-depth conversations with participants, allowing them to share detailed perspectives while giving the researcher flexibility to probe emerging themes. The material was then analysed thematically to identify recurring patterns related to cost efficiency, reliability, and sustainability (Braun & Clarke, 2006:79).

All in all, the qualitative, exploratory design provided the necessary methodological flexibility to investigate this underexplored field. It enabled the study to go beyond simple comparisons of OEM and LSP models, generating deep, contextually grounded insights that can benefit both academic understanding and practical decision-making in the South African renewable energy industry.

3.2.3 Research approach

The research adopted an inductive approach, whereby data is first collected and then analysed to identify patterns, concepts, or theoretical insights (Saunders *et al.*, 2019:155).

3.2.4 Methodological choice

This study utilised a mono-method qualitative research approach. This involved a literature review complemented by mainly one-on-one, semi-structured interviews with representatives from six OEMs and six LSPs (Section 3.4). When participants were unable to attend a meeting, the interview schedule was sent to them by email with clear instructions, allowing them to complete it at their convenience. These methods were selected to obtain in-depth and nuanced insights into the advantages and challenges of wind farm maintenance, thereby enabling a meaningful comparative analysis of the two provider types in the following ways:

- Ruslin *et al.* (2022:24) discussed semi-structured interviews from a methodological perspective. According to these authors, semi-structured interviews enable the researcher to clarify misunderstandings immediately and ask probing questions to gather more detailed information. This method fosters a personal connection with participants, encouraging more open and candid sharing in a conversational setting. It also enables the observation of non-verbal cues, such as pauses and body language, that add valuable context. Furthermore, this approach facilitates focused discussions, ensuring that key topics, including the advantages of OEM- versus LSP maintenance, are

thoroughly explored.

- Self-completion minimises interviewer bias by reducing the influence of tone, follow-up prompts, or expectations, resulting in more authentic and considered responses (Harling *et al*, 2017:2). This method also supports comparative analysis, as the richer, well-reflected answers can reveal subtle differences between the two provider types, enabling a deeper examination of performance, cost, and operational challenges.

The use of one-on-one interviews and self-completed schedules has certain limitations. One-on-one interviews are time-consuming, less scalable, and may be influenced by interviewer bias, where tone, phrasing, or reactions affect participants' responses. Some participants may feel pressured in a face-to-face setting, which can limit openness, and the conversational nature may lead to inconsistent depth of responses. In contrast, self-completion limits opportunities for clarification if participants misinterpret questions, may result in lower response rates due to delays or non-completion, and can produce variable response quality, as participants might provide brief or superficial answers. Furthermore, this method does not allow observation of non-verbal cues and delays the opportunity for immediate probing or feedback.

3.2.5 Research strategy

This study adopted a comparative research strategy to systematically examine and contrast maintenance practices within the South African wind energy sector. It focused on identifying patterns, similarities, and contrasts between OEM and LSP practices through thematic analysis of interview data, supported by documentary evidence. The strategy is particularly suited to the qualitative, exploratory design of the study, as it allows for the juxtaposition of different organisational approaches without presupposing homogeneity across service providers. The central comparison is between OEMs and LSPs, with a focus on their performance in delivering preventive, predictive and corrective maintenance. These three maintenance categories were chosen because they represent the core pillars of wind farm asset management, each directly influencing reliability, cost-efficiency, downtime management, and long-term sustainability (Li *et al.*, 2024:2).

The comparative strategy was appropriate as the research aim is to evaluate whether OEMs or LSPs provide more effective maintenance outcomes. By directly contrasting the two models, the study captured differences in cost, reliability, and responsiveness that would be overlooked in a single-case design. For this research, evaluating whether OEMs or LSPs provide more effective maintenance is the most appropriate comparative analysis. It facilitated the identification of

contextual factors (such as contractual obligations, technological capabilities, and resource constraints) that shape maintenance outcomes. By highlighting both strengths and weaknesses of each service model, the strategy supported the formulation of evidence-based recommendations for industry stakeholders and policymakers.

Data was gathered from twelve participants, six OEM and six LSP representatives, through semi-structured interviews or self-completed schedules (Section 3.4). Participants were purposively selected and met the criteria outlined in Section 3.3.2. In addition to interviews, industry reports were reviewed to triangulate findings and enrich the comparative analysis.

The analysis was guided by a set of predefined evaluation criteria developed from literature on wind farm maintenance and industry best practices. These include:

- Lifecycle cost implications (long-term cost-effectiveness of maintenance approaches).
- Reliability and availability (impact on turbine performance and downtime reduction).
- Responsiveness to failures (speed and adequacy of corrective interventions).
- Integration of predictive technologies (use of digital tools and 4IR applications in forecasting failures).

At the same time, the study remained open to emergent themes that arose inductively during the thematic coding process, ensuring that context-specific insights were not overlooked.

To ensure fairness and trustworthiness in comparing OEMs and LSPs, the study applied the criteria of credibility, dependability, confirmability, and transferability (Section 3.6).

The comparative strategy faces constraints such as limited access to proprietary data, especially from OEMs, which may restrict the depth of technical benchmarking. The relatively small interview sample, while sufficient for a qualitative exploratory study, may not capture the full heterogeneity of industry practices. These limitations are acknowledged and addressed by triangulating interview insights with secondary data (PSI Repair Services, 2022; SKYSPECS, 2023:7; Wind Systems Magazine, 2023) and by clearly delimiting the scope of claims made.

3.2.6 Time horizon

This study adopted a cross-sectional time horizon, which was appropriate because the research was a one-off study conducted over a specific, short-term period, consistent with the definition provided by Saunders *et al.* (2019:155). Data was collected at a single point in time, either

through one-on-one virtual interviews with nine participants or by sending a modified interview schedule via email for three participants to complete independently. The data was then analysed to provide a snapshot of comparative maintenance practices. This approach was suitable for the exploratory and comparative nature of the research, allowing for an in-depth analysis of the participants' current perspectives and experiences.

3.3 Population and sampling

3.3.1 Target group

The population for this study comprised OEMs and LSPs involved in wind farm maintenance operations in South Africa. This includes operations or plant managers, lead technicians and engineers who possess experience with the maintenance of South African wind farms.

The OEM or LSP team responsible for maintaining a wind farm depends on factors such as the size of the wind farm, the contractual scope of the OEM/LSP, and the geographic layout. However, standard staffing patterns are commonly used globally to ensure efficient operation and maintenance (Kotarbinski *et al.*, 2020:10–16). The target participants were individuals employed by both OEMs and LSPs, as they possess the relevant knowledge and experience. Typically, an OEM or LSP team includes one operational or plant manager, two to three lead technicians, two to three engineers, and six to ten additional technicians. Based on this structure, a sample of six participants per organisation was recruited for the study.

3.3.2 Sample inclusion and exclusion criteria

To ensure ethical and methodological integrity during the research process, the following criteria were set for individuals in the studied wind farm to participate:

Inclusion criteria:

- Participants must have a relevant technical background in wind farm maintenance or operations.
- Participants from the OEMs and LSPs were selected based on their direct involvement in wind farm maintenance in South Africa, including roles such as technicians, managers, or engineers, ensuring that the insights captured both technical and strategic perspectives.
- Participants must have at least one year of experience working in the wind energy

sector.

- Participants must demonstrate willingness and motivation to participate and be available for a full interview session.
- Participants must be able to provide informed consent.

Exclusion criteria:

- Individuals who are vulnerable, such as minors, cognitively impaired persons or unable to provide informed consent, were excluded.
- Individuals with conflicts of interest, such as those working for competitors, with prior insider knowledge of the research objectives, or in decision-making roles on the research team, were not invited.
- Participants who have recently participated in similar research studies within the last six months were excluded to avoid bias or overrepresentation.

3.3.3 Sampling method

The researcher contacted managers at selected service provider organisations and provided them with a brief guide outlining the inclusion criteria as described in Section 3.3.2. Managers assisted in identifying employees who meet these criteria.

Once a pool of potential participants was identified, the researcher conducted an initial screening via phone or email. The screening assessed:

- Relevance of the participants' role and experience to the study
- Willingness and motivation to participate
- Availability for a 45–60-minute interview
- Existence of any conflicts of interest (Section 3.3.2).

Participants who did not meet the inclusion criteria (Section 3.3.2) or presented a conflict of interest were excluded from further consideration.

To mitigate the risk of participant non-attendance, the researcher recruited two additional individuals beyond the required sample size. These individuals were informed of their status and

thanked for their participation. When they were not needed, they were notified and excused respectfully.

Participants who passed the screening were either invited to a virtual enrolment meeting via Zoom or Microsoft Teams or received the interview schedule by email for self-completion. During the virtual semi-structured interviews, and for those completing the schedule independently, the researcher:

- Explained the purpose and scope of the study
- Outlined the expectations, including the format and estimated duration for those participating in semi-structured interviews
- Addressed any questions or concerns
- Obtained written informed consent (Annexure 1) before data collection began.

Only participants who provided informed consent were officially enrolled in the study.

For the interviews, the researcher coordinated with each participant to agree on a suitable date, time, and virtual platform (Zoom or Microsoft Teams) and sent a calendar invitation to ensure clarity and attendance. For self-completion, a deadline was set for returning the completed semi-structured interview schedule.

The interviews were conducted in a respectful and neutral manner, guided by a semi-structured schedule (Section 3.4.1). Each session lasted approximately 45-60 minutes, was audio-recorded with the participants' consent, and complemented by the researcher's notes.

The focus was on gathering real-world experiences, technical insights, and informed perspectives on wind farm maintenance strategies.

All data was stored securely in compliance with the POPI Act, and strict confidentiality was maintained throughout the study. Participants were de-identified in all research outputs.

3.4 Data collection

3.4.1 Semi-structured interview schedule

A semi-structured interview schedule (Annexure 2) was developed to align with the study's objectives, ensuring that the data collected directly addressed the research aims. A single, consistent set of open-ended questions was designed to facilitate a comparative analysis

between LSPs and OEMs. These questions focused on key dimensions, including operational flexibility, responsiveness, competitive positioning, and maintenance strategies.

The open-ended format encouraged participants to provide detailed, context-rich responses, allowing the researcher to probe further when unexpected themes or critical issues emerged during the interviews. This approach ensured that nuanced insights and diverse perspectives were captured.

3.4.2 Method of data collection

Semi-structured interviews were conducted virtually via Microsoft Teams or Zoom, depending on participant preference. Each interview lasted approximately 45-60 minutes and was audio-recorded with participant consent. Researcher notes supplemented the recordings to capture non-verbal cues and contextual observations.

In some cases, participants were unable to attend a virtual meeting, and the questionnaire was sent to them by email.

Prior to participation, individuals signed an Informed Consent form (Annexure 1), which outlined the study's purpose, the voluntary nature of participation, confidentiality measures, data storage procedures, and their right to withdraw at any time without penalty.

The interviews followed the pre-developed schedule (Annexure 2) while allowing flexibility to explore emerging topics. All data collected was securely stored, and confidentiality was maintained throughout.

3.4.3 Questionnaire distribution and follow-up procedures

For participants unable to attend interviews, the same semi-structured questionnaire was distributed via email. The process included:

- Pre-testing the questionnaire to ensure clarity and functionality.
- Obtaining ethical clearance (Section 3.7) and including a Letter of Consent (Annexure 1).
- Emailing the questionnaire with a clear subject line ("Invitation to Participate in Wind Farm Maintenance Study"), a concise introduction, instructions for completion, an estimated time to respond, a submission deadline, and the researcher's contact information.

- Follow-up reminders sent 1-2 weeks after the initial invitation to non-respondents, politely reiterating the importance of participation and providing the questionnaire link again.
- Ensuring compatibility and security: links and attachments were tested across devices, and email formatting was optimised to avoid spam filters.
- Maintaining a participation log to track invitations, responses, and follow-ups, ensuring transparency.

Recording refusals or dropouts for reporting in the methodology section.

3.4.4 Data collection process

The data collection process combined both interviews and emailed questionnaires to maximise participation while accommodating participant availability. Interviews were conducted one-on-one, ensuring an open and respectful environment for sharing perspectives.

Participants provided informed consent prior to data collection, and all data was handled confidentially. This process ensured depth of understanding while maintaining ethical compliance and methodological rigour.

3.5 Data analysis

After completing the interviews and receiving the self-completed responses, the data was transcribed and analysed electronically using ATLAS.ti, a computer-assisted qualitative data analysis software (CAQDAS) (NYU Libraries, 2025). Thematic analysis, as defined by O'Reilly and Kiyimba (2015:132), was employed to identify, analyse, and report recurring patterns, thereby facilitating the descriptive organisation of the data for interpretation.

The analysis process involved inductive coding of the transcripts, followed by organising the codes around the predefined comparative framework. Themes were then reviewed, refined, and mapped against the evaluation criteria to identify patterns of convergence, divergence, and gaps between OEM and LSP models. Where possible, findings were corroborated with maintenance records and documented practices to strengthen credibility.

Following Braun and Clarke's six phases of thematic analysis (2006), the researcher moved through familiarisation with the data, generating codes, grouping related codes into broader themes, reviewing and defining these themes, and finally incorporating direct quotations to

illustrate the findings (Figure 3.1). ATLAS.ti was instrumental in supporting this systematic process.

