Techno-Economic Feasibility Study into
Wind Farm Management
for utility scale
Wind Energy Facilities in South Africa

by

Felix Juani Bielefeld

Thesis presented in partial fulfilment of the requirements for the degree

Master of Engineering Industrial Engineering at the Stellenbosch University

Supervisor: Konrad von Leipzig

Faculty of Engineering

Department of Industrial Engineering

March 2016

DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

March 2016

ABSTRACT

The steadily increasing energy demand exceeded South Africa's energy supply in early 2008 and continues to be a limiting factor for the country's economical growth. In order to keep up with the increasing demand and to diversify the country's electricity mix, the government rolled out a Renewable Energy Procurement Process (REIPPPP). For the first time in South Africa, utility scale Wind Energy Facilities (WEFs) owned and operated by Independent Power Producers (IPPs) are integrated into the existing electricity grid. WEFs are mainly project financed and owned by institutional investors without any technical background. The Wind Farm Management (WFM) operates the project on behalf of its shareholders, who consider the project as a long-term investment. Thus the investors are in need of a turnkey solution, combining technical operations management (TOM) and business management (BM) tailored to the local requirements. From an international perspective, WFM in South Africa faces unique challenges. The most prominent being, having to operate WEFs without an existing local supply chain and adequately trained local workforce for this technology. This poses the question if professional WFM for South African WEFs is technically and economically feasible. An independent feasibility study on this topic has not been performed in South Africa before; local experience operating this technology based on early-implemented small scale WEFs emphasises the need for a professional management approach.

The study is approached by developing a framework for WFM based on the technical requirements as well as the socio-economic context of the REIPPPP. Therefore, a qualitative research approach of data gathering was used, which consists of a literature review and job-shadowing. The developed framework investigates a scope of work from which the requirements to perform the tasks are derived. The developed framework was then validated through its application to a case study. The economic feasibility of the technical framework is determined by relevant financial indicators. In addition, a sensitivity analysis provides insight on the volatility of the results.

The study finds that it is technically and economically feasible to establish an independent WFM entity, which is aligned with the project's timeline and provides services according to the developed framework. The key requirements in order to conduct professional WFM are identified: Technical Operations Management Systems, Human Resources, Condition Monitoring and Technical Inspection Services.

WFM mitigates the risks for investors during the operational phase of a WEF. Application of the developed framework provides the owner with great insight into the performance of single Wind Turbines (WTs), as well as performance of the contracted maintenance provider. Thus, it sets the basis for informed decision-making and safeguards the investor's return on investment (ROI).

OPSOMMING

Die voortdurend toenemende energiebehoefte het Suid-Afrika se energievoorrade reeds vroeg in 2008 oorstyg en bly ’n beperkende faktor vir die land se ekonomiese groei. Om tred te hou met die toenemende aanvraag en om die land se elektrisiteits mengeling te diversifiseer, het die regering ’n Hernubare Energie Verkrygingsproses bekendgestel. In die loop daarvan word nutsskaal windenergiefasiliteite in die besit van en bedryf deur Onafhanklike Kragvoorsieners vir die eerste keer in die bestaande elektrisiteitsnetwerk opgeneem. WEFs word hoofsaaklik projek-gefinansier en besit deur institusionele beleggers sonder enige tegniese agtergrond. Die Windplaasbestuur bedryf die projek namens sy aandeelhouers wat die projek as ’n langtermyn-belegging beskou. Die beleggers benodig dus ’n gebruiksklaar oplossing wat tegniese bedryfsbestuur en besigheidsbestuur wat by plaaslike vereistes aangepas is, kombineer. Vanuit ’n internasionale oogpunt staan WFM in Suid-Afrika voor unieke uitdagings. Die belangrikste uitdaging is om die WEFs sonder ’n voldoende opgeleide arbeidsmag vir hierdie tegnologie te bestuur. Dit stel die vraag of professionele WFM vir Suid-Afrikaanse WEFs tegnies en ekonomies lewensvatbaar is. ’n Onafhanklike lewensvatbaarheidsstudie oor hierdie onderwerp is nog nie voorheen in Suid-Afrika gedoen nie; plaaslike ervaring met die bedryf van hierdie tegnologie op die basis van vroeg geimplementeerde kleinskaalse WEFs beklemtoon die behoefte aan ’n professionele bestuursbenadering.

Die studie word deur die ontwikkeling van ’n raamwerk vir WFM benader, gebaseer op die tegniese vereistes sowel as die sosio-ekonomiese konteks van die REIPPPP.

’n Kwalitatiewe navorsingsbenadering tydens die data-insameling wat uit ’n literatuuroorsig en werk-skadu bestaan. Die ontwikkelde raamwerk ondersoek die omvang van die werk waaruit die vereistes vir die uitvoering van die take afgelei word. Tydens die tweede stap is die ontwikkelde raamwerk deur die toepassing van ’n gevallestudie bekragtig. Die ekonomiese lewensvatbaarheid van die tegniese raamwerk word deur finansiële hoofaanwysers bepaal. Verder verleen ’n sensitiwiteitsanalise insig in die volatiliteit van die resultate.

Die studie bevind dat dit tegnies en ekonomies lewensvatbaar is om ’n onafhanklike WFM-entiteit te vestig wat met die projek se tydlyn ooreenstem en dienste volgens die ontwikkelde raamwerk aanbied. Die hoofvereistes om ’n professionele WFM te kan bedryf, is geïdentifiseer: Tegniese Operasionele Bestuurssisteme, Menslike Hulpbronne, Monitering van Voorwaardes en Tegniese Inspeksiedienste.

WFM versag die risikos vir beleggers tydens die operasionele fase van ’n WEF. Die toepassing van ’n ontwikkelde raamwerk voorsien die eienaar van groter insig in die prestasie van enkele windturbines sowel as die prestasie van die gekontrakteerde verskaffer. Dit stel dus die basis vir ingeligte besluitneming en waarborg die belegger se opbrengs op sy belegging.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Stellenbosch University and my supervisor Konrad von Leipzig for his support and guidance throughout the research process.

I further would like to thank my respected colleagues, co-workers and friends in South Africa and Germany for their valuable input and support namely David Wolfromm, Isaac Mmuschi, Florian Burmeister and Roman Wolff.

In particular I wish to thank Carla Lee Hing for encouraging me, her constant moral support and for all her efforts in breaking the language barrier. And of course my family in Germany and South Africa.