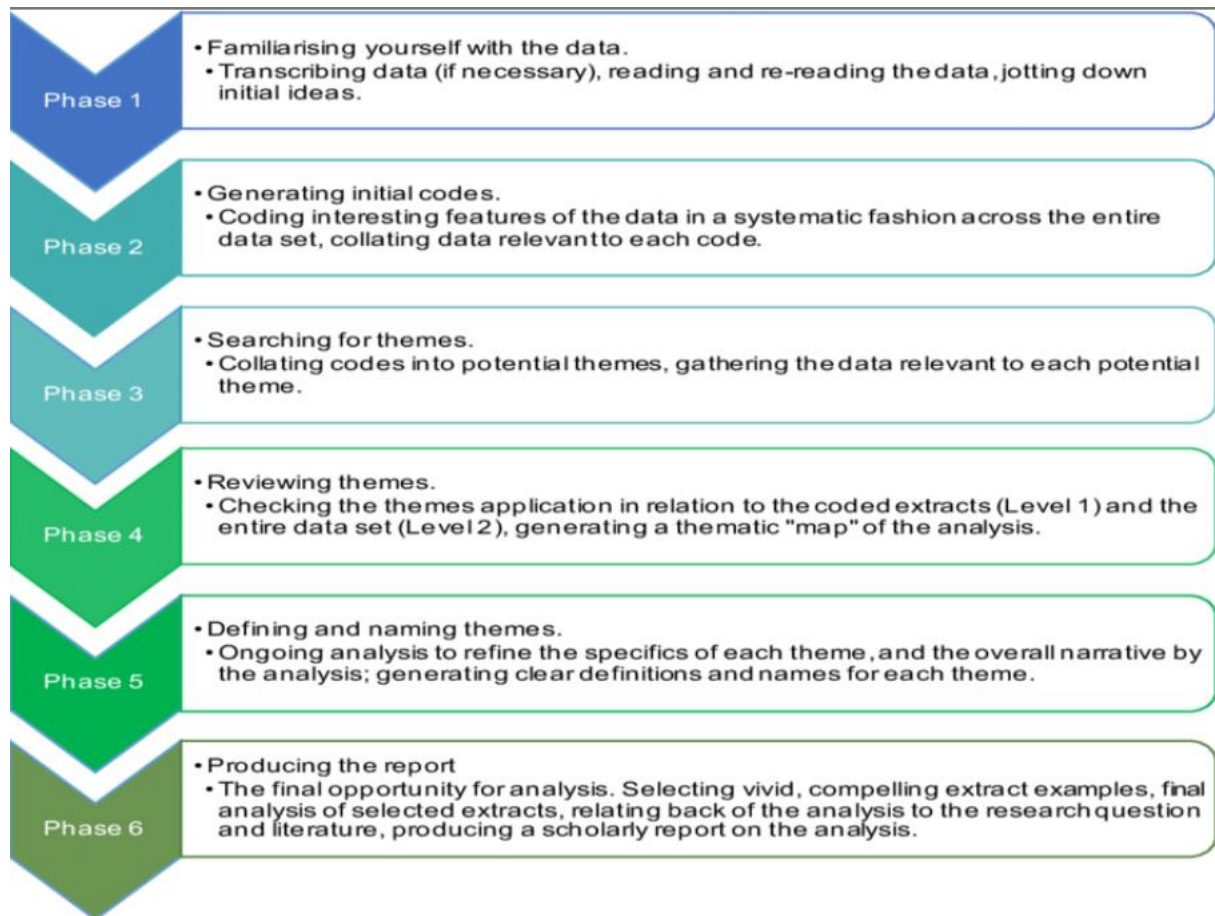


Figure 3.1: Braun and Clarke's Six Phases of Thematic Analysis (Adapted from Braun & Clarke, 2006; Nowell *et al.*, 2017; Saunders *et al.*, 2019:651)

3.6 Study trustworthiness

The researcher enhanced the study's credibility by presenting the findings to participants for validation, a process known as member checking (McKim, 2023:45). This allowed participants to confirm whether their perspectives were accurately interpreted within their social and organisational contexts. Adhering to ethical standards in this process, as emphasised by Erdmann and Potthoff (2023:8-9) and Bryman and Bell (2014:272), strengthens credibility by ensuring that researchers remain objective and minimise personal values or theoretical bias, thereby aligning with the principle of confirmability.

Validity in qualitative research largely depends on the appropriateness and richness of the data collected in relation to the research questions (Hennink & Kaiser, 2022:2). A primary indicator of

data validity is data saturation, which occurs when no new information or themes emerge from additional data collection, and participant responses begin to repeat (Fusch *et al.*, 2018:24). According to Hennink and Kaiser (2022:2), reaching saturation signals that the data collected is sufficiently comprehensive to address the study's objectives.

This study involved nine interviews and three self-completed questionnaires with six employees from an OEM and six from an LSP, totalling twelve participants. While this sample is limited, it is considered appropriate for a mini dissertation, where depth of insight is prioritised over broad generalisation. Full saturation across all OEMs and LSPs is unlikely due to the limited organisational representation; however, saturation is expected within the context of the two organisations included, allowing for a meaningful exploration of differences in wind farm maintenance practices. This limitation is acknowledged, and the findings are presented as context-specific, offering rich qualitative data without claiming generalisability to all OEMs or LSPs.

Data validity was further supported through consistent interview procedures, detailed documentation, careful interpretation grounded in participants' responses, and transparency regarding the study's scope and limitations. As a limitation, full data saturation across all OEMs and LSPs is unlikely, due to the limited organisational representation; however, saturation is expected within the context of the two organisations included, allowing for a meaningful exploration of differences in wind farm maintenance practices. Time and resources were managed effectively to ensure completeness, considering factors that influence data saturation (Mwita, 2022:416-417):

- **Pre-determined codes and themes:** The literature review and theoretical framework provided a clear understanding of the expected data scope, guiding theme identification and helping to assess when saturation was reached.
- **Relevance of research participants:** Non-probability purposive sampling was used to select respondents most relevant to the study's objectives, enhancing the quality and richness of the data (see Section 3.7) collected.

Although complete objectivity is rarely attainable in business research, the researcher ensured confirmability by grounding the findings in the data rather than allowing personal values or theoretical assumptions to influence the results. In line with the principle of confirmability, which closely aligns with objectivity, the researcher demonstrated methodological transparency and maintained neutrality throughout the research process (Bryman & Bell, 2014:276).

Transferability refers to the extent to which the findings can be applied to other contexts or settings. As noted by Korstjens and Moser (2018: 122), this was achieved by providing a thick description—a detailed account of the research setting, participants, and processes—which allowed readers to assess the applicability of the findings to their own contexts.

Dependability in qualitative research refers to the consistency and reliability of the research process over time (Stahl & King, 2020:27). These authors highlight the following aspects of dependability:

- It involves ensuring that the study's findings are stable and can be replicated in similar contexts with similar participants.
- To enhance dependability, researchers should keep thorough documentation of the research design, data collection, and analysis processes, enabling others to audit or review the procedures followed.
- This transparency ensures that the interpretations and conclusions are firmly grounded in the data and not influenced by arbitrary decisions.
- Participant feedback and peer review are frequently employed to support the reliability of qualitative studies.

Consequently, this study supported dependability by maintaining thorough documentation of the research design, data collection, and analysis processes, enabling future review or replication. Participant feedback on the findings further ensured that interpretations and conclusions were firmly grounded in the original data, while transparency in reporting enhanced the overall reliability of the study.

In conclusion, this study adopted a comprehensive approach to ensure the trustworthiness of its qualitative findings by adhering to the key principles of credibility, confirmability, validity, transferability, and dependability. Ethical research conduct, participant validation (member checking), and careful attention to data saturation contributed to the accuracy, richness, and meaningfulness of the insights generated. Methodological transparency, purposive sampling, triangulation, and peer debriefing further strengthened the integrity of the study. Together, these strategies ensured that the findings are both reliable and contextually relevant, offering valuable contributions to the field of wind farm maintenance practices.

3.7 Data richness

Data richness was achieved through semi-structured interviews that encouraged participants to provide detailed accounts of their experiences and practices. Purposive sampling ensured that respondents were directly involved in maintenance operations, contributing relevant and insightful perspectives. The combination of multiple roles within each organisation, contrasting viewpoints between the OEM and LSP, and detailed contextual examples allowed for a nuanced and comprehensive exploration of differences in wind farm maintenance practices.

3.8 Ethical considerations

The study commenced only after obtaining approval from both the Scientific Committee (SCom) and the Research Ethics Committee (EMS-REC) of the NWU Business School, ensuring compliance with ethical standards and the protection of participants' rights. Informed consent was secured from all participants through a consent letter that clearly outlined the study's aims, methodology, and potential risks and benefits.

The researcher was guided by the principle of altruism, prioritising the well-being, dignity, and benefit of participants and society over personal or academic advancement (Engelbrecht *et al.*, 2018:2–3). Ethical principles applied in this study included:

- Ensuring participants' involvement contributed to positive change in policy, practice, or community benefits, such as improved service models, job creation, energy sustainability, or cost savings.
- Protecting vulnerable participants unless the research directly benefits them or their communities (Section 3.3.2).
- Maintaining confidentiality by not using proprietary or sensitive information without authorisation (Snyder, 2019b:11).
- Providing participants and stakeholders with a summary of findings in accessible language to show how their input contributed to broader societal benefits.

Data was collected through interviews and self-completion of the Interview Schedule by participants, with CAQDAS used to manage, code, and analyse the qualitative data efficiently, in consultation with NWU's statistical department. Ethical standards were maintained throughout all stages of the study, interviews, data analysis, and reporting, to ensure the integrity, transparency, and reliability of findings (Jol & Stommel, 2016:37; Rose & Johnson, 2020:15).

Participants and participating organisations were fully informed about the study, could seek clarification at any time, and were assured that their rights, well-being, and interests would be protected. The study was committed to sharing results in a clear format with those who could benefit, demonstrating transparency and accountability.

Key ethical principles applied were:

- **Informed Consent:** Participants signed a Letter of Consent, explained by a third party to ensure understanding and prevent coercion.
- **Confidentiality:** No proprietary or sensitive information was used without permission.
- **Transparency:** Findings were shared in an accessible format to show participants' contributions to positive change.

3.9 Contributions of the study

This research will advance maintenance theory by investigating the unique setting of wind energy and the dynamics between OEMs and LSPs. This study will examine how longer-term performance and lifecycle costing, influenced by the involvement of OEMs versus LSPs, may impact maintenance strategies and highlight differences from traditional industries. The proposed research will also explore the outsourcing debate in a capital-intensive and technologically advanced industry, which ties into more general theories on utilising specialised knowledge within complex projects. By investigating maintenance practices in a practical setting, the research will bridge the gap between theory and practice, providing evidence to support or reject existing frameworks related to maintenance, outsourcing, and OEM involvement. The research aims to identify potential risks associated with the two types of maintenance (OEM versus LSP) and the impact of these decisions on operations, thereby enhancing wind farms' risk management capabilities in delivering renewable energy.

Although exploratory factor analysis is typically quantitative, the coding process involved clustering themes and sub-themes that act as “factors” influencing maintenance performance. These factors include contractual structure and governance, technical skill levels, supply chain and parts availability, response times to breakdowns, and cost structure and long-term sustainability. These themes provided a structured basis for interpretation and helped frame the findings. These themes provided a structured basis for interpretation and helped frame the findings in chapter four.

3.10 Chapter summary

This chapter detailed the research methodology used to conduct a comparative analysis of maintenance practices between OEMs and LSPs in the South African wind energy sector. The study employed a qualitative research approach and an interpretivist paradigm to gain an in-depth understanding of the participants' experiences. The research design was exploratory, and a mono-method approach was utilised, combining a literature review with one-on-one, semi-structured interviews.

A cross-sectional time horizon was adopted, collecting data at a single point in time from twelve participants (six from OEMs and six from LSPs). A purposive sampling method was employed, targeting professionals with at least two years of experience in the field. This ensured that participants were knowledgeable and directly relevant to the research topic, with the goal of gaining an in-depth understanding rather than generalising to a larger population. Consequently, hypothesis testing was not applicable to this study.

The process of data collection, however, was not without challenges. Initial contact with potential participants began even before the formal ethics clearance number was issued, to prepare for the scheduling of interviews. While several participants committed early on during these conversations, delays soon emerged. It took approximately one week from the time of making the first appointment until the first successful interview was conducted. In several cases, participants who had initially agreed to take part postponed repeatedly, sometimes for more than two weeks, despite regular reminders every second day. Eventually, three of the twelve participants were only able to provide written responses, as they did not have the availability for live interviews via Microsoft Teams. These delays mirrored earlier struggles in obtaining the necessary authorisations to access the research setting, highlighting the persistence required to gain entry and participate in professional environments.

The data analysis process involved transcribing interviews and using ATLAS.ti software for thematic analysis. The study's trustworthiness was ensured through the application of credibility, transferability, dependability, and confirmability criteria, including the use of member checking. Finally, the chapter outlined the ethical considerations that guided the research, including informed consent and confidentiality, and highlighted the study's theoretical and practical contributions.

The next chapter presents the research findings and interprets them within the context of the literature and research objectives.

CHAPTER FOUR: EMPIRICAL STUDY AND FINDINGS

4.1 Introduction

This chapter presents and interprets the findings of the empirical investigation into wind farm maintenance practices in South Africa. The primary objective was to conduct a comparative evaluation of the roles, strengths, and weaknesses of OEMs and LSPs in delivering preventive, predictive, and corrective maintenance. The chapter draws on qualitative data collected through semi-structured interviews with twelve participants representing both stakeholder groups, which were analysed using Atlas.ti as a computer-assisted qualitative data analysis software (CAQDAS).

The analysis was guided by the study's research questions and objectives, with a focus on understanding how maintenance models differ, what factors shape their effectiveness, and how these differences affect the sustainability and cost-effectiveness of South Africa's wind energy sector. Themes emerging from the analysis are presented thematically, supported by direct quotations where applicable, to provide a rich, evidence-based interpretation.

4.2 Participant demographics

The achieved sample confirms the participation of 12 individuals, evenly divided between OEMs and LSPs, thereby validating the balanced representation outlined in chapter three and enabling meaningful comparative insights.

Table 4.1 shows that participants representing OEMs typically held senior positions, including engineers, service managers, and technical directors. Their expertise reflected the specialised and technically complex nature of OEM operations, particularly in areas requiring proprietary knowledge, access to advanced diagnostic tools, and responsibility for warranty-bound interventions.

By contrast, LSP participants occupied more hands-on and operational roles, including technicians, supervisors, and operations managers. This demographic profile underscores the practical and site-level strengths of LSPs, whose value lies in their ability to respond quickly, mobilise locally, and contribute to skills development within the surrounding communities.

This demographic profile illustrates the natural hierarchy between OEM and LSP service models in South Africa, where OEMs dominate complex and warranty-bound interventions while LSPs form the operational backbone for day-to-day responsiveness.

Table 4.1: Organisation of participants and their job descriptions

Participant	Role	Position/Function
Participant 1	LSP	Technician – Routine & Corrective Maintenance
Participant 2	LSP	Maintenance Supervisor – Preventative Maintenance
Participant 3	LSP	Operations Manager
Participant 4	LSP	Technician – Corrective Repairs & Inspections
Participant 5	LSP	Senior Technician – Preventative & Fault Response
Participant 6	OEM	Senior Engineer – Condition Monitoring
Participant 7	LSP	Technician – On-site Maintenance
Participant 8	OEM	Regional Service Manager
Participant 9	OEM	Engineer – Diagnostics & Predictive Systems
Participant 10	OEM	Technical Director – OEM Services
Participant 11	OEM	Service Manager
Participant 12	OEM	Service Contract Manager

4.3 Qualitative results

4.3.1 Introduction

This section presents a thematic analysis of the qualitative data collected to assess and compare the operational performance, cost efficiency, and strategic contributions of OEMs and LSPs in South Africa’s wind farm maintenance sector. The analysis identifies ten key themes that form the basis for interpreting the findings, highlighting the complex interaction between technical expertise, service delivery, client perceptions, and sustainability considerations. The themes reflect a broad spectrum of factors influencing maintenance practices. These themes were further organised into sub-themes, enabling a detailed analysis of differences between OEM and LSP models.

4.3.2 Themes identified

The data analysis identified ten key themes and corresponding sub-themes, which provided the framework for interpreting the findings. These themes captured the core dimensions through which the comparative performance of OEMs and LSPs was evaluated. They included:

- 1 **Scope of services** – Range and depth of maintenance activities performed.
- 2 **Technical expertise** – Skills, qualifications, and access to proprietary knowledge.
- 3 **Cost efficiency** – Pricing models and cost drivers.
- 4 **Responsiveness** – Speed and reliability of fault resolution.
- 5 **Predictive and preventive maintenance capabilities** – Tools and practices for anticipating failures.
- 6 **Client trust and perception** – How clients perceive each provider in terms of reliability and competence.
- 7 **Localisation and capacity building** – Extent of local skills integration and training.
- 8 **Lifecycle relevance** – Suitability of services across turbine lifecycle stages (warranty vs. post-warranty).
- 9 **Collaboration potential** – Opportunities and barriers for hybrid models.
- 10 **Sustainability impact** – Contribution to long-term operational and environmental sustainability.

Table 4.2 and Figure 4.1 collectively present the emergent themes and their relative emphasis based on the number of quotations extracted during coding. Table 4.2 provides a structured overview of each theme, outlining the scope, descriptions, and relevant sub-themes that form the analytical framework. Figure 4.1 complements this by visually illustrating the frequency of references across themes, thereby indicating the relative weight participants placed on specific issues. For example, “Strengths and weaknesses of maintenance models” (22 quotations) and “Recommendations for improving wind farm maintenance” (20 quotations) emerged as dominant themes, while “Regulatory and contractual influences” (10 quotations) received less emphasis. Taken together, the table establishes the analytical categories, and the figure demonstrates their significance in practice, creating a sequential flow from defining the current

landscape to identifying areas for future improvement.

The distribution reflects strong emphasis on technical expertise, cost efficiency, and responsiveness, three domains where participants reported the most pronounced differences between OEM and LSP performance.

Table 4.2: Emergent themes in wind farm maintenance

Theme	Description	Sub-theme
Theme 1: Scope of maintenance services	Examines the range of maintenance tasks handled by OEMs (full-spectrum, warranty-backed services) versus LSPs (routine, corrective, and reactive maintenance).	1.1 Types of services performed
Theme 2: Strengths and weaknesses of maintenance models	Identifies comparative advantages and limitations of OEM and LSP approaches, focusing on cost, expertise, flexibility, and access to technology.	2.1 Strengths 2.2 Weaknesses
Theme 3: Performance monitoring and evaluation	Explores the tools, metrics, and reporting mechanisms used by OEMs and LSPs to track turbine performance and service effectiveness.	3.1 Monitoring tools and KPIs
Theme 4: Impact on turbine availability and energy output	Assesses how OEMs and LSPs contribute to uptime, energy production, and identifies challenges such as logistical delays or restricted access to data.	4.1 Contribution to availability 4.2 Barriers to maximising output
Theme 5: Cost drivers and cost efficiency	Analyses the main cost elements in each model (labour, tools, parts, logistics) and compares cost-effectiveness between OEMs and LSPs.	5.1 Key cost drivers 5.2 Comparative cost efficiency
Theme 6: Use of predictive maintenance and	Investigates the role of SCADA, diagnostics, and predictive systems in OEM models versus the preventative/manual approaches	6.1 Adoption of predictive systems 6.2 Barriers to digital

digital tools	used by LSPs.	adoption
Theme 7: Regulatory and contractual influences	Examines the impact of long-term OEM contracts, short-term LSP agreements, and compliance with international versus local regulations.	7.1 Contractual frameworks 7.2 Regulatory environment
Theme 8: Sustainability, localisation, and skills development	Evaluates contributions of OEMs and LSPs to local job creation, skills transfer, and broader sustainability goals in the wind sector.	8.1 Local skills and employment 8.2 Long-term sustainability
Theme 9: Client perceptions (OEM vs LSP)	Captures how clients view OEMs and LSPs in terms of trust, reliability, cost, and service quality across different turbine lifecycle phases.	9.1 Perceived reliability and trust 9.2 Client preferences
Theme 10: Recommendations for improving wind farm maintenance	Discusses the stakeholder recommendations to improve maintenance, highlighting opportunities for collaboration, localisation, and skills development.	10.1 Suggested improvements by OEMs 10.2 Suggested improvements by LSPs

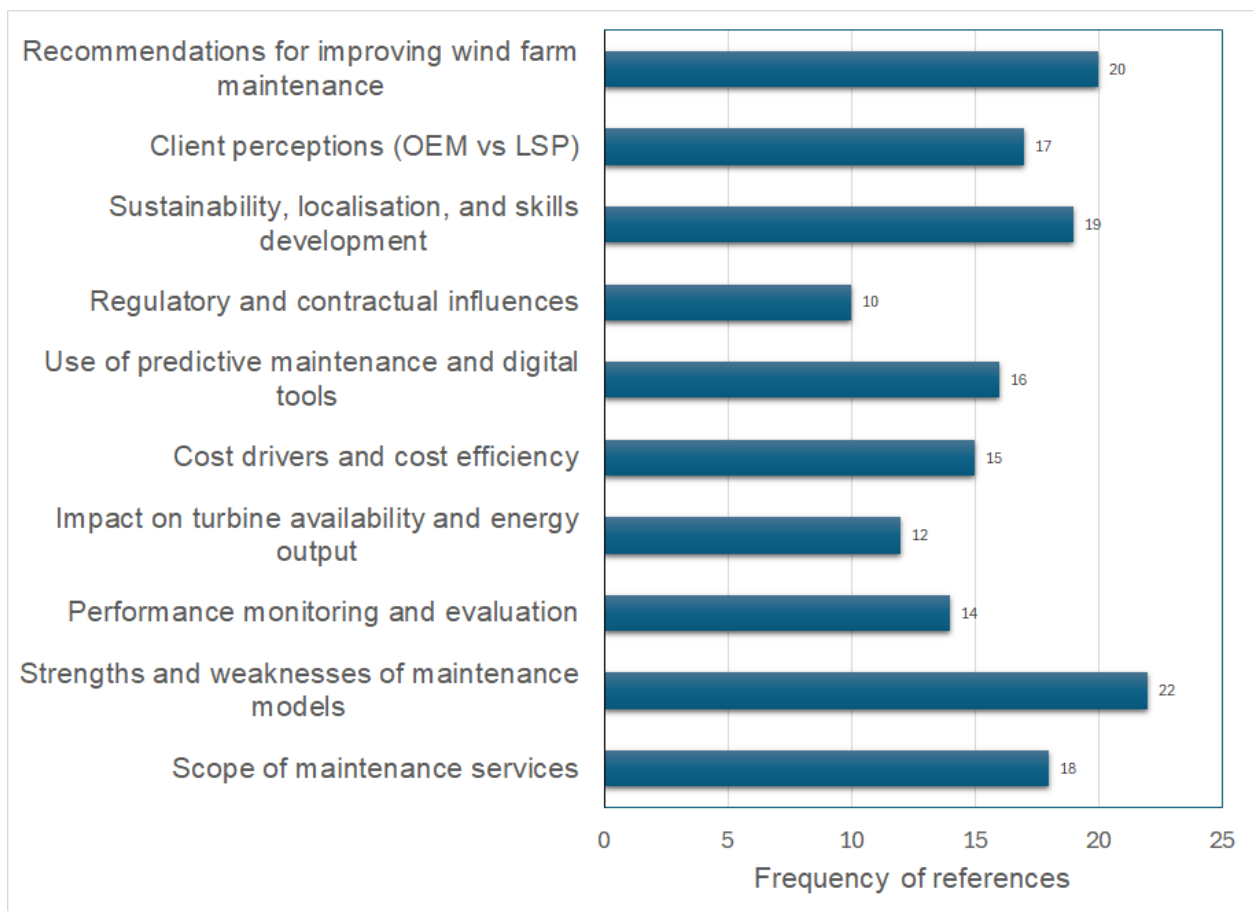


Figure 4.1: Key themes forming the framework for interpreting the findings

4.3.3 Interpretation of wind farm maintenance practices

The thematic analysis revealed a clear lifecycle-based dynamic in the sector: OEMs are dominant during the warranty period due to their technical exclusivity and warranty-linked obligations, whereas LSPs gain a competitive edge in the post-warranty period, primarily due to cost pressures and the need for rapid, localised response. The following themes are related to wind farm maintenance practices:

Theme 1. Scope of maintenance services

OEM participants consistently described their role as comprehensive, covering both routine and complex maintenance tasks. Their responsibilities extend across the turbine lifecycle, supported by proprietary diagnostic systems and warranty agreements. One participant explained, “As OEMs, we handle everything from blade inspections to gearbox replacements. Clients expect full coverage under our long-term service agreements, especially during warranty periods” (Participant 6).

By contrast, LSPs reported a narrower scope, largely focused on routine upkeep and corrective repairs. Their work concentrated on inspections, consumables replacement, and fault response. As one technician noted, *“As a local provider, we mostly cover routine maintenance like visual inspections, oil changes, and torquing bolts. Major component replacements are usually handled by OEMs, but we sometimes assist them”* (Participant 1).

The findings demonstrate that, while OEMs provide a “full-service” model, LSPs contribute by ensuring operational continuity at the site level. Together, these complementary roles shape the maintenance ecosystem, with OEMs dominating high-complexity tasks and LSPs providing day-to-day operational support.

Themes 3 + 4. Cost Efficiency and Responsiveness

OEM participants acknowledged that their services are often costlier, largely due to proprietary parts, global supply chain structures, and specialised expertise. One manager admitted, *“Clients often raise concerns about high service fees, especially when delays occur because parts are not readily available locally”* (Participant 10). While clients valued the reliability and advanced diagnostics that accompany OEM contracts, the financial burden was seen as a limiting factor for long-term sustainability, particularly once turbines moved beyond their warranty period.

By contrast, LSPs highlighted affordability and rapid mobilisation as their competitive strengths. Their cost models were often leaner, supported by local sourcing and smaller operational overheads. One respondent explained, *“Our biggest advantage is cost and speed. Because we’re close to the farms, we can send a team out the same day, which helps minimise downtime”* (Participant 3). However, participants also conceded that lower costs sometimes came at the expense of advanced fault detection and consistency.

The findings indicate a clear trade-off: OEMs provide costlier but technically comprehensive solutions, while LSPs deliver more affordable, responsive services suited to immediate operational needs. Together, these contrasting approaches shape the decision-making of wind farm operators, who must balance budgetary constraints with the demand for reliability.

Themes 5 + 10: Predictive/Preventive Maintenance and Sustainability Impact

OEM participants emphasised predictive maintenance as central to their value proposition. Their use of SCADA-integrated diagnostic systems and data analytics was repeatedly described as reducing downtime and extending component lifespan. As one engineer explained, *“Predictive analytics is built into our contracts. It allows us to identify issues before they become failures,*

which saves costs over time” (Participant 6).

By contrast, LSPs reported reliance on preventive approaches such as scheduled inspections, consumables replacement, and oil analysis. One technician noted, *“We don’t have access to advanced diagnostic platforms, so our work is still preventative rather than predictive”* (Participant 1). This limited their ability to proactively manage failures, reinforcing dependence on OEMs for high-tech optimisation.