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LIST OF ABBREVIATIONS

▪ AEP	Annual Energy Production
▪ AOM	Annual Operation & Maintenance
▪ ASG	Asynchronous Generator
▪ BOP	Balance of Plant
▪ BW	Bid Window
▪ BM	Business Management
▪ CF	Capacity Factor
▪ CAPEX	Capital Expenditure
▪ COD	Commercial Operation Date
▪ CMMS	Computerised Maintenance Management System
▪ CM	Condition Monitoring
▪ CMC	Condition Monitoring Concept
▪ CMS	Condition Monitoring System
▪ CMP	Construction Measurement Period
▪ CPI	Consumer Price Index
▪ COE	Cost of Energy
▪ DWF	Darling Wind Farm
▪ DoE	Department of Energy
▪ DEAT	Department of Environment and Tourism
▪ DFIG	Double Fed Induction Generator
▪ EBITDA	Earning Before Interest Tax Depreciation and Amortisation
▪ EBIT	Earnings Before Interest and Tax
▪ ED	Economic Development
▪ EDO	Economic Development Obligation
▪ EOW	End of Warranty
▪ ESI	Energy Supply Industry
▪ EPC	Engineering Procurement Construction
▪ F	Failure
▪ FC	Financial Close
▪ GWEA	German Wind Energy Association
▪ GDP	Gross Domestic Product
▪ HR	Human Resources
▪ IA	Implementation Agreement
▪ IPP	Independent Power Producers
▪ ISP	Independent Service Provider
▪ ICC	Initial Capital Cost

IRP	Integrated Resource Plan
IRR	Internal Rate of Return
KPI	Key Performance Indicator
LCD	Life Cycle Documentation
LCM	Life Cycle Management
LTMS	Long Term Mitigation Scenario
LPF	Lost Production Factor
MDT	Mean Down Time
MTBF	Mean Time Between Failure
MTTR	Mean Time to Repair
MWT	Mean Waiting Time
OMP	Operating Measurement Period
OPEX	Operational Expenditure
OHSA	Operational Health & Safety
O&M	Operations & Maintenance
OEM	Original Equipment Manufacturer
PMSG	Permanent Magnet Synchronous Generator
P	Potential Failure
PPA	Power Purchase Agreement
PPP	Public Private Partnership
REFIT	Renewable Energy Feed-In-Tariff
REIPPPP	Renewable Energy Ind. Power Producer Procurement Programme
RFP	Request for Proposal
ROI	Return on Investment
RPM	Revelation pro Minute
SPV	Special Purpose Vehicle
SCIG	Squirrel Cage Induction Generator
SCADA	Supervisory Control and Data Acquisition
SG	Synchronous Generator
TOM	Technical Operations Management
TOMS	Technical Operations Management Systems
TEFS	Techno-Economic Feasibility Study
TSA	Turbine Supply Agreement
WEF	Wind Energy Facility
WFM	Wind Farm Management
WT	Wind Turbine
WRSG	Wound Rotor Synchronous Generator

CHAPTER ONE:

INTRODUCTION

Wind energy in South Africa is an evolving industry in its infancy, even though wind energy is internationally considered a proven technology. The success of establishing a South African wind energy industry is not only dependent on the integration in the South African power generation mix, but also on soft factors inter alia local up- and downstream industries, job creation and knowledge transfer. [1] [2]

The first wind energy projects reached financial close (FC) at the end of 2012 and commercial operation date (COD) in 2014. These are South Africa's first of a kind utility scale renewable energy projects, owned and operated by Independent Power Producers (IPP), which will be integrated into the South African electricity generation mix. [1] [3]

The case of the Darling Wind Farm (DWF), South Africa's first commercial wind farm project, was supposed to act as a light house project in order to demonstrate to government and prospected investors the capabilities of this technology. Only 60% of the expected Annual Energy Production (AEP) of 13.2GWh could be achieved on a yearly basis. This massive underperformance due to mismanagement in all project phases, but mainly during the operational phase, led to the consequential liquidation of the project. [4] [5] [6]

This illustrates the importance of proper independent WFM. The lack of local knowledge managing this technology surfaced not only in the private sector, but as well as at Eskom's WT research site, Klipheuwel Wind Farm. The parastatal entity Eskom, one of the world's largest electricity producers, must undergo a learning curve in order to manage its own utility scale wind farms. [7]

This research paper investigates the techno-economic feasibility for independent WFM based on the policy framework of the REIPPPP and the specific technological requirements of utility scale wind farms in South Africa.

WFM can be described as management of the technical and commercial aspects of a project financed public private partnership (PPP). The technical aspects are technology related in this case wind energy specific and the commercial aspects are extended by certain obligations of the procurement process such as EDO-Management.

Research investigating WFM in South Africa has not been performed. Some of the reviewed research presents feasibility studies for utility scale WEF in South Africa; however, none included operations or management aspects of WEF. Studies in other parts of the world have researched operational aspects (e.g. condition monitoring), yet none included the background of independent WFM. [8] [9]

1.1 THE PROBLEM STATEMENT

The REIPPPP worked well procuring in a relatively short time period a large number of wind projects. A few of these projects reached COD in the recent past or plan to start operation in the near future. An operations management approach is required to operate WEF efficiently and to reduce the associated risks for the investors. The competitive approach of the REIPPPP led to low tariffs and profit margins, thus the underperformance during the first years of operation could drastically impact the viability of projects.

1.2 SUMMARY AND PROBLEM DEFINITION

This study will provide a technical and economical overview of managing the operations of a WEF from an owner's or investor's perspective in South Africa. Even though WTs are highly automated [10] and require less supervision compared to other electricity generation, a great understanding of this technology is necessary in order to run a successful project. A unique framework for the operations of the WEFs in SA is outlined by the procurement process, while having to deal with challenges of an industry, which is in its infancy. Investors in renewable energy projects can be categorized into two categories: *'utilities'*, investors with technical knowledge, and *'institutional investors'* without background or experience in wind energy. [11] Utilities headquartered overseas might have an interest in contracting an independent WFM company due to certain obligations of the procurement process inter alia *'job creation obligation'* and due to the prolonged distance to their core markets in Europe and or North America. Institutional investors generally invest in project-financed projects. These infrastructure investments are especially interesting for retirement funds due to the low risk and long-term of the investment. Institutional investors are often unexperienced in managing renewable energy projects and solely interested in the financial returns and thus need WFM, which is independent of the *'Wind Turbine Manufacturer'* (OEM)[1], and thus acts purely in their interests and provides supervision and monitoring of the contracted parties. [11]

Wind projects procured under the REIPPPP in South Africa range in capacity from 30MW to 150MW, while single WTs range between 1.8MW to 3MW, thus each project attracts between 2bn and 5bn Rand (see Table 32). [1]

Investors without a technical background require professional input in order to operate the WEF as professional power stations. The relatively large amount of fixed capital makes it clear that WEFs in South Africa are built to perform and generate according to specifications from day one onwards. Compared to the matured markets like Germany, where the industry underwent an intense and prolonged learning period, the single project sizes (63% of all WEFs consist of 6 or less WTs [12]) are a fraction of the average project size of projects procured under the REIPPPP in South Africa (see Annex I, Table 32).