From a sustainability perspective, OEMs highlighted lifecycle extensions achieved through predictive tools, while LSPs emphasised reduced carbon footprints due to localised supply chains and workforce presence. The findings suggest a complementary balance: OEMs drive technological sustainability, whereas LSPs strengthen localised and environmental sustainability by reducing travel, import dependence, and community exclusion.

Themes 2 + 6: Technical Expertise and Client Trust/Perception

OEMs consistently underscored their technical depth, citing access to proprietary turbine data, original parts, and specialised training. One manager observed, *“Because we designed the turbines, clients trust us with the complex work. They know we can guarantee quality”* (Participant 9). This reputation fostered high levels of client trust during the warranty period, despite concerns about cost.

LSPs, in contrast, emphasised practical skills, field experience, and contextual knowledge of local operating conditions. A technician explained, *“We might not have the OEM systems, but we know the terrain, we know the farms, and clients value that familiarity”* (Participant 4). Clients often viewed LSPs as more approachable and flexible, though doubts persisted about their consistency and diagnostic capacity.

The findings suggest that technical exclusivity drives trust in OEMs, while personal relationships and local embeddedness generate trust in LSPs. These divergent bases of credibility significantly shape how clients perceive long-term reliability.

Themes 7 + 8: Localisation, Capacity Building, and Lifecycle Relevance

OEM participants acknowledged limited local capacity building during the warranty phase, as most technical expertise remained concentrated within global networks. One respondent conceded, *“We bring in specialist teams from abroad when major repairs are needed, which sometimes frustrates local partners”* (Participant 7).

LSPs, by contrast, highlighted their role in skills development and job creation. One supervisor explained, *“We employ and train local technicians, so the skills stay in the community”* (Participant 2). Their embeddedness within the local labour market was framed as both a social and economic benefit.

Lifecycle stage also influenced provider selection. OEMs remained indispensable during the warranty period, when technical exclusivity prevailed, but LSPs gained ground post-warranty. As one manager summarised, *“OEMs dominate early on, but cost pressure and localisation targets mean clients shift to LSPs later”* (Participant 8).

These findings show that OEMs sustain technical control early in the turbine lifecycle, while LSPs strengthen local capacity and continuity in later phases.

Theme 9: Collaboration Potential

Both OEM and LSP participants recognised potential benefits of collaboration, particularly in balancing cost, responsiveness, and technical expertise. One OEM manager commented, *“There are times when we subcontract LSPs for urgent work because they’re already nearby”* (Participant 9). Similarly, LSPs reported opportunities to provide site-level support under OEM guidance, effectively blending strengths.

However, structural barriers remained significant. OEMs cited intellectual property protection and risk management as obstacles, while LSPs pointed to the lack of access to proprietary diagnostic systems. One technician expressed frustration: *“We’re willing to collaborate, but without access to the data, we’ll always be second-tier partners”* (Participant 5).

The findings suggest that hybrid models offer promise for cost-effective and sustainable maintenance, but effective collaboration depends on striking a balance between proprietary control and local empowerment.

4.3.4 Alignment of thematic findings with the primary objective

The thematic findings align closely with the primary objective by providing a structured comparison of OEM and LSP maintenance outcomes across dimensions of effectiveness, cost-efficiency, and operational performance. Themes such as the scope of services, technical expertise, and predictive maintenance capabilities highlight the effectiveness of OEMs in delivering comprehensive, technologically advanced solutions, while responsiveness, cost efficiency, and localisation reflect the strengths of LSPs in offering affordable, flexible, and context-specific services. At the same time, themes addressing client trust, lifecycle relevance,

and sustainability underscore the broader operational and strategic trade-offs between the two models. Together, these insights enable a holistic evaluation of how OEMs and LSPs differ in practice, directly supporting the study’s primary objective of comparing their contributions to wind farm maintenance in South Africa.

4.3.5 Mapping themes against secondary objectives

To ensure coherence between the study’s aims and its findings, the themes generated through the qualitative data analysis were mapped against the secondary research objectives. This alignment demonstrates how each objective is addressed within the thematic structure, showing the relationship between the intended scope of inquiry and the empirical insights gained. Table 4.3 presents this alignment, highlighting which themes correspond to each objective and clarifying the specific ways in which stakeholder perspectives, operational practices, and strategic considerations inform the study’s outcomes.

Table 4.3: Alignment of secondary objectives with thematic findings

Secondary objective	Linked themes	Key insight
1. To identify the key factors influencing the choice between OEMs and LSPs	Theme 1: Scope of services Theme 2: Technical Expertise Theme 3: Cost efficiency Theme 4: Responsiveness Theme 8: Lifecycle relevance	Provider choice depends on service range, depth of expertise, affordability, response times, and suitability across warranty/post-warranty phases.
2. To analyse stakeholder perceptions of reliability and responsiveness	Theme 2: Technical expertise Theme 4: Responsiveness Theme 6: Client trust and perception	Reliability is linked to OEM expertise, while responsiveness is linked to LSP proximity and flexibility. Client trust reflects the balance between technical assurance and service accessibility.
3. To determine the role of data-driven maintenance practices	Theme 5: Predictive & preventive maintenance capabilities Theme 10: Sustainability impact	OEMs dominate predictive maintenance using SCADA systems, while LSPs rely on preventive/manual methods. Predictive tools reduce downtime

		and enhance sustainability.
4. To evaluate the long-term sustainability and localisation potential	<p>Theme 7: Localisation & capacity building</p> <p>Theme 8: Lifecycle relevance</p> <p>Theme 9: Collaboration potential</p> <p>Theme 10: Sustainability impact</p>	<p>OEMs support technological sustainability; LSPs strengthen localisation and capacity building.</p> <p>Hybrid models offer the potential to balance efficiency, cost, and sustainability goals.</p>

The alignment illustrates that the themes are not isolated but interdependent, collectively addressing the study’s research problem. For example, themes relating to the scope of services, technical expertise, and cost efficiency directly inform secondary objective 1 by clarifying the factors that influence the choice between OEMs and LSPs. Similarly, stakeholder perceptions of reliability, responsiveness, and trust correspond with secondary objective 2, while predictive maintenance capabilities directly address secondary objective 3. Finally, themes of localisation, lifecycle relevance, collaboration, and sustainability provide insights for secondary objective 4, highlighting broader implications for long-term industry development. Together, this mapping confirms that the thematic analysis captures the full range of issues central to the research objectives, strengthening the coherence and credibility of the study’s findings.

4.3.6 Comparison of advantages and challenges of OEM services

A structured comparison of the strengths and weaknesses of OEMs and LSPs is provided in Table 4.4. The data show that each model exhibits distinct advantages and limitations, which influence client choices depending on turbine age, contractual commitments, and financial priorities.

OEMs were widely regarded as the more technically reliable option due to:

- Exclusive access to proprietary diagnostic tools, software, and original parts.
- Advanced predictive maintenance capabilities that reduce unplanned downtime.
- Warranty integration, which ensures accountability during early operational phases.

However, OEM services also came with significant drawbacks:

- High service fees driven by skilled labour, proprietary parts, and global supply chain costs.
- Centralised decision-making often causes slower response times.
- Rigid contractual terms, with long durations and limited flexibility.

LSPs, by contrast, excelled in:

- Affordability, with more competitive pricing structures.
- Flexibility and responsiveness, often deploying technicians within hours.
- Stronger local presence, enabling tailored services and quicker mobilisation.

Their limitations, however, included:

- Restricted access to OEM data and proprietary tools, constraining their ability to conduct complex repairs.
- Lower perceived technical authority, particularly for high-risk interventions.
- Limited training pipelines, which hinder upskilling in advanced diagnostics.

The findings confirm an explicit lifecycle dependency: clients tend to favour OEMs during warranty phases, shifting to LSPs post-warranty as cost considerations outweigh the perceived technical risks. However, LSPs face significant challenges, particularly their restricted access to OEM-controlled systems and advanced diagnostic tools. This limits their ability to handle high-risk or complex repairs, sometimes undermining client confidence in their technical expertise (SKYSPECS, 2023:9).

This comparison highlights a complementary relationship rather than a purely competitive one: OEMs dominate where technical certainty is paramount, while LSPs thrive where agility and cost-efficiency are valued.

Table 4.4: Comparative strengths and weaknesses of OEMs and LSPs

KPI	OEMs	LSPs
Key strengths	Technical expertise, advanced predictive tools, warranty assurance, and reliability	Affordability, flexibility, faster response times, local presence
Key weaknesses	High costs, long-term contracts, centralised decision-making, and slower response times	Limited access to OEM proprietary tools, lower client perception of technical expertise for complex repairs
Cost drivers	Highly skilled labour, proprietary parts and software, and specialised equipment	Labour, transport, safety compliance training
Client perception	Trusted and reliable for warranty-backed services	Cost-effective but seen as secondary in technical expertise

4.3.7 Future role improvements and recommendations

Participants proposed several strategies to improve the wind energy maintenance landscape:

- Hybrid service models: OEM participants supported models where routine maintenance is delegated to LSPs while OEMs retain control of high-level tasks, reducing operational costs and improving fault response times.
- Controlled access to diagnostic platforms: Shared, limited-access digital systems could empower LSPs without exposing OEM intellectual property (WindEurope, 2020:22).
- Training and certification programmes: LSP participants emphasised the need for OEM-led training initiatives, technical documentation sharing, and joint certification schemes to build trust and capacity.

- Contractual reforms: Encouraging joint ventures, subcontracting, and skills-transfer clauses could strengthen the local supply chain and promote economic localisation (Kostka & Anzinger, 2020:14).

Both stakeholder groups acknowledged that a more collaborative ecosystem would benefit the sector by balancing cost-efficiency with technical integrity.

Overall, the recommendations reflect a shared recognition that the future of South Africa's wind farm maintenance industry lies not in exclusive competition but in synergistic partnerships. By combining OEMs' technical depth with LSPs' cost efficiency and responsiveness, the sector can achieve more sustainable long-term outcomes.

4.4 Discussions of findings

The purpose of this section is to interpret the findings in relation to the study's primary and sub-research questions, while linking them to the literature reviewed in chapter two. The discussion highlights where the results converge with- or diverge from prior research and outlines practice-oriented recommendations.

4.4.1 Primary research question: How do OEMs and LSPs compare in terms of effectiveness, cost-efficiency, and operational performance in the maintenance of wind farms in South Africa?

The findings reveal that OEMs are widely perceived as technically authoritative, particularly in high-risk diagnostics and warranty-bound interventions, due to their proprietary access to software, spare parts, and structured preventive maintenance protocols. However, their services are costly and characterised by slower response times linked to global supply chains and centralised decision-making.

By contrast, LSPs were seen as more flexible, affordable, and responsive, with the ability to mobilise within hours. Yet, their limited access to OEM diagnostic platforms and restricted training opportunities constrained their ability to perform advanced repairs. These dynamics mirror findings that OEMs provide certainty at higher cost, while LSPs offer competitive affordability but face structural barriers to technical depth (Wiser *et al.*, 2019:15).

The comparison confirms a trade-off that OEMs maximise technical reliability and warranty assurance, while LSPs deliver agility and cost efficiency, especially post-warranty. A hybrid model appears to be the most pragmatic solution.

4.4.2 Sub-research question 1: How do OEMs and LSPs use predictive or data-driven maintenance practices, and what is their impact on cost-efficiency and performance?

Participants indicated that OEMs employ advanced predictive tools such as SCADA integration and condition-monitoring sensors, which directly reduce downtime and improve cost-efficiency through early fault detection. LSPs, however, reported limited predictive capacity due to a lack of access to OEM-owned platforms and data. This aligns with WindEurope's (2020:22) observation that predictive analytics remain OEM-driven because of intellectual property restrictions.

4.4.3 Sub-research question 2: What are the long-term implications for sustainability and localisation when relying on OEMs as opposed to LSPs in wind farm maintenance?

Respondents stressed that LSP participation promotes local employment, capacity-building, and economic empowerment. However, insufficient training pipelines risk capping their technical development. The literature echoes this concern: Kostka and Anzinger (2020:14) highlight localisation as a sustainability driver but note that inadequate skills-transfer mechanisms hinder progress in emerging renewable markets.

4.4.4 Sub-research question 3: How do OEMs and LSPs compare in terms of operational performance indicators such as downtime, fault resolution rates, response times, parts availability, and logistical efficiency?

Findings from interviewees revealed a dual pattern. LSPs consistently outperformed OEMs on response time due to proximity and flexibility, but struggled with complex repairs requiring proprietary diagnostics or imported parts. OEMs, in contrast, were slower to mobilise but achieved higher fault-resolution success once on site. These findings align with Wisser *et al.* (2019:14-15), who noted that the mean time to repair (MTTR) tends to be longer under OEM models because of globalised supply chains. Conversely, LSPs can shorten mobilisation delays, although they may have limited capacity for resolving complex faults.

4.4.5 Sub-research question 4: What impact does the provider type have on long-term asset reliability and turbine lifespan, and how are these outcomes influenced by local presence, supply chain structures, and workforce skills?

Participants linked OEM stewardship with higher confidence in turbine lifespan and reliability, particularly in the first five to ten years. However, when LSPs were supported with training and longer-term contracts, they could maintain similar reliability standards. Zhao *et al.* (2017:1156) confirm that predictive maintenance access, workforce expertise, and supply-chain resilience are more decisive than provider type alone in determining long-term reliability.

4.4.6 Sub-research question 5: How do regulatory frameworks, contractual agreements, and workforce capabilities shape the comparative effectiveness of OEMs and LSPs?

OEM contracts were described as long-term and rigid, protecting proprietary systems but limiting LSP involvement. LSP contracts were more flexible but often too short to justify significant investment in advanced tools or training. This converges with Kostka and Anzinger (2020:16), who noted that contractual structures in renewable industries often determine whether local suppliers can scale their technical capabilities.

4.5 Convergence and divergence with literature

Convergence: The study confirms established findings that OEMs dominate warranty periods while LSPs provide competitive, localised solutions post-warranty. Both empirical data and literature stress that lack of data access and rigid contracts are significant barriers for LSP advancement (WindEurope, 2020:22; Kostka & Anzinger, 2020:14).

Divergence/Nuance: The interviews placed a stronger emphasis on the operational agility of LSPs, especially their same-day mobilisation capacity, than the literature. Conversely, OEM-related supply-chain delays were highlighted as a greater performance bottleneck in South Africa than in some international studies (Zhao *et al.*, 2017: 1176).

4.6 Recommendations

- Hybrid service models: Adopt performance-based contracts where OEMs retain responsibility for complex, high-risk tasks while LSPs manage routine and first-response maintenance.
- Controlled data-sharing: Develop role-based access to SCADA/digital-twin systems to empower LSPs without compromising OEM intellectual property (WindEurope, 2020).

- Accredited training pipelines: Establish OEM-led, multi-brand certification programmes to raise LSP competence in diagnostics and high-risk maintenance (Kostka & Anzinger, 2020).
- Local spares strategies: Implement vendor-managed inventories and refurbishment channels within South Africa to reduce MTTR and supply-chain delays (Abderrahmane *et al.*, 2022:938).
- Contractual reforms: Encourage joint ventures, subcontracting, and skills-transfer clauses in OEM contracts to foster localisation and workforce sustainability.

4.7 Conclusions

The qualitative results, supported by the literature, highlight that maintenance strategies lie at the heart of wind farm performance and investment returns, with indicators such as availability, capacity factor, and energy production serving as the key benchmarks. The analysis confirms that OEMs remain indispensable during warranty periods and for servicing complex components, yet their contractual rigidity and supply-chain delays often constrain operational efficiency. By contrast, LSPs demonstrate agility and local responsiveness, offering tangible benefits in reducing downtime after the warranty period. However, their advancement is hindered by barriers such as data access limitations and restrictive contracts. Taken together, these findings emphasise that the balance between OEM dominance and LSP agility directly influences both operational sustainability and competitiveness in South Africa's wind sector. This discussion, therefore, provides the foundation for the concluding chapter, which reflects on the implications of these insights for industry stakeholders and future research.

4.8 Chapter summary

This chapter presented the qualitative findings of the study, offering a comparative analysis of OEM and LSP maintenance services in South Africa's wind energy sector. The results revealed a complementary dynamic: OEMs dominate in areas requiring advanced expertise and proprietary access, while LSPs offer cost-effective, responsive, and localised solutions, particularly post-warranty. A clear pattern emerged: OEM reliance is high during the warranty period, after which LSPs become the preferred option for cost-conscious operators.

The chapter also highlighted that the future of wind farm maintenance in South Africa may lie in hybrid models that integrate OEM expertise with LSP flexibility and localisation benefits, provided appropriate training, data-sharing, and contractual reforms are introduced. Taken

together, these findings emphasise that the balance between OEM dominance and LSP agility directly influences both operational sustainability and competitiveness in South Africa's wind sector. Therefore, this discussion provides the foundation for the concluding chapter, which reflects on the implications of these insights for industry stakeholders and future research.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter synthesises the study's findings, concluding both the literature review and the empirical research. It also presents recommendations for industry stakeholders, highlights the limitations of the study, demonstrates how the research objectives were achieved and concludes with a chapter summary

5.2 Findings

5.2.1 Findings from the literature study

The literature indicates that South Africa's wind energy sector is currently shaped by a reliance on OEMs during the early lifecycle of wind farms, driven by their technical expertise, access to proprietary data, and warranty-backed services. While OEMs ensure reliability, LSPs present significant opportunities for cost reduction, operational flexibility, and localisation benefits, particularly after warranty periods. Lessons from international markets suggest a gradual shift toward hybrid models, combining OEM oversight with LSP implementation to optimise performance and reduce costs. Across all contexts, critical themes such as cost efficiency, skills transfer, knowledge barriers, technological access, and long-term sustainability underscore the importance of strategically balancing OEM and LSP roles to support the growth, resilience, and localisation of South Africa's wind energy sector.

5.2.2 Findings from the empirical study

- Interview responses confirmed a firm reliance on OEMs during the warranty period.
- Operators expressed increasing confidence in LSPs post-warranty, citing lower costs and quicker responsiveness.
- A significant concern with LSPs was limited access to technical upgrades, spare parts, and specialised diagnostic tools.
- Stakeholders noted the potential of partnerships between OEMs and LSPs to balance expertise with cost efficiency.
- Local employment and skills development emerged as an added advantage of LSP utilisation, aligning with South Africa's socio-economic priorities.

5.3 Conclusions

The study concludes that OEMs and LSPs serve complementary, rather than competing, roles in wind farm maintenance. While OEMs provide irreplaceable technical depth and access to innovation, LSPs strengthen localisation, reduce costs, and ensure sustainability beyond the warranty phase. The optimal strategy for South Africa involves integrated approaches that leverage both entities.

5.4 Recommendations

- Based on the results of this study, the following recommendations are made:
- Adopt a hybrid maintenance strategy: Operators should combine OEM expertise with LSP flexibility for long-term sustainability.
- Invest in LSP capacity building: Training, certification, and technology transfer should be encouraged to reduce reliance on OEMs.
- Policy and regulatory support: Government frameworks should incentivise localisation while ensuring compliance with international technical standards.
- Promote partnerships: Encourage collaboration between OEMs and LSPs to share knowledge and develop joint maintenance solutions.
- Future research: Further studies should explore long-term cost trajectories and quantify the economic impact of LSP-driven localisation.

5.5 Shortcomings of the study

- The study was limited to a small sample size due to the difficulty in obtaining willing participants from other OEMs and LSPs, as well as the nature of the qualitative design.
- Findings may not be generalisable across all renewable sectors or geographies since only one OEM and one LSP were able to permit the study.
- Reliance on interviewee perspectives introduces subjectivity.
- Lack of access to specific proprietary OEM data restricted comparative financial analysis.

5.6 Meeting research objectives

Primary objective: The primary objective of this study is to evaluate and compare the effectiveness, cost-efficiency, and operational performance of OEMs and local service providers in the maintenance of wind farms in South Africa.

Achievement of the objective. The qualitative study, based on semi-structured interviews with key stakeholders and supported by a literature review, yielded insights into the operational, cost, and strategic differences between OEMs and LSPs. The thematic findings support the primary objective by comparing OEM and LSP maintenance in terms of effectiveness, cost efficiency, and operational performance. OEMs excel in technical expertise and comprehensive solutions, while LSPs offer flexibility, affordability, and localisation. Broader themes such as client trust, lifecycle relevance, and sustainability highlight strategic trade-offs, enabling a holistic evaluation of their contributions to wind farm maintenance in South Africa.

Secondary objectives:

- 1 To identify the key factors influencing the choice between OEMs and LSPs for wind farm maintenance in South Africa.

Achievement of the objective. The literature review highlighted cost, access to proprietary technology, contractual obligations, and localisation requirements as critical determinants. Empirical findings confirmed these factors, with stakeholders emphasising cost-efficiency, response times, and availability of technical expertise as the main influences in provider selection.

- 2 To analyse stakeholder perceptions (e.g., wind farm owners, technicians, and managers) of the reliability and responsiveness of OEMs versus LSPs.

Achievement of the objective. Semi-structured interviews provided first-hand perspectives on reliability and responsiveness. Stakeholders reported that OEMs were perceived as highly reliable due to their access to original parts and advanced tools, whereas LSPs were seen as more responsive and flexible, especially in remote areas; however, concerns about consistency and quality control remained.

- 3 To determine the role of data-driven maintenance practices (e.g., predictive maintenance) in enhancing cost-efficiency and operational performance.

Achievement of the objective. Insights from both the literature and interviews revealed that predictive- and condition-based maintenance are underutilised in South Africa, particularly

by LSPs, due to limited resources. OEMs were noted to incorporate more advanced data-driven diagnostics, but these practices remain constrained by high costs and limited local application.

- 4 To evaluate the long-term sustainability and localisation potential of relying on local service providers versus OEMs.

Achievement of the objective. Literature showed that LSPs contribute significantly to localisation, job creation, and skills transfer, aligning with South Africa's developmental goals. Empirical findings supported this, as participants confirmed that increased reliance on LSPs fosters local capacity and sustainability, although long-term sustainability is limited without greater investment in training, certification, and access to OEM technologies.

The study achieved its primary objective of assessing and comparing the effectiveness, cost-efficiency, and operational performance of OEMs and LSPs in South African wind farm maintenance, finding that OEMs provide greater technical expertise, reliability, and advanced diagnostics, while LSPs offer flexibility, affordability, and stronger localisation benefits. The secondary objectives were also met by identifying key factors influencing provider selection, such as cost, proprietary technology, contractual obligations, and localisation needs, and demonstrating that stakeholders value OEMs for reliability and quality. In contrast, LSPs are preferred for responsiveness and adaptability despite concerns about consistency. Additionally, predictive and condition-based maintenance were found to be underused, and LSPs support sustainability through job creation and skills transfer; however, the long-term advantages require greater investment in training, certification, and access to OEM technologies.

5.7 Chapter summary

This chapter synthesised the findings of the study, drawing conclusions from both the literature review and the empirical research. The results highlighted that OEMs dominate maintenance during the warranty phase due to their technical expertise, proprietary access, and reliability. In contrast, LSPs contribute significantly during the post-warranty phase through cost-efficiency, responsiveness, and localisation benefits. Notably, the study established that OEMs and LSPs function as complementary, rather than competing, actors in the South African wind energy sector.

The conclusions confirmed that hybrid models, which combine OEM technical expertise with LSP adaptability, represent the most sustainable strategy for operators. Recommendations were provided to guide stakeholders, emphasising capacity building, regulatory support, and

collaborative partnerships. Shortcomings of the study were acknowledged, particularly the limited sample size, qualitative focus, and restricted access to OEM data, which may limit the generalisability of findings.

The chapter also demonstrated how the research objectives were met, with both the primary- and secondary objectives successfully addressed through the integration of literature insights and empirical evidence.

As the closing chapter of this dissertation, chapter five underscores the contribution of this research to both theory and practice. It provides industry stakeholders with insights into optimising maintenance models while aligning with South Africa's localisation and sustainability priorities, and it sets a foundation for further academic exploration into hybridised renewable energy maintenance frameworks.

REFERENCES

Abderrahmane, F., Bouslikhane, S., Hajej, Z., Dellagi, S. & Trabelsi, W. 2022. An improved integrated maintenance/spare parts management for wind turbine systems with adopting switching concept. *Energy Reports*, 8:936-955

African Energy Council. 2022. *Enel Green Power South Africa commissions 140MW wind farm*. https://africanenergycouncil.org/enel-green-power-south-africa-commissions-140mw-wind-farm/?utm_source=chatgpt.com Date of access: 9 June 2025.

Africa Energy Portal. 2022. *SOUTH AFRICA: EDF signs power purchase agreements for three wind farms*. <https://africa-energy-portal.org/news/south-africa-edf-signs-power-purchase-agreements-three-wind-farms> Date of access: 11 June 2022.

AP News. 2024. *2023 was a record year for wind installations as the world ramps up clean energy* report says. <https://apnews.com/article/energy-global-wind-report-2024-74dd788b62c429edd004332808440b60>. Date of access: 7 June 2025.

Arsenova, M. & Wlokas, H.L. 2019. *Local Benefit Sharing in Large-Scale Wind and Solar Projects*. International Finance Corporation. https://commdev.org/wp-content/uploads/2019/06/IFC-LargeScaleWindSolar_Web.pdf . Date of access: 5 May 2025.

Aspers, P. & Corte, U. 2019. What is qualitative in qualitative research? *Qualitative Sociology*, 42(2):599-608.

AWEA, 2017. *Operations and Maintenance Recommended Practices*. <https://www.awea.org> Date of access: 3 May 2025.

Baker, L. 2015. *South Africa's renewable energy procurement: a new frontier?* https://www.researchgate.net/publication/274952345_South_Africa%27s_renewable_energy_procurement_a_new_frontier. Date of access: 7 May 2025.

Bashir, M.B.A. 2022. Principle parameters and environmental impacts that affect the performance of wind turbine: An Overview. *Arabian Journal for Science and Engineering*, 47:7891-7909.

Bearman, M. 2018. Focus on methodology: Eliciting rich data: A practical approach to writing semi-structured interview schedules. *Focus on Health Professional Education: A Multi-Professional Journal*, 20(3):1-11.

Bishoge, C.K., Kombe, G.G. & Mvile, B.N. 2020. Renewable energy for sustainable development in sub-Saharan African countries: Challenges and way forward. *Journal of Renewable Sustainable Energy*, 12:1-14.

Biznews. 2023. *South Africa's wind power surge: 34 wind farms generate over 3,400MW (with more on the horizon!)*. https://www.biznews.com/energy/2023/09/26/south-africas-wind-power-surge?utm_source=chatgpt.com Date of access: 13 June 2025

Braun, V. & Clarke, V. 2006. Using thematic analysis in psychology. *Qualitative research in psychology*, 3(2):77-101.

Bryman, A. & Bell, E. 2014. *Research Methodology: Business and Management Contexts*. Cape Town: Oxford University Press Southern Africa (Pty) Ltd.