In order to study the described problem, the following research questions can be posed:

(i) How can the operational risk for owners of WEF be minimized?

(ii) How are maintenance and service contracts structured?

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[1] *Original Equipment Manufacturer (OEM) are used in this research paper synonymously to wind turbine manufacturer*

(iii) What are the requirements of WFM in South Africa?

(iv) How can the maintenance regime of WTs be monitored?

(v) What is the scope of work for BM of WEFs?

(vi) What is the scope of work for TOM of WEFs?

(vii) What are the requirements for the TOM posed by the local framework?

(viii) What are the main process-flows regarding TOM?

(ix) How can the technical condition of WTs be assessed by WFM?

(x) How can WFM be implemented for local WEFs?

1.3 RESEARCH SCOPE

A significant aspect of this study is the feasibility analysis of a WFM entity, which manages both the financial and the technical side of the WEF. The technical side acts as a control body for the maintenance work carried out by the maintenance and service provider and other contracted parties. Where the financial side acts as the management and decision maker of the project.

The research focuses on projects developed according to the REIPPPP framework in South Africa using modern wind energy technology and gearbox driven WTs.

The requirement analysis focuses on the technical management aspects of WEF. Business management for wind energy projects is to a great extend comparable with business management of any project financed public private partnerships, where there is a vast local knowledge-base in the country. [13]

A case study representing a realistic scenario based on the averaged outcome of successful REIPPPP projects is used to validate the economic feasibility of a technical framework developed in this research paper. Specific project details and contractual frameworks vary from case to case, which may result in an adapted technical framework and could influence the project’s specific economic feasibility.

1.4 RESEARCH AIM & OBJECTIVES

The research was based on several objectives with the final aim to analyse the technical and economic feasibility of an independent WFM entity for WEFs developed under the REIPPPP. The objective was to first and foremost form a research basis, which consists of three parts: firstly, the analysis of the REIPPPP with regards to electricity generation in South Africa, secondly, the technical background of WTs and thirdly, a high level insight into different aspects concerning the operations of wind energy projects, e.g. project finance, maintenance contracts and the wind energy value chain.

Based on the research basis, a framework for WFM was developed with the aim to investigate the requirements on WFM. The key requirements were identified and analysed regarding the following objectives:

(i) Determine the required human resources and identifying suitable organisational structures
(ii) Determine the scope of work for WFM
(iii) Determine the requirements on a Technical Operations Management System (TOMS)
(iv) Outlining a Condition Monitoring Concept as part of WFM
(v) Identifying suitable technical inspections to determine the technical condition of WTs

Lastly the developed framework was applied to a case study to determine the economic feasibility this was done performing by financial modelling on the basis of the outlined scenario.

Overall this paper investigates the hypothesis: “*An independent wind farm management entity for WEFs in South Africa is technically and financially feasible.*”

1.5 RESEARCH METHODOLOGY

The research is based on a deductive approach. From a broad data base, a framework is deduced and validated by application on a case study. The findings are discussed consequentially. The focus point of the study is the Techno-Economic Feasibility Study (TEFS), which was identified as the most suitable approach for the validation of the framework.

> *"Techno Economic Feasibility Study ... provides appraisal of technological parameters and its impact on the financial viability of a project. It is an in-depth study and analysis of the Technical, Financial and Operational viability of a project. TEFS study is a risk mitigation task undertaken in respect of any industrial activity prior to decision making."* [14]

Figure 1 provides an overview, which is also reflected in the structure of the following chapters of the study.

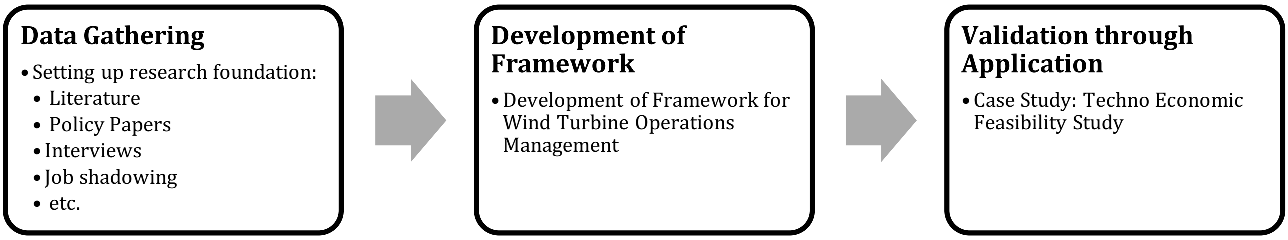

Figure 1: Research Design

(i) **Data Gathering:** The research foundation is based on the data gathered using a qualitative approach and mainly focuses on literature, policy papers and conference presentations. The data gathering resulted in a broad basis discussing interdisciplinary topics due to the nature of the TEFS.

(ii) **Development of Framework:** The framework is developed in close conjunction with the industry. Job shadowing and expert interviews added a real perspective in analysing the requirements, needs and obligation for wind projects.

(iii) Validation: The framework is validated by application on a representable case study based on averaged data of the outcome of the REIPPPP.

1.6 CONCLUSION

This ends the introduction chapter of this research paper. The need for the WFM for project financed WEFs was introduced along with the research questions and objectives. Further was the scope of the research outlined and delimitated. A Techno-Economic Feasibility study was selected as the most suitable approach to investigate the stated hypotheses and to answer the research questions.

In the following chapters the three major steps of the applied methodology are investigated as outlined in individual chapters, starting with the research foundation in the next chapter.