Cevasco, D., Koukoura, S. & Kolios, A.J. 2021. Reliability, availability, maintainability data review for the identification of trends in offshore wind energy applications. *Renewable and Sustainable Energy Reviews*, 136:1-21.

Chatterjee, J. & Dethlefs, N. 2021. Scientometric Review of Artificial Intelligence for Operations & Maintenance of Wind Turbines: The Past, Present and Future. *Renewable and Sustainable Energy Reviews*, 144:1-49.

Chen, Z. 2023. Challenges and Perspectives of Wind Energy Technology. *Wind*, 3:545-547.

Christou, P.A. 2023. How to use thematic analysis in qualitative research. *Journal of Qualitative Research in Tourism*:1-17.

Clifton, A., Barber, S., Bray, A., Enevoldsen, P., Fields, J., Sempreviva, A-M...Ding, Y. 2023. Grand challenges in the digitalisation of wind energy. *Wind Energy Science*, 8:947-974.

Costa, Á.M., Orosa, J.A., Vergara, D. & Fernández-Arias, P. 2021. New tendencies in wind energy operation and maintenance. *Applied Sciences*, 11(4):1-26.

Creamer Media's Engineering News. 2023. *South Africa must build renewables skills pool to catch up with renewable power demands*. <https://www.engineeringnews.co.za/article/south-africa-must-build-renewables-skills-pool-to-catch-up-with-renewable-power-demands---Nordex-2023-08-03>. Date of access: 13 May 2025.

Creamer Media's Engineering News. 2025. *Despite intense power disruptions, no new wind turbines were connected to South Africa's grid in 2022, the Global Wind Energy Council's (GWEC's) latest report has confirmed*. <https://www.engineeringnews.co.za/article/no-new-wind-turbines-connected-to-south-africas-grid-in-2022---gwec-2023-03-28> Date of access: 9 June 2025.

Creswell, J.W. 2009. *Qualitative, quantitative, and mixed methods approaches*. 3rd ed. Thousand Oaks, CA: SAGE Publications.

Creswell, J.W. & Poth, C.N., 2018. *Qualitative inquiry and research design: Choosing among five approaches*. 4th ed. Thousand Oaks, CA: SAGE Publications.

CSI Energy Group. 2023. *The Role of Independent Power Producers in Africa's Renewable Energy Future*. <https://www.csi.energy/insights/articles/the-role-of-independent-power-producers-in-africa-s-renewable-energy-future/> Date of access: 6 Sept. 2025.

CSIR. 2025. *Utility-scale power generation statistics in South Africa*.
file:///C:/Users/10000445/Downloads/Statisticsofutility-scalepowergenerationinSouthAfrica_Jul_2021.pdf. Date of access: 5 June 2025.

Department of Mineral Resources and Energy. 2021. *REIPPPP focus on wind*.
file:///C:/Users/10000445/Downloads/20210630_Wind%20Focus_Mar%202021_vFINAL.pdf .
Date of access: 23 April 2025.

Department of Mineral Resources and Energy. 2023. *Annual energy statistics 2022/23*. Pretoria: Government of South Africa.

Department of Mineral Resources and Energy. 2024. *Renewable energy update – Q1 2024*. Pretoria: Government of South Africa.

Desalegn, B., Gebeyehu, D., Tamrat, B., Tadiwose, T. & Lata, A. 2023. Onshore versus

offshore wind power trends and recent study practices in modeling of wind turbines' life-cycle impact assessments. *Cleaner Engineering and Technology*,17:1-12.

Deutsche Windtechnik Internal. 2024. *20 years Deutsche Windtechnik – 20 years ISP. Our company history and the evolution of service markets*. https://www.deutsche-windtechnik.com/en/news/news/details/20-year-deutsche-windtechnik/?utm_source=chatgpt.com Date of access: 8 June 2025.

Devenish, A. 2021. *Data Analytics for predictive maintenance of Wind Turbines*. Stellenbosch: Stellenbosch University. (Thesis - PhD).

DNV GL. 2017. *Definitions of Availability Terms for the Wind Industry*. chrome-extension://efaidnbmnnnibpcajpcgiclfndmkaj/<https://www.ourenergypolicy.org/wp-content/uploads/2017/08/Definitions-of-availability-terms-for-the-wind-industry-white-paper-09-08-2017.pdf> Date of access: 9 May 2025.

Eberhard, A. & Naude, R. 2016. The South African Renewable Energy Independent Power Producer Procurement Programme: A review and lessons learned. *Journal of Energy in Southern Africa*, 27(43):1-14.

EIMS Africa. 2019. *Cookhouse Wind Farm: Operational Impact*. <https://www.eimsafrica.com> . Date of access: 3 May 2025.

EIMS Africa. 2021. *Wind farm operations and maintenance renegotiation*. <https://eimsafrica.com/wind-farm-om-renegotiation/> Date of access: 5 May 2025.

Electric Power Research Institute. 2023. *Wind Turbine Generator Reliability Analysis to Reduce Operations and Maintenance (operations and maintenance) Costs. White Paper, June 2023*. chrome-extension://efaidnbmnnnibpcajpcgiclfndmkaj/<https://docs.nrel.gov/docs/fy23osti/86721.pdf> Date of access: 10 June 2025.

El-Naggar, M. Sayed, A., Elshahed, M. & EL-Shimy, M. 2023. Optimal maintenance strategy of wind turbine subassemblies to improve the overall availability. *Ain Shams Engineering Journal*, 14:1-14.

ENEL Green Power. 2019. *The Soetwater wind farm, South Africa. In operation.*
<https://www.enelgreenpower.com/our-projects/operating/soetwater-wind-farm> Date of access: 9 June 2025.

ENEL Green Power. 2021a. *Garob wind farm ready for commercial operation.*
<https://www.enelgreenpower.com/media/press/2021/12/garob-wind-farm-ready-commercial-operation> Date of access: 9 June 2025.

ENEL Green Power. 2021b. *Oyster Bay Wind Farm, South Africa.*
<https://www.enelgreenpower.com/our-projects/operating/oyster-bay-wind-farm> Date of access: 9 June 2025.

ENEL Green Power. 2022. *The Soetwater wind farm.* <https://www.enelgreenpower.com/our-projects/operating/soetwater-wind-farm> Date of access: 9 June 2025.

ENEL Green Power. 2024. *ENEL Green Power drives winds of change in South Africa.*
<https://www.enelgreenpower.com/media/press/2024/03/enel-green-power-drives-winds-of-change-in-south-africa>. Date of access: 9 June 2025.

Engelbrecht, A.S., Kemp, J. & Mahembe, B. 2018. The effect of altruism and integrity on ethical leadership and organisational justice. *Management Dynamics*, 27(4):1-11.

Enerdata. 2022. *China added almost 17 GW of offshore wind capacity in 2021.*
https://www.enerdata.net/publications/daily-energy-news/china-added-almost-17-gw-offshore-wind-capacity-2021.html?utm_source=chatgpt.com Date of access: 9 June 2025.

Enerdata. 2023. *Share of wind and solar in electricity production.*
https://yearbook.enerdata.net/renewables/wind-solar-share-electricity-production.html?utm_source=chatgpt.com Date of access: 9 June 2025.

Erdmann, A. & Potthoff, S. 2023. Decision Criteria for the Ethically Reflected Choice of a Member Check Method in Qualitative Research: A Proposal for Discussion. *International Journal of Qualitative Methods*, 22:1–11.

Farhan, M., Schneider, R., Thöns, S. & Gündel, M., 2025. Probabilistic cost modelling as a basis for optimising inspection and maintenance of turbine support structures in offshore wind

farms. *Wind Energy Science*, 10(2):461-481.

Farina & Anctil. 2022. Material consumption and environmental impact of wind turbines in the USA and globally, Resources, Conservation and Recycling. *Resources, Conservation and Recycling*, 176, 105938. <https://doi.org/10.1016/j.resconrec.2021.105938>.

Fox, H., Pillai, A.C., Friedrich, D., Collu, M., Dawood, T. & Johanning, L. 2022. Review of Predictive and Prescriptive Offshore Wind Farm Operation and Maintenance. *Energies*, 15(504):1-28.

Frederiksen, R.D., Bocewicz, G., Radzki, G., Banaszak, Z. and Nielsen, P. 2024. Cost-Effectiveness of Predictive Maintenance for Offshore Wind Farms: A Case Study. *Energies*, 17(13):4-24.

Fusch, P., Fusch, G.E. & Ness, L.R. 2018. Denzin's paradigm shift: Revisiting triangulation in qualitative research. *Journal of Sustainable Social Change*, 10(1):19-32.

Gambal, M., Asatiani, A. & Kotlarsky, J. 2022. *Strategic innovation through outsourcing: A theoretical review*. <https://arxiv.org/abs/2206.00982>. Date of access 19 Apr. 2025.

George, T. 2023. *Semi-structured interview. Definition, Guide & Examples*. <https://www.scribbr.com/methodology/semi-structured-interview/>. Date of access: 9 April 2025.

Gigoni, L., Betti, A., Tucci, M. & Crisostomi, E. 2019. *A scalable predictive maintenance model for detecting wind turbine component failures based on SCADA data*. file:///C:/Users/10000445/Downloads/A_Scalable_Predictive_Maintenance_Model_for_Detect.pdf Date of access: 8 June 2025.

Gipe, P. & Möllerström, E. 2023. An overview of the history of wind turbine development: Part I—The early wind turbines until the 1960s. *Wind Engineering*, 46(6):1973-2004.

Global Growth Insights. 2025. *Wind Energy Market Size, Share, Growth, and Industry Analysis, By Types (Turbine Blade, Electricity Generator, Tower, Control Equipment), Applications (Power Plants, Street Lamp) and Regional Insights and Forecast to 2033*. <https://www.globalgrowthinsights.com/enquiry/request-sample-pdf/wind-energy-market-106954> Date of access: 6 Sept. 2025.

Global Wind Energy Council. 2025. *Global Wind Report 2025*.

<https://www.gwec.net/reports/globalwindreport> Date of access: 7 June 2025.

Gonzalez, E., Nanos, E.M., Seyr, H., Valldecabres, L., Yürüşen, N.Y., Smolka, Y., Muskulus, M. & Melero, M.M. 2017. Key Performance Indicators for Wind Farm Operation and Maintenance. *Energy Procedia*, 137:559-570.

Green Building Africa. 2022. *How will the industry combat the cost challenge and secure cheaper onshore wind?* <https://www.greenbuildingafrica.co.za/how-will-the-wind-industry-combat-the-cost-challenge-and-secure-cheaper-onshore-wind/>. Date of access: 4 May 2025.

GreenCape. 2022. *South African Renewable Energy Masterplan. An industrialisation plan for the renewable energy value chain to 2030. Draft Masterplan for review by Executive Oversight Committee*.

file:///C:/Frans%20backup/worddoc/MBA%20thesis/Brenda/South%20African%20Renewable%20Energy%20Masterplan.pdf Date of access: 11 June 2025.

Hansen, U.E., Nygaard, I., Morris, M. & Robbins, G. 2021. *The wind energy global value chain: Localisation and industrial policy failure in South Africa*.

https://orbit.dtu.dk/files/265125618/Final_JIBP_Paper_The_Wind_Energy_Global_Value_Chain_Localisation_and_Industrial_Policy_Failure_in_South_Africa_.pdf. Date of access: 7 June 2025.

Harling, G., Gumede, D., Mutevedzi, T., McGrath, M., Seeley, J., Pillay, D., Bärnighausen, T.W. & Herbst, A.J. The impact of self-interviews on response patterns for sensitive topics: a randomised trial of electronic delivery methods for a sexual behaviour questionnaire in rural South Africa. *BMC Medical Research Methodology*, 17(125):17:125

Hennink, M. & Kaiser, B. 2022. *Qualitative research methods: A practical approach*. 3rd ed. Los Angeles: SAGE Publications.

Hippe, M., Scheu, M., Hjorth, R. & Conradsen, L. 2024. *Unlocking value through operations and maintenance: Seven levers to boost offshore wind profitability*. chrome-extension://efaidnbmnnnibpcajpcgclefindmkaj/https://web-assets.bcg.com/23/f1/5bac3a644530a268fe78b05c9171/unlocking-value-through-operations-and-maintenance.pdf Date of access: 10 April 2025.

HSRC. 2024. *Wind energy in SA: Balancing global expertise and inclusivity*.

<https://hsrc.ac.za/news/review/wind-energy-in-sa-balancing-global-expertise-and-inclusivity/> .

Date of access: 5 May 2025.

Hu, M., Shi, J., Yang, S., Chen, M., Tang, Y. & Liu, S. 2024. Current Status and Future Trends in Installation, Operation and Maintenance of Offshore Floating Wind Turbines. *Journal of Marine Science and Engineering*, 12:1-38.

Hussain, M., Mirjat, N.H., Shaikh, F. & Laxmi, L. 2024. *Wind turbine failure rate and downtime survey with special reference to Pakistan*. In: *Conference Proceedings*. Proceedings of the 5th International Conference on Sustainable Energy Technologies (ICSET 2023). Peshawar, Pakistan. UET Peshawar. pp 322-330.

Ibrahim, H.A. & Thopil, G.A. 2025. Life cycle external cost assessment of an onshore wind farm in South Africa. *Applied Energy*, 388:1-16.

IEA. 2025. *Denmark community ownership of renewables – Policies*. International Energy Agency. <https://www.iea.org/policies/17800-denmark-community-ownership-of-renewables>.

Date of access: 07 June 2025.

Independent Online. 2024. *Eastern Cape gets investment boost as Nordex Energy SA to manufacture wind turbine towers*. https://iol.co.za/business-report/economy/2024-03-27-eastern-cape-gets-investment-boost-as-nordex-energy-sa-to-manufacture-wind-turbine-towers/#google_vignette Date of access: 9 June 2025.