CHAPTER TWO:

RESEARCH FOUNDATION

This chapter provides the research foundation for this study. In order to conduct a TEFS a comprehensive research foundation covering different aspects and approaches of this topic needs to be investigated, which represent the techno-economic regulatory framework of WFM in South Africa. [14]

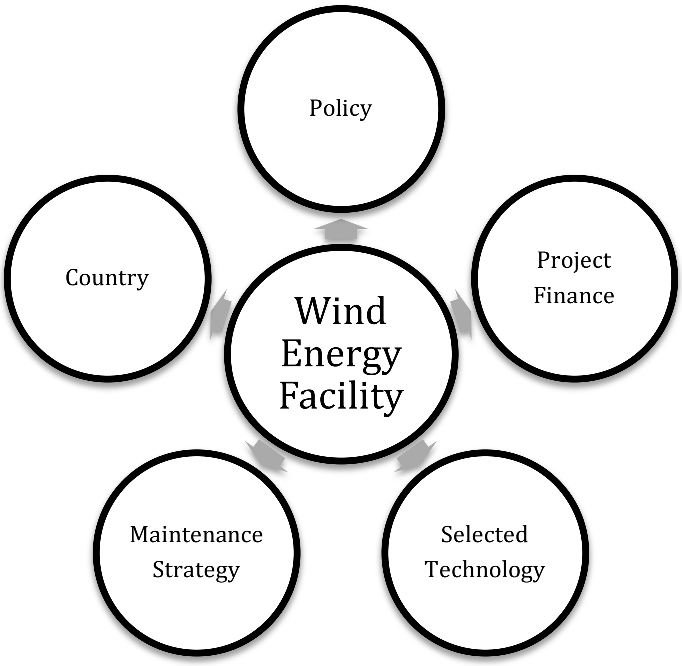

Figure 2: Influences & Constraints on IPPs (author's compilation)

Electricity production is always strongly interlinked with local policies & regulations, [15] financial models and technical requirements amongst others (see Figure 2). The following paragraphs will discuss these mentioned aspects briefly, with the aim to set a foundation in order to perform the TEFS of the proposed topic.

2.1 COUNTRY OVERVIEW: SOUTH AFRICAN WIND ENERGY INDUSTRY

Since the power crisis in 2008, electricity production in South Africa is an important topic of discussion in the public sphere. Due to the revived demand of electricity, South Africa is in the middle of its second energy crisis within a few years. [16] In order to understand the current developments and the role of renewable energy, in particular wind energy, the following paragraphs provide insight into this topic.

2.1.1 South African Energy Background

In 2013 about 95% of South Africa’s energy mix fell into the portfolio of the parastatal organisation, Eskom, of which the major share (85% of the installed capacity) consist of coal-fired power stations. The remaining capacity consists of power imports from neighbouring countries and own generation, e.g. from municipalities. Table 1 provides an overview of the South African *“Energy-Mix”* consisting of Eskom and Non-Eskom power generating assets. [17]

	Generating Assets	**Generation Capacity**	**Allocation**
Eskom Generation: **41’922MW (95%)**	*13 x Coal-fired Power Stations*	*35’650 MW*	*85%*
	1 x Nuclear Power Station	*1’860 MW*	*4.4%*
	6 x Hydro Power Station	*600 MW*	*1.4%*
	2 x Pumped Storage Power Station	*1’400 MW*	*3.4%*
	4 x Liquefied Gas Power Stations	*2’409 MW*	*5.7%*
	1 x Wind Power Station	*3 MW*	*0.01%*
Non-Eskom Generation: **2’655MW** **(5%)**	*Sasol Syfuel Plans*	*520 MW*	*19.6%*
	Kelvin	*128 MW*	*4.8%*
	Rooival	*155 MW*	*3.8%*
	Pretoria West	*100 MW*	*3.8%*
	Steenbras	*180 MW*	*6.8%*
	Mini-Hydro	*65 MW*	*2.4%*
	Darling Wind Farm	*5,2 MW*	*0.1%*
	Cahora Bassa Hydro Power (Import)	*1’500 MW*	*56.5%*

Table 1: South African Energy-Mix (2013) [17]

The dependency on coal as the primary source of energy is due to its vast availability and the ability for most of Eskom’s assets to run on low-grade coal. South Africa possesses one of the largest coal deposits in the world. According to the Department of Energy (DoE) 65% of the annual coal production is used to fire Eskom’s power stations, 8% for other coal application (e.g. Sasol coal-to fuel process) and 27% for export. [18] It is important to mention that most of the exported coal is of a higher grade compared to that of the coal used for the local power stations. The demand for low-grade coal however increases due to the shortage of energy in other developing countries (e.g. India, China). This results in an increase of coal prices in the medium to long-term. [19] [20]

2.2 RENEWABLE ENERGY POLICY

The importance of the introduction of renewable energy to the South African electricity sector may not only be the solution to protect the environment, but could also lead to job creation, social development of the poor and foreign investments into the country. [21]

In the last decade renewable energy systems have not played important roles in providing electricity to the masses, but in rural areas it was often the most affordable solution to bring electricity to the people. For a long time renewable energy was underestimated by the general public and therefore the “poor man’s electricity” was abolished. [21]

The government published the Integrated Resource Plan (IRP) in 2010 [22], which inherently only a capped amount was allocated for renewable energies, even though the industry appeared to be prepared to invest in a large scale. The DoE estimated a potential of over 64’000 GWh to be generated out of wind energy per annum. Other estimations were calculated closer towards the 100TWh per annum. Measured against the current consumption of 240’000 GWh, the estimation could reach a percentage of 25% to 41%, which could be generated through wind energy. [23] [24]

The awareness of the public regarding wind energy increased. Wind energy is now associated with economic growth and job creation. Especially in the course of Cop17, which was held in Durban 2011, where it was evident that the public began focusing on climate change, air pollution and related topics. [25]

In 2010, the national energy regulator issued the “Renewable Energy Feed-In-Tariff” (REFIT) [26], with little success as no “power purchase agreement” (PPA) was signed. The IPPs were put into a position, where the connection to the grid was placed in Eskom’s hands, resulting in uncertainty, which prohibited possible investors to commit and invest into projects.

Even though REFIT was not a success, it initiated South Africa’s focus towards the renewable energy industry, especially the wind industry sector due to favourable wind conditions. South Africa was the first country on the continent that followed the example of countries where renewable energies became a success and issued a feed in tariff which was the second highest in the world (1.25ZAR/kWh, 0.11€/kWh) at the time. [27]

The IRP is a long-term plan for the South African electricity demand over the next 20 years. It describes in detail how the demand will be supplied. The IRP underlies the steady growth of the gross domestic product (GDP) of an average of 4.6% over the next 20 years, which requires 52’284MW of newly installed capacity and at least a reduction by Demand Side Management of 3’420MW in peak periods. [27]

With the announcement of the Integrated Resource Plan 2011, the country has progressed. The IRP is a milestone for renewable energy. [28]

The IRP is imperative for the Renewable Energy Industry, as it provides the capacity of Renewable Energy Systems. These capacities are planned to be installed within years to come, whereas the REFIT commenced in 2010. In comparison the IRP indicates an increase in the allocated capacities to the REFIT-Programme.

In order to assess the energy demand, the DoE considered three different scenarios: *low cost*, *low carbon* and the suggested *balanced scenario.* The balanced scenario was set up according to the following points [29]:

(i) Least Cost investment

(ii) Climate change mitigation

(iii) Localisation and job creation

(iv) Regional development

(v) Diversity of energy sources

(vi) Energy efficiency and Demand Side Management

(vii) Security of supply

To cope with the steady increase of demand, these scenarios are to diversify the energy production structurally and regionally.

Three different scenarios analyse the allocation for the next 20-year forecast. All scenarios make use of the same generating techniques; yet vary in the allocation of the "new capacity".

The DoE selects the *balanced scenario* as the realistic mix, thus reducing the carbon footprint of the country with regards to the cost aspects. This enables the industry to remain competitive, as compared to other newly developed countries. [29]

Balanced Scenario	**Total allocations**	**New allocations**
Renewables	*14%*	*33%*
Base load Nuclear:	*14%*	*25%*
Peaking: OCGT	*9%*	*14%*
Base load: coal	*49%*	*9%*
Mid-merit Gas	*5%*	-
Base load: Imported Hydro	*2%*	*4%*
Peaking: Pump Storage	*5%*	*4%*

Table 2: Balanced Scenario, Total Allocations opposed New Allocations [29]

From the point of view of the renewable energy sector, 33% of the newly installed capacity will be "green", in relation to the total installed capacities; "only" 14% is allocated for renewables that is the same amount as for nuclear energy. More than half of the total installed capacity (63%) is allocated to "fossil energy".

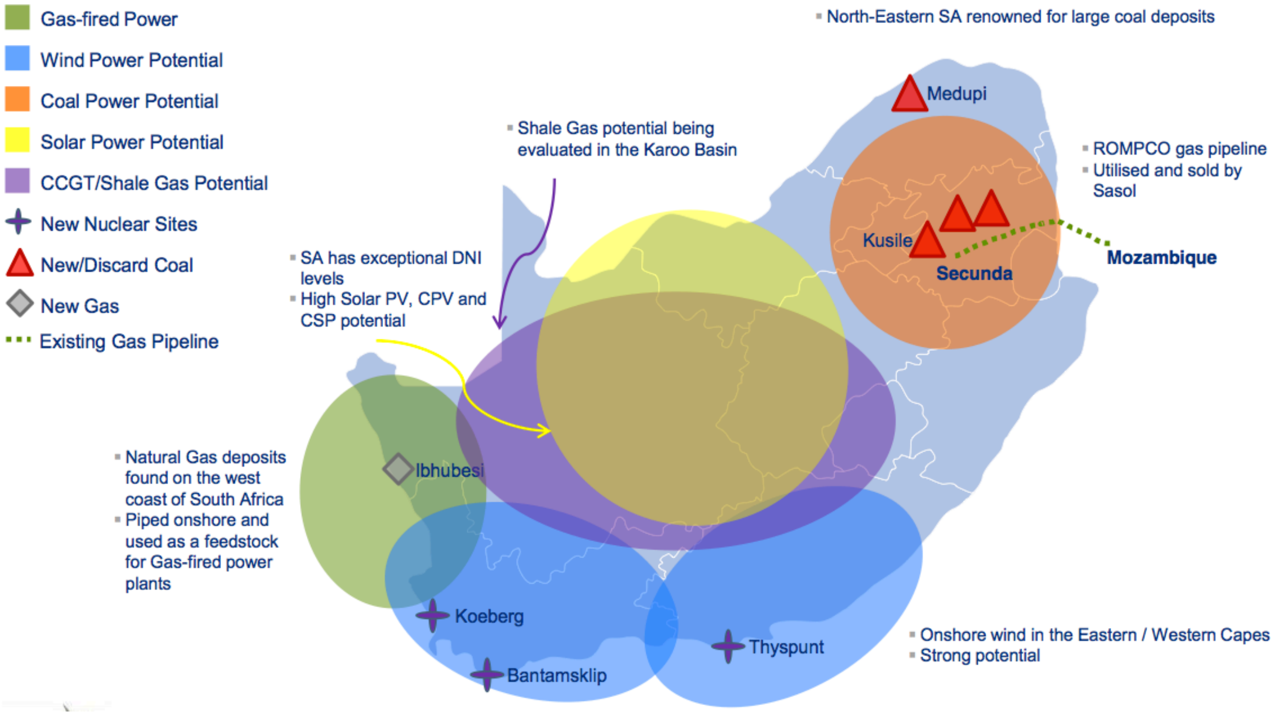

Figure 3: Geographical Overview of a potential new Electricity Generation [30]

As wind energy is the ‘*cheapest’* renewable energy option and wind energy matches the scheme of localisation and job creation, the biggest amount of the planned *‘green energy’* is allocated for wind energy. In order to develop the more expensive Concentrated Solar Power, a modest commitment was made in order to increase the local knowledge in this field. [29]

Figure 3 shows a potential distribution of the planned capacities. The preferred way of generating the capacity depends on the local conditions of the different areas in South Africa. The planned coal fired power stations are in the mining areas in the south-eastern part of the country, whereas the Northern and Western-Cape are allocated for the generating of wind energy.

2.2.1 From REFIT to REIPPPP

Following suit of other countries, where the roll out of renewable energy schemes were successfully introduced in a relatively short time span and with relatively little red tape, inter alia Germany, Canada and Ireland. NERSA[2] announced in 2009 a Feed-In-Tariff for renewable

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[2] *National Energy Regulator of South Africa*

energy named REFIT in order to procure renewable energy generation and to fulfil obligations created by local policies, IRP2010, White Paper of Renewable Energy, etc.

Technology	**Feed-In-Tariff**
Wind	*1.25 R/kWh*
Small Hydro	*0.94 R/kWh*
Concentrated Solar Power	*2.10 R/kWh*
Landfill Gas	*0.90 R/kWh*
Solar PV	*3.94 R/kWh*

Table 3: Feed-In-Tariff per Technology [27]

The announcement of REFIT placed South Africa in the scope for international investors and project developers. Table 3 illustrates the price per kWh for the different renewable energy technologies. For solar and wind REFIT offered promising returns compared to other countries, given the local wind and solar resources, which led to the initiation of a couple of hundred renewable energy projects by the end of 2011. It followed a rather abrupt shift in policy away from Feed-In-Tariff to a competitive bidding process namely REIPPPP. The change in policy certainly did not increase the confidence for local and especially foreign investments in the South African energy sector. [31]

2.3 RENEWABLE ENERGY IPP PROCUREMENT PROGRAMME

The REIPPPP is the practical application of the long term IRP, which laid the foreground for the renewable energy sector in South Africa. Eskom's activities in this field should not be counted directly towards the renewable energy industry, as Eskom's projects (e.g. Sere Wind Farm) are not subject to restrictions and obligations of the REIPPPP)