Independent Power Producer Office. 2021. *REIPPPP focus on wind*.

file:///C:/Users/10000445/Downloads/20210630_Wind%20Focus_Mar%202021_vFINAL%20(2).

PDF Date of access: 24 April 2025.

Infosys. 2021. *Wind Farm Maintenance and Associated Challenges (Part 4 of 6)*.

<https://blogs.infosys.com/infosys-cobalt/digital-supply-chain/wind-farm-maintenance-and-associated-challenges-part-4-of-6.html> Date of access: 21 April 2025.

IPP Projects. 2024. *Independent Power Producer Procurement Programme*. <https://www.ipp-projects.co.za/Home/About> Date of access: 12 June 2025.

IRENA. 2019. *Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects*. United Arab Emirates, Abu Dhabi: International Renewable Energy Agency.

IRENA. 2020. Renewable Energy Prospects: South Africa. *IRENA*: 1-157.

Jol, G. & Stommel, W. 2024. Practising ground rules in police interviews with child witnesses. *Language in Society*, 53(3):445-469.

Kiunke, T., Gemignani, N., Malheiro, P. & Brudermann, T. 2022. Key factors influencing onshore wind energy development: A case study from the German North Sea region. *Energy Policy*, 165:1-11.

Knerr, P. & D'Amelia, R.P. 2020. *Introduction to the ethics of scientific conflict of interest (COI)*. <https://www.acs.org/content/dam/acsorg/about/governance/committees/ethics/conflict-of-interest-10-2.pdf>. Date of access: 21 April 2025.

Konstantakos, P.C., Chountalas, P.T. & Magoutas, A.I. 2019. The contemporary landscape of asset management systems. *General Management*, 20(169):10-17.

Konstantinidis, E.I. & Botsaris, P.N. 2016. Wind turbines: current status, obstacles, trends and technologies. *Materials Science and Engineering*, 161:1-8.

Korstjens, I. & Moser, A. 2018. Series: Practical guidance to qualitative research. Part 4: Trustworthiness and publishing. *European Journal of General Practice*, 24(1):120-124.

Kostka, G. & Anzinger, N. 2020. Local content requirements and the green energy transition: Evidence from the wind industry in South Africa. *Energy Policy*, 138:111–124.

Kotarbinski, M., Keyser, D. & Stefek, J. 2020. Workforce and Economic Development Considerations from the Operations and Maintenance of Wind Power Plants. *Golden, CO: National Renewable Energy Laboratory, NREL/TP-5000-76957:1-58*.

Labuschagne, H. 2023. *All 34 wind farms providing power to South Africa*. <https://mybroadband.co.za/news/energy/508804-all-34-wind-farms-providing-power-to-south-africa.html>. Date of access: 23 April 2025.

Larsen, H. & Nielsen, J. 2018. Maintenance challenges for offshore wind turbines. *Offshore Engineering Journal*, 27(1):73-85.

Li, M., Jiang, X., Carroll, J., & Negenborn, R.R. 2024. Operation and maintenance management for offshore wind farms integrating inventory control and health information. *Renewable Energy*, 231:1-20.

Lim, W.M. 2024. What Is Qualitative Research? An Overview and Guidelines. *Australian Marketing Journal*:1-31.

Lloyd's Register. 2018. *How well are South African wind farms performing?* chrome-extension://efaidnbmnnnibpcajpcgiclfndmkaj/https://sawea.org.za/sites/default/files/content-files/Research%20Studies/LR-Whitepaper-The-performance-of-wind-farms-in-South-Africa.pdf
Date of access: 11 June 2025.

Lombard, A. & Ferreira, S.L.A. 2015. The spatial distribution of renewable energy infrastructure in three particular provinces of South Africa. *Bulletin of Geography. Socio-economic Series*, 30:71–85

Lumivero, N.D. *Thematic analysis of interview data: 6 ways NVivo can help.*
<https://lumivero.com/resources/blog/thematic-analysis-of-interview-data-nvivo/>. Date of Access: 7 June 2025.

Ma, X., Li, Z., Zhang, L. & Zhang, X. 2020. An improved opportunistic group replacement maintenance strategy for wind turbines. *Energy Science & Engineering*, 8(8), 3627–3637.

Maqbool, M.A., Rizvi, M.J., Lee, Y.C. & Rosales, P.B. 2025. Technical Feasibility Analysis of Green Energy Storage Options and Hornsea Wind Farms. *Energies*, 18(9):1-34.

McKim, C. 2023. Meaningful Member-Checking: A Structured Approach to Member-Checking. *American Journal of Qualitative Research*, 7(2):41-52.

Mello, G., Dias, M.F. & Robaina, M. 2020. Wind farms life cycle assessment review: CO₂ emissions and climate change. *Energy Reports*, 6:214–219.

Merem, E.C., Twumasi, Y., Wesley, J. Olagbegi, D., Crisler, M., Romorno, C.,...Emeakpor, S.

2022. The Evaluation of Wind Energy Potentials. *Energy and Power*, 12(1):9-25.

Morris, M., Robbins, G., Hansen, U.E. & Nygaard, I. 2020. *The wind energy global value chain: Localisation and industrial policy failure in South Africa*.

https://orbit.dtu.dk/files/265125618/Final_JIBP_Paper_The_Wind_Energy_Global_Value_Chain_Localisation_and_Industrial_Policy_Failure_in_South_Africa_.pdf Date of access: 7 June 2025.

Mukonza, C. & Nhamo, G. 2018. Wind energy in South Africa: A review of policies, institutions and programmes. *Journal Energy Southern Africa*, 29(2):1-18.

Mulder, K. 2021. *Wind power: The struggle for control of a new global industry*. 1st ed. London: Earthscan.

Muñoz Cabré, M., Ndhlukula, K., Musasike, T., Bradlow, D., Pillay, K., Gallagher, K.P. Chen Y., Loots J. & Ma X. 2020. *Expanding Renewable Energy for Access and Development: the Role of Development Finance Institutions in Southern Africa*. Boston, Boston University: Global Development Policy Center.

Mwita, M. 2022. Factors influencing data saturation in qualitative research. *Journal of Social Science Research*, 11(3):416–417.

NS Energy. 2015. *Siemens to supply 360MW of turbines for three South African wind power projects*. https://www.nsenergybusiness.com/news/newssiemens-to-supply-360mw-of-turbines-for-three-south-african-wind-power-projects-190215-4515197/?utm_source=chatgpt.com Date of access: 9 June 2025.

NYSERDA. 2020. *Wind energy basics*. file:///C:/Users/10000445/Downloads/NY-Wind-Energy-Guide-1.pdf Date of access: 13 May 2025.

NYU Libraries. 2025. *ATLAS.ti Software Access*. <https://guides.nyu.edu/gda/atlasti> Date of access: 22 Sept. 2025.

Oblakovic, G., Dogan, I.D. & Lajtman, M.K. 2023. *Life-Cycle Analysis*.

file:///C:/Users/10000445/Downloads/Life-CycleAnalysis%20(1).pdf Date of access: 11 June 2025.

OECD. 2025. Recommendation of the Council on OECD Legal Instruments: OECD Guidelines for Managing Conflict of Interest in the Public Service. *OECD/Legal:1-16/0316:1-16*.

Onsomu, E. 2022. *Wind turbines*.

https://constructionreviewonline.com/knowhow/renewables/wind-turbines/?utm_source=chatgpt.com. Date of access: 9 June 2025.

O'Reilly, M. & Kiyimba, N. 2015. *Advanced qualitative research: A guide to using theory*. Los Angeles, CA: Sage Publications.

Ørsted. 2025. *Investor Presentation. O1 2025*: chrome-

extension://efaidnbmnnnibpcajpcgclclefindmkaj/https://cdn.orsted.com/-/media/q12025/orsted-investor-presentation---q1-

2025.pdf?rev=c099712d7c2e4c1f91e4ac663eb21269&hash=1B4C13E92648BF52CF46F7E81CF25EC0 Date of access: 7 Jun. 2025.

Ozturk, S. & Fthenakis, V. 2020. Predicting frequency, time-to-repair and costs of wind turbine failures. *Energies*, 13:1-25.

Papadopoulos, P., Fallahi, F., Yildirim, M. & Ezzat, A.A. 2023. *Joint optimisation of production and maintenance in offshore wind farms: Balancing the short-and long-term needs of wind energy operation*. *IEEE Transactions on Sustainable Energy*, 15(2):835-846.

Pattison, D., Segovia Garcia, M., Xie, W., Quail, F., Revie, M., Whitfield, R. & Irvine, I. 2016. Intelligent integrated maintenance for wind power generation. *Wind Energy*, 19:547-562.

Pervin, N. & Mokhtar, M. 2022. The Interpretivist Research Paradigm: A Subjective Notion of a Social Context. *International Journal of Academic Research in Progressive Education and Development*, 11(2):419-428.

Pfaffel, S., Faulstich, S. & Sheng, S. 2019. *Recommended key performance indicators for operational management of wind turbines*. Golden, CO: National Renewable Energy Laboratory. <https://www.nrel.gov/docs/fy20osti/72373.pdf> Date of access: 4 August 2025.

Poorun, A. & Radmore, J. 2023. *2023 Energy services market intelligence report*. chrome-extension://efaidnbmnnnibpcajpcgclclefindmkaj/https://greencape.co.za/wp-

content/uploads/2023/04/ES_MIR_2023_DIGITAL_SINGLES.pdf Date of access: 5 Sept. 2025.

Pragma. 2023. *Enhancing wind farm equipment reliability through effective asset and maintenance management*. <https://www.pragmaworld.net/enhancing-wind-farm-equipment-reliability-through-effective-asset-and-maintenance-management/> Date of access: 9 May 2025.

Presidential Climate Commission. 2022. *South Africa's Just Energy Transition Investment Plan*. <https://www.climatecommission.org.za/south-africas-jet-ip> Date of access: 11 June 2025.

PSI Repair Services. 2022. *Independent service providers vs. original equipment manufacturers*. <https://www.psi-repair.com/resources/blog/113-independent-service-providers-vs-Original-Equipment-Manufacturers-who-should-you-call-when-your-wind-turbine-production-equipment-fails> Date of access: 30 April 2025.

Rasheed, A., Stadtmann, F., Fonn, E., Tabib, M., Tsiolakis, V., Panjwani, B., ... Rasmussen, T. 2024. *Digital Twin for Wind Energy: Latest updates from the NorthWind project*. <https://arxiv.org/abs/2403.14646> Date of access: 9 June 2025.

Reddit. 2024a. *Questions about turbine downtime?* https://www.reddit.com/r/wind/comments/1hmxy10/questions_about_turbine_downtime/?utm_source=chatgpt.com Date of access: 8 June 2025.

Reddit. 2024b. *2023 Was a record year for wind power growth – in numbers*. https://www.reddit.com/r/OptimistsUnite/comments/1f2vn2f/2023_was_a_record_year_for_wind_power_growth_in/?utm_source=chatgpt.com Date of access: 8 June 2025.

Reddit. 2024c. *A record 116.6 GW new wind energy capacity added worldwide in 2023 — Percentage of 116.6 GW added by country, %-onshore/%-offshore — China 66/58 — India 3/N.A. — Taiwan N.A./6 — Brazil 5/N.A. — Netherlands 0.5/18 — UK 0.5/8 — Germany 3/2 — France 1/3 — Denmark N.A./3 — USA 6/0 — Canada 2/N.A.* https://www.reddit.com/r/climatechange/comments/1c7k5g3/a_record_1166_gw_new_wind_energy_capacity_added/?utm_source=chatgpt.com Date of access: 9 June 2025.

REGLOBAL. 2023. *Operations and maintenance Opportunity: Wind market trends and outlook*. https://reglobal.org/om-opportunity-wind-market-trends-and-outlook/?utm_source=chatgpt.com Date of access: 8 June 2023.

Research and Markets. 2023. *Wind energy global market opportunities and strategies to 2032*.
<https://www.researchandmarkets.com/reports/5866800/wind-energy-global-market-opportunities-strategies?srsId=AfmBOopCe8t9qjYiITklJfB4nz51eY36I-smAZOWjolHg7nGNqogUUf7> Date of access: 6 Sept. 2025

Reuters, 2024a. *Global offshore wind industry poised to miss big targets as obstacles mount*.
<https://www.reuters.com/sustainability/global-offshore-wind-industry-poised-miss-big-targets-obstacles-mount-2024-11-18/> Date of access: 6 May 2025.

Reuters. 2024b. *Vestas wins 1.1 GW order in Scotland*.
https://www.reuters.com/business/energy/vestas-wins-11-gw-order-scotland-2024-12-13/?utm_source=chatgpt.com Date of access: 9 June 2025.

Rivett-Carnac, K. 2022. Insights into the Wind Energy Value Chain in South Africa. *Department & Industrial Policy Strategies*: 1-24.

Roggeveld Wind Farm. 2022. *Roggeveld Wind Power Station fact sheet*.
https://en.wikipedia.org/wiki/Roggeveld_Wind_Farm Date of access: 7 June 2025.

Rose, J. & Johnson, C.W. 2020. Contextualising reliability and validity in qualitative research: Toward more rigorous and trustworthy qualitative social science in leisure research. *Journal of Leisure Research*: 1-20.

Ruslin., Mashuri, S., Rasak, M.S.A. & Syam, H. 2022. Semi-structured Interview: A Methodological Reflection on the Development of a Qualitative Research Instrument in Educational Studies. *Journal of Research & Method in Education*, 12(1):22-29.