> *"This IPP Procurement Programme has been designed to contribute towards the target of 3'725 megawatts and towards the socio-economical and environmentally sustainable growth."* [32]

The REIPPPP is a competitive bidding process with the aim to select the renewable energy projects, which bring the best value to the country[3] and comply with local laws and regulations. The programme is structured within the so-called bidding windows (BW). It is planned that on a yearly basis projects can be submitted on the bid submission date. [30]

Technology	Initial Capacity (up to 2016)	Percentile	Additional Capacity (up to 2020)	Percentile	Total
Onshore Wind	*1'850MW*	*49.7%*	*1'470MW*	*46%*	*3'320MW*
Concentrated solar	*200MW*	*5.4%*	*400MW*	*12.5%*	*600MW*
Solar PV	*1'450MW*	*38.9%*	*1'075MW*	*33.5%*	*2'525MW*
Biomass	*12.5MW*	*0.36%*	*47.5MW*	*1.5%*	*60MW*
Biogas	*12.5MW*	*0.36%*	*47.5MW*	*1.5%*	*60MW*
Landfill Gas	*25MW*	*0.67%*	-	*0%*	*25MW*
Small Hydro	*75MW*	*2%*	*60MW*	*1.9%*	*135MW*
Small Projects	*100MW*	*2.6%*	*100MW*	*3%*	*200MW*
Total	***3'725MW***	***100%***	***3'200MW***	***100%***	***6'925MW***

Table 4: Planned Capacities according REIPPPP[4] [33]

Table 4 illustrates the available capacity for each technology. The initial allocation was supposed to be procured until 2016 in three rounds (BW1 to BW3). In 2012 the DoE announced additional capacity for the time frame up to 2020 (BW4 and BW5). For both allocations wind energy represents the major share of about 50% or 33'200MW. [33] This number provided the first outline of the evolving new industry sector, based on an average wind farm (about 90MW - 45 x 2MW WTs) in the near future 37 wind farms totaling 1'660WTG will be installed in South Africa (author's conclusion based on various sources and project documentation; [34] [1]).

Due to the current *'energy crisis'* and based on the success of the projects awarded, preferred

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[3] *"South Africa has done an incredible job. This is important to acknowledge. Countries like Spain have got themselves into trouble with committing to excessive Feed in Tariffs. REIPPPP is a competitive programme, meaning that the country is getting the best value possible." Vivian Boberts, Energy Rambling (http://www.energyramblings.com/2015/05/07/)*

[4] *Excluding new announcement made in Q1 2015.*

bidder's status in BW1 and BW2 the Minister of Energy Ms Joematt Petersen announced an early extension of the programme, thus strengthening the commitment to IPPs. [35] Additionally, the total commitment of 6'925MW for BW1 to BW4 another 6'300MW will be allocated to renewable energies. The allocation starts with the reopening of BW4 in order to fast track the procurement of new capacity due to the current constraints in electricity generation. [36]

2.3.1 Procurement Process

The procurement process is structured into different steps and phases. Projects can be registered against a fee[5] in order to receive the tender documents, consisting of three major documents: Request for Proposal (RFP), Power Purchase Agreement (PPA) and Implementation Agreement (IA). [30] The process can be subdivided into five phases, namely; (i) bid preparation, (ii) bid submission, (iii) bid qualification, (iv) bid evaluation and finally reaching (v) financial close, which are explained in the latter.[6] [37]

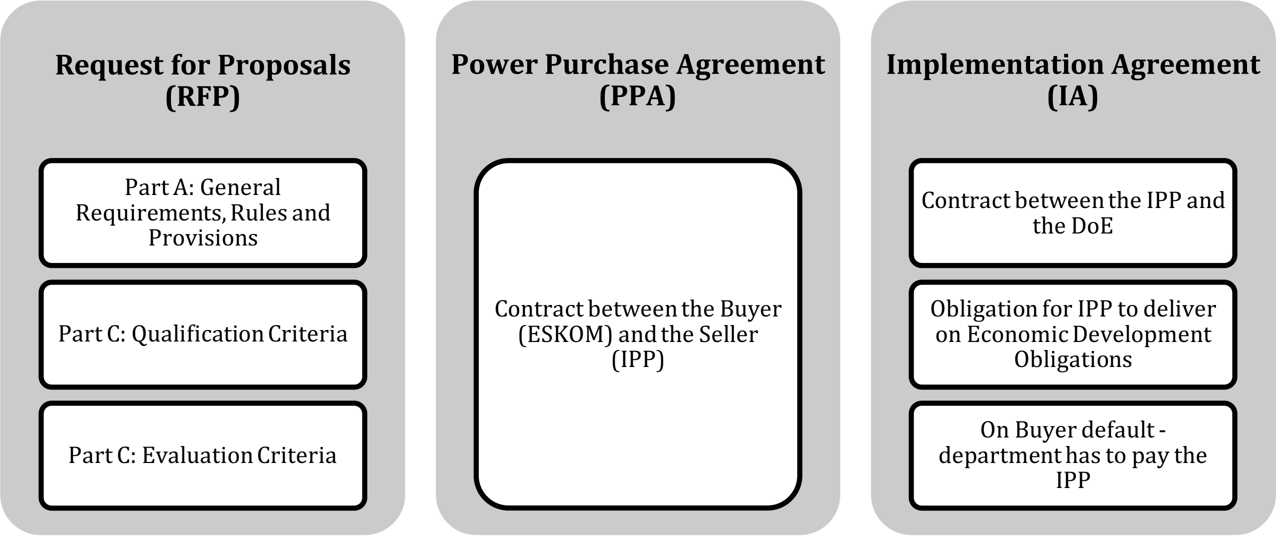

Figure 4: Tender Documents REIPPPP [30]

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[5] *Non-refundable fee (BW 1-5) of 15'000 Rand must be paid to IPP Office of the DoE for administrative work by the department.*

[6] *Following paragraphs are based on insight in the tender documents of the BW1 and BW2*

(iii) **Bid Preparation:** Figure 4 and Figure 5 illustrates the tender documents and respectively the underlying contractual arrangements of the REIPPPP, between the IPP, Eskom and the government, whereas Figure 8 describes the IPP in the bigger context with the energy regulator and the end consumer. [37]

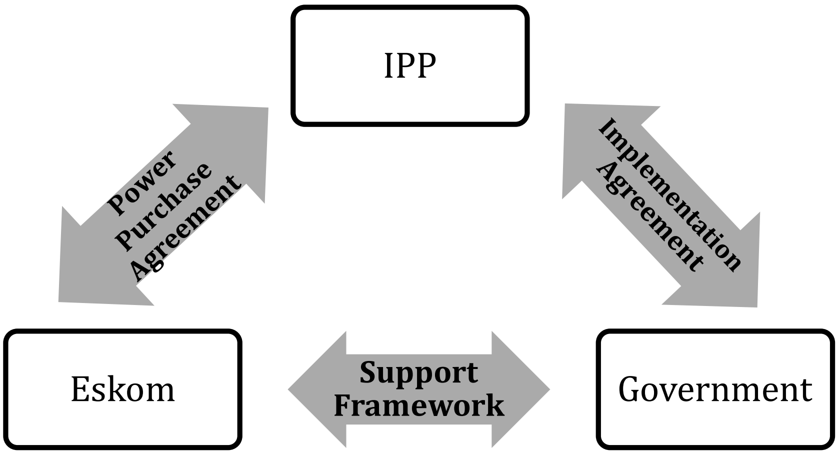

Figure 5: Contractual Framework REIPPP [30]

(ii) Bid Submission: For bid submissions, the projects need to be prepared for the tender according to '*Part A'* of the provided documents regarding inter alia; project structure, contractual arrangements and permitting. Registered projects can submit a proposal on the bid submission date; in the same token a so-called bid bond[7] needs to be placed with a local bank. [37]

(iii) – (iv) Bid Qualification and evaluation: The REIPPPP is by design a competitive tender. After the bid submission, the project's proposal is tested if all requirements are fulfilled and the project qualifies for the tender (Figure 6, '*Part B*'), but as well if the projects are technically and economically feasible as well as in accordance with all laws and regulations. Projects which

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[7] *The bid bond depends on the proposed project capacity. 100'000 Rand per MW results for an average project of about 10 million Rand. This fee is refundable, non-successful projects will be reimbursed. Successful projects (preferred bidders) need to double the amount in order to proceed in the programme.*

passed the qualification-stage are evaluated against each other by use of a scorecard. Figure 6, *'Part C'*, lists the qualification and evaluation criteria.

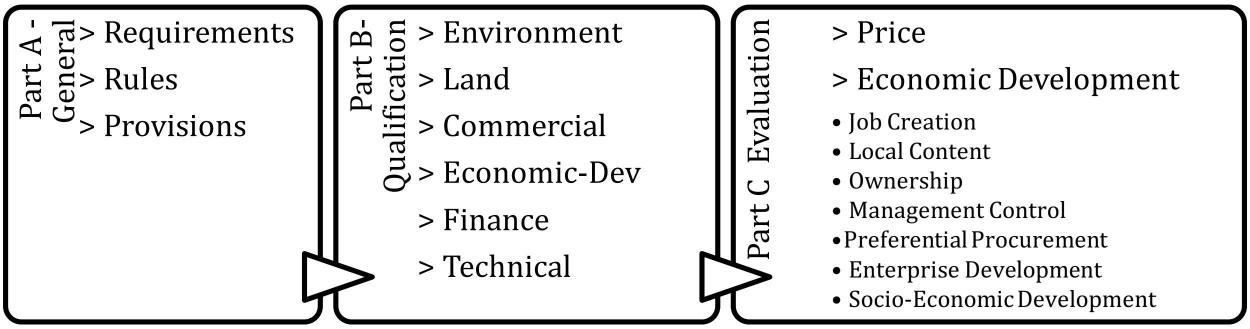

Figure 6: Bidding Stages REIPPPP [27]

As seen in Figure 7, the proposed tariff is the main driver of the project's evaluation, representing 70% of the score; the other 30% is driven by commitments to economic development (ED). [30] [33] These commitments result in EDOs, which are monitored by monthly- and quarterly-reporting during realization- and operation phase of the project.[8] [37]

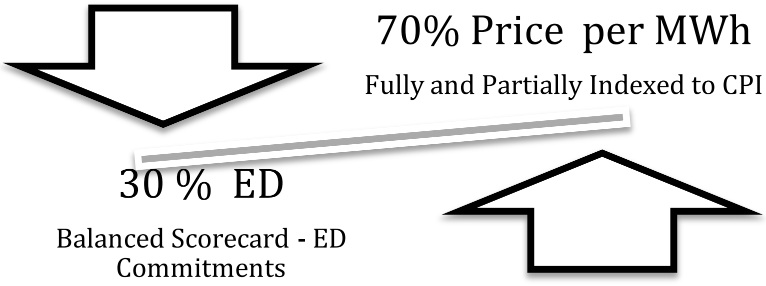

Figure 7: Tariff Influence on Bid Evaluation [30]

(v) Preferred Bidder – Financial Close: The available capacity is allocated to the projects scored highest overall in the bid evaluation. These successful projects are announced as

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[8] *The EDO set the boundaries for later operation and operation management of the project. Any activities need to be in compliance with the set obligations. Non-compliance may result in a project default.*

preferred bidders. Figure 8 shows the structure of the IPP in context with the contractual arrangement. In order to reach FC, the projects need to enter into the agreements with the respective parties. [37]

(i) The *'Generation License'* between IPP and NERSA, which provides the base for generating electricity on a utility scale and the permission to feed into the grid. [37]

(ii) The '*PPA'* between IPP and Eskom's Single Buyers Office, which sets the terms for sale and purchase of electricity, e.g. Price, Grid Code, etc. for the entire operational phase. [37]

(iii) It is to add the *'Implementation Agreement'*, which binds the DoE to the compensation of the IPP in case of a Eskom default and on the other hand, binds the IPP to strict timelines, EDO, etc. [37]

The IPP is the seller of the electricity and the '*Single Buyer Office'* functions as the buyer. The electricity is sold and bought on conditions based on the outcome of the REIPPPP. The renewable energy is added towards Eskom's energy mix and sold to the consumer based on tariffs regulated by NERSA.