SANEDI. 2023. *ANNUAL PERFORMANCE PLAN 2022/2023*. chrome-extension://efaidnbmnnnibpcajpcgclefindmkaj/https://sanedi.org.za/wp-content/uploads/2024/01/SANEDI-APP-2022-WEB-VERSION.pdf Date of access: 8 June 2025.

Saunders, M., Lewis, P. & Thornhill, A. 2019. *Research methods for business students*. 8th ed. Harlow: Pearson Education.

SAWEA. 2024. *South Africa's Wind Energy: Gaining Momentum and Scaling New Heights*.
<https://sawea.org.za/news/south-africas-wind-energy-gaining-momentum-and-scaling-new->

heights Date of access: 7 June 2025.

Schelling, G. 2021. *Unleash your growth potential by insourcing wind O&M.*

<https://go.hitachienergy.com/DigitalEnterprise-insights-unleashing-your-growth-potential> Date of access: 7 Sept. 2025.

Siemens Gamesa. 2025. *A big step towards full circularity.*

<https://www.siemensgamesa.com/global/en/home/explore/journal/a-big-step-towards-full-circularity.html> Date of access: 11 June 2025.

SKYSPECS. 2023. *Self-perform or Original Equipment Manufacturer-driven? The best model for turbine maintenance.* Chrome-

extension://efaidnbmnnnibpcajpcgiclfndmkaj/https://dkf1ato8y5dsg.cloudfront.net/uploads/8/412/wpm-skyspecs-1.pdf Date of access: 11 April 2025.

Snyder, H. 2019. Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104:333-339.

Spain, H. & Ahearne, E. 2022. *Creating an Industry 4.0 Maturity Model for Wind Farm Asset Management.* file:///C:/Users/10000445/Downloads/Spain_Ahearne_2022%20(1).pdf Date of access: 10 June 2025.

SSACI. 2024. *Identification of Skills Gaps in South Africa: A Popular Research Report.*

file:///C:/Frans%20backup/worddoc/MBA%20thesis/Brenda/Identification%20of%20Skill%20Gaps%20in%20South%20Africa-2023.pdf Date of access: 12 June 2025.

Stahl, N.A. & King, J.R. 2020. Understanding and Using Trustworthiness in Qualitative Research. *Journal of Developmental Education*, 44(1):26-28.

Statista Research Department. 2025. *Total wind energy capacity in South Africa 2013-2023.*

<https://www.statista.com/statistics/1218114/south-africa-total-wind-energy-capacity/> Date of access: 13 June 2025.

Suzlon. 2025. *Building A Sustainable Future.* <https://www.suzlon.com/> Date of access: 12 June 2025.

TIPS. 2022. *Insights into the wind energy value chain in South Africa*.

[file:///C:/Users/10000445/Downloads/TIPS WWF Insights into the Wind Energy value chain in South Africa 2022%20\(2\).pdf](file:///C:/Users/10000445/Downloads/TIPS%20WWF%20Insights%20into%20the%20Wind%20Energy%20value%20chain%20in%20South%20Africa%202022%20(2).pdf) Date of access: 10 June 2025.

Tusar, M.I.H. & Sarker, B.R. 2022. Maintenance cost minimisation models for offshore wind farms: A systematic and critical review. *International Journal of Energy Research*, 46(4):3739-3765.

TWI. 2024. *What is Corrective Maintenance? (Definition, Pros, Cons and Examples)*. <https://www.twi-global.com/technical-knowledge/faqs/what-is-corrective-maintenance> Date of access: 6 May 2025.

Ugwu, C.N. & Eze, V.H.U. 2023. Qualitative Research. *IDOSR Journal of Computer and Applied Sciences*, 8(1):20–35.

Ukoba, K., Jen, T-C. & Yusuf, A.A. 2025. Transformation of South Africa's energy landscape: Policy implications, opportunities, and technological innovations in the Fourth Industrial Revolution. *Energy Strategy Reviews*, 59:1-18.

Ullah, F., Zhanga, X., Khanb, M., Mastroia, M.S., Munirc, H.M., Flahd, A. & Said, Y. 2024. A comprehensive review of wind power integration and energy storage technologies for modern grid frequency regulation. *Heliyon*, 10, e30466.
<https://www.sciencedirect.com/science/article/pii/S2405844024064971>.

Vestas Mediterranean. 2023. *Vestas wins 373 MW order in South Africa featuring the first V163-4.5 MW wind turbines*. https://www.vestas.com/en/media/company-news/2023/vestas-wins-373-mw-order-in-south-africa-featuring-the--c3733385?utm_source=chatgpt.com Date of access: 9 June 2025.

Volker, P.J.H., Hahmann, Badger, N., Badger, J. & Jørgensen, E. 2017. Prospects for generating electricity by large onshore and offshore wind farms. *Environmental Research Letters*, 12:1-8.

Wilkie, D. & Galasso, C. 2021. A Bayesian model for wind farm capacity factors. *Energy Conversion and Management*, 252:1-12.

Windpower. 2025. *Wind energy market intelligence*.

https://www.thewindpower.net/country_windfarms_en_58_south-africa.php Date of access: 13 June 2025.

Windpower Engineering & Development. 2023. *Deciding between an ISP and Original Equipment Manufacturer for wind-farm maintenance*.

<https://www.windpowerengineering.com/deciding-between-an-isp-and-oem-for-wind-farm-maintenance/> Date of access: 30 April 2025.

Windpower Engineering and Development. 2024. *The future of O&M: Will turbine OEMs require certified maintenance crews?* <https://www.windpowerengineering.com/future-om-will-turbine-oems-require-certified-maintenance-crews/> Date of access: 5 Sept. 2025.

Windpower Monthly. 2015. *Denmark's wind operations and maintenance market opens up to ISPs*. <https://www.windpowermonthly.com/article/1340845/denmarks-wind-o-m-market-opens-isps> Date of access: 7 June 2025.

Wind Systems. 2018. *South Africa's wind needs to invest in blade repair capacity*.

<https://www.windsystemsmag.com/news/south-africa-wind-will-need-to-invest-in-blade-repair-capacity/>. Date of access: 21 April 2025.

Wind Systems Magazine. 2023. *Comparing maintenance options: Original Equipment*

Manufacturers and ISPs. <https://www.windsystemsmag.com/comparing-maintenance-options-oems-and-isps/> Date of access: 22 Sept. 2025.

Wiser, R., Bolinger, M. & Lantz, E. 2019. Assessing Wind Power Operating Costs in the United States: Results from a Survey of Wind Industry Experts. *Renewable Energy Focus*, 30:46–57.

World Economic Forum. 2025. *Fostering effective energy transition 2025. Insight Report June 2025*. Switzerland, Genève: World Economic Forum.

Wu, Z., Gong, X. & Guan, X. 2023. *Wind energy: History, basic principles, implementation, environmental and economic impacts*. In: Spanopoulos, I., Mofarah, S.S. & Ahmed, N., eds.

Conference Proceedings. Proceedings of the 3rd International Conference on Materials Chemistry and Environmental Engineering (CONF-MCEE 2023), Part II. Online due to Covid-19. pp. 516-527.

Yan, R., Dunnett, S. & Jackson, L. 2023. Impact of condition monitoring on the maintenance and economic viability of offshore wind turbines. *Reliability Engineering and System Safety*, 238:1-16.

Yu, Q. & Strömberg, A-B. 2021. *Mathematical optimisation models for long-term maintenance scheduling of wind power systems*. <https://arxiv.org/abs/2105.06666> Date of access: 8 June 2025.

Zappalá, D. & Tavner, P. J. 2022. Wind turbine reliability - Maintenance strategies. In: Letcher, T.M., ed. *Comprehensive Renewable Energy*. Oxford: Elsevier. pp. 353-370.

Zhang, J., Ding, Y. & Wang, L. 2019. A review of wind turbine condition monitoring and fault diagnosis. *Renewable and Sustainable Energy Reviews*, 109:391-412.

ANNEXURE 1: INFORMED CONSENT

Study title: *Original equipment manufacturers versus local service providers: A comparative evaluation of wind farm maintenance outcomes in South Africa.*

Ethics number: _____

Dear Participant,

You are invited to take part in a research study conducted by Sefularo Sidaki, an MBA student at the North-West University (NWU) Business School. This study is part of the requirements for completing the MBA degree and has received ethical clearance from the NWU Ethics Committee.

Purpose of the study

The purpose of the research is to evaluate and compare the cost, performance, and sustainability implications of using original equipment manufacturers versus local service providers for wind farm maintenance in South Africa. The findings will contribute to informed decision-making in the wind energy sector.

What your participation involves

You are invited to participate in a semi-structured interview, which will last no longer than 30 minutes. Questions will relate to your experience with maintenance operations and practices at your organisation. Participation is entirely voluntary, and you may decline to answer any question or withdraw from the interview at any point without any consequence.

Data handling, confidentiality, and POPIA compliance

Your responses will be kept confidential and will be used exclusively for academic purposes. Following the Protection of Personal Information Act (POPIA):

- No personal or identifying information will be collected.
- The name of your organisation will not be disclosed. A coding system will be used to ensure anonymity.
- Information will be stored securely in the researcher's password-protected database.
- All data will be destroyed after the completion and examination of the dissertation.

- You have the right to access, correct, or request deletion of any personal information you provide during this process.
- Sensitive personal data (e.g., race, political affiliation, health, etc.) will not be collected.

Risks and benefits

There are no anticipated physical or psychological risks associated with participating in this study. You will not receive direct benefits from participating, but your input may help improve decision-making in South Africa's wind energy maintenance sector.

Voluntary participation and right to withdraw

The following ethical principles will be applied during the interview:

- I understand that participation is voluntary.
- I understand that even if I agree to participate now, I can withdraw at any point from the study or decline to answer any question without any consequence of any kind
- I have had the purpose and nature of the study explained to me in writing, and I have had the opportunity to ask questions about the survey.
- I understand that my responses will be confidential.
- I can withdraw from the interview at any time without penalty.
- Personal information will be handled in strict compliance with the POPI Act and used only for the dissertation, stored temporarily, and participants may access, correct, or delete their data. No sensitive personal data will be collected.
- In accordance with the PAIA, formal permission was obtained from the organisation to conduct the research, and management approved the study. The OEM and LSP involved in the study requested anonymity; therefore, the permission letter could not be included in the dissertation.
- I understand that I will be required to provide informed consent before the interview by signing this document.

Conflicts of interest

To uphold academic integrity and ensure ethical research conduct, the following measures will

be taken:

- The researcher declares no personal, professional, or financial interests that could influence the study or its outcomes.
- The researcher will maintain neutrality and professionalism throughout the interview process.
- Participants will be treated with respect and without judgment, regardless of their responses, role, gender, or background.
- The findings will be reported objectively and will not be used to criticise or single out any individual, organisation, or stakeholder.
- All responses will be anonymised and analysed solely for the purpose of academic research.

Approval and organisational consent

Formal permission to conduct this study at your organisation was requested and approved by management.

Contact information

If you have any questions about this study, or if you wish to raise a concern, please feel free to contact my supervisor, Dr FF Prinsloo, with the following contact details:

Cellphone number: 0769818483.

Email address: ffprinsloo9706@gmail.com

I consent: Yes No

Signed at _____ on this _____ day of _____ 2023

Signature

ANNEXURE 2: INTERVIEW SCHEDULE

This interview schedule is designed to collect in-depth insights and perspectives from stakeholders involved in wind farm maintenance conducted by Original Equipment Manufacturers and LSPs.

Introduction:

- Introduce yourself and explain the purpose of the interview as part of a research study on wind farm maintenance models in South Africa.
- Confirm that the participant has signed the consent form.
- Ask for permission to record the interview for accurate note taking and transcription.

Q1. Could you describe the scope of maintenance services your company offers for wind farms?

Purpose: Understand the provider's role, service coverage, and whether services are reactive, preventive, or predictive.

Q2. What are the main strengths and weaknesses of your maintenance model?

Purpose: Capture perceived advantages and limitations, including responsiveness, flexibility, and cost-efficiency.

Q3. How is the performance of maintenance monitored and evaluated in your contracts?

Purpose: Assess accountability frameworks, performance indicators (e.g., turbine uptime), and the use of data-driven monitoring tools.

Q4. What is the impact of your maintenance model on turbine availability and energy output?

Purpose: Explore operational performance and potential enhancements from predictive or condition-based maintenance.

Q5. What are the primary cost drivers in providing wind farm maintenance services? How does your model compare to that of other providers in terms of cost-efficiency?

Purpose: Understand the economic aspects and comparative affordability between Original

Equipment Manufacturers and LSPs.

Q6. To what extent does your organisation use data-driven or predictive maintenance technologies? What benefits or limitations have you experienced with these tools?

Purpose: Explore innovation in maintenance strategy and its influence on efficiency and reliability.

Q7. How do regulatory or contractual frameworks influence your maintenance operations or service delivery?

Purpose: Understand the role of compliance, policy restrictions, and contractual obligations in shaping maintenance practices.

Q8. Does your maintenance model support long-term sustainability goals, such as localisation, skills development, or environmental responsibility?

Purpose: Investigate contributions to local economic development, community involvement, and broader sustainability.

Q9. How do clients perceive your service offering compared to OEMs or other independent service providers (ISPs)?

Purpose: Capture market perceptions, preferences, and factors influencing client decisions.

Q10. Based on your experience, what recommendations would you make to improve wind farm maintenance practices and policies in South Africa?

Purpose: Gather expert insights to inform future strategies and regulatory development.

Conclusion:

- Thank the interviewee for their time and responses.
- Ask if they have any additional thoughts or suggestions regarding maintenance practices or service providers.