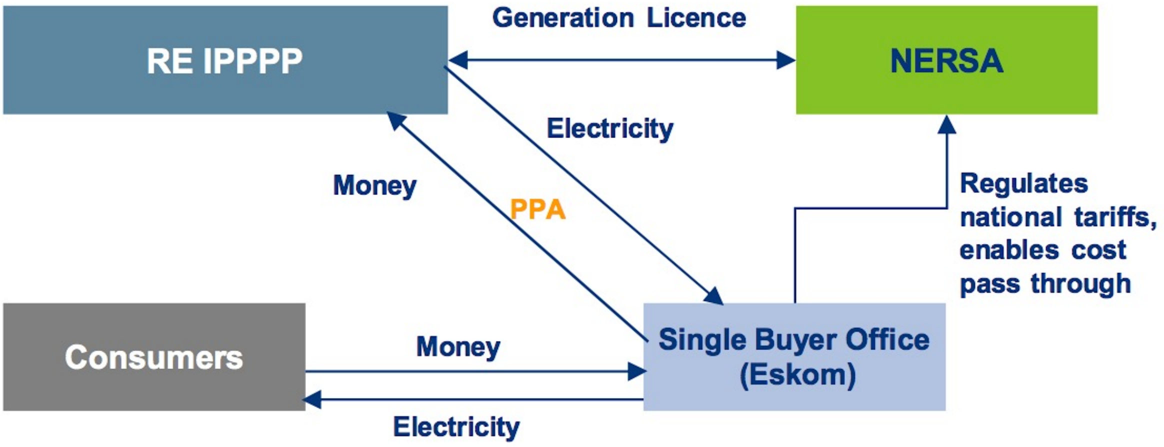

Figure 8: Structure of REIPPPP [30]

2.3.2 Outcome of the REIPPPP

To date, the REIPPPP has procured over 4GW across all technologies in the four BWs. The programme earned international recognition and is perceived in the industry as transparent and on track. From a macro perspective, the process can be seen as a success. Within the first four rounds the prices decreased significantly. [38]

In total 79 projects in the four BWs were announced as the preferred bidders. All projects of BW1 and BW2 reached FC and it is expected that the last two projects will reach FC within 2015. [34]

BW1 and BW2 projects are in construction or reached operational phase already. It is important to mention that projects completed thus far, were on-time and within budget, [39] compared to Eskom’s new build power stations, this may be seen as a great achievement. [40] However, this comparison across the technologies may be based on different requirements. The modularity approach of most renewable energy technologies is a great advantage compared to conventional power stations. To name a few of these advantages even besides the obvious use of *‘renewable resources’* instead of fossil based resources:

(i) Short procurement and construction time lines
(ii) Smaller project sizes reduce overall risk
(iii) Distributed approach strengthens the grid and creates economic upliftment in rural areas
(iv) Competitive pricing

Table 5 provides an overview of the total amount of procured capacity across the different technologies.

	First Bid Window	**Second Bid Window**	**Third Bid Window**	**Fourth Bid Window**	**(Expedited BW Four)**	**Total**
Solar PV	*632 MW*	*417 MW*	*435 MW*	*415 MW*		***1’899MW***
Wind	*634 MW*	*563 MW*	*787 MW*	*676 MW*	*(551MW)*	***(3’211MW)***

CSP	*150 MW*	*50 MW*	*200 MW*	*N/A*	-	***400MW***
Small Hydro	-	*14 MW*	-	*5 MW*		***21MW***
Landfill Gas	-	-	*18 MW*	-		***18MW***
Biomass	-	-	*16 MW*	*25 MW*		***41MW***
Biogas	-	-	-	*N/A*		***0MW***
TOTAL	***1'416 MW***	***1'044 MW***	***1'456 MW***	***1'121 MW***	***(551MW)***	

Table 5: Overview Allocation per Technology REIPPPP [39]

2.3.3 Wind Projects Bid Window 1 to 4

Compared across technologies, wind energy received the highest allocation with 2.6GW and 3.2GW including expedited round 4. Annex I (Table 32) lists all selected preferred bidders with their contracted capacity and province in which the projects are based. When comparing this internationally, the average project size is reasonably larger with a capacity of 98MW.

2.3.4 Tariff Evaluation

From BW1 to BW4 the tariffs of the selected wind energy projects declined drastically, from 1.363 R/kWh to 0.619 R/kWh (both tariffs are based on 2014 financial terms). This decline shows the competiveness of the South African market created by the REIPPPP and can only be achieved by favourable wind regimes on-site and economy of scale using relatively large project sizes, averaging at about 100MW and between 30 to 50WTs per project.

In fact, in many cases these prices were lower than the average generation cost of the Eskom fleet and were in most cases under the estimated cost of electricity of Eskom's new power stations (0.97R/kWh), which are under construction. [41]

A study conducted by the CSIR [42] concluded that wind energy is the cheapest form of electricity in the South African energy mix based on real data of operational wind farms. These plants were procured in BW1 and BW2, which were relatively high priced. A further finding of the study, is that for the first time wind energy is the cheapest form of electricity even without any government subsidies or any secondary costs attached to the ecological footprint of conventional power plants. This finding combined with the high local content and job creation shown in Table 7 illustrates the benefits to the South African economy of this new industry.

	Bid Window 4	Bid Window 3	Bid Window 2	Bid Window 1
2011 terms	*R 519*	*R 656*	*R 897*	*R 1’143*
2013 terms	*R 583*	*R 737*	*R 1’008*	*R 1’284*
2014 terms	*R 619*	*R 782*	*R 1’069*	*R 1’363*
MW Allocation	*676 MW*	*787 MW*	*563 MW*	*634 MW*
Total Project Cost	***R 13’466***	***R 16’969***	***R 10’897***	***R 13’312***
(in 1’000’000)	*(Price based on Avg. / MWh fully indexed)*			

Table 6: Tariff Evolution Wind Energy Projects BW1 to BW4 [40] [35]

2.3.5 Economic Development Requirements

ED requirements for IPPs in South Africa have been controversially discussed and are expensive for project companies. The importance of the ED by government is reflected in the weight of the bid value (30%). The actual figures of the total ED fulfilment (local content, job creation etc.) are illustrated in Table 7 The high job creation and local content can be seen as one of the success factors of the REIPPPP. [1]

	Bid Window 4	Bid Window 3	Bid Window 2	Bid Window 1
MW allocation	*676 MW*	*787 MW*	*563 MW*	*634 MW*
Local Content Value (ZAR Millions)	*R 5’146*	*R 6’283*	*R 4’817*	*R 2’727*
Local Content %	*44,6%*	*46,9%*	*48,1%*	*27,4%*
Job Creation: Construction (Citizens)	*2’831*	*2’612*	*1’787*	*1’810*
Job Creation: Operations (Citizens)	*8’161*	*8’506*	*2’238*	*2’461*

Table 7: Economic Development of Wind Projects BW1 to BW4 [35] [40]

Part of the job creation obligation during operations is passed on to the WFM entity, where the exact figures depend on the specific project. The WFM entity must therefore implement its organisational structure according to the obligations of the specific projects.

2.4 WIND ENERGY PROJECT LIFE CYCLE

The life cycle for wind energy projects consists of four major phases. The phases begin / end when a major milestone is reached and often then responsibilities shift amongst the parties involved.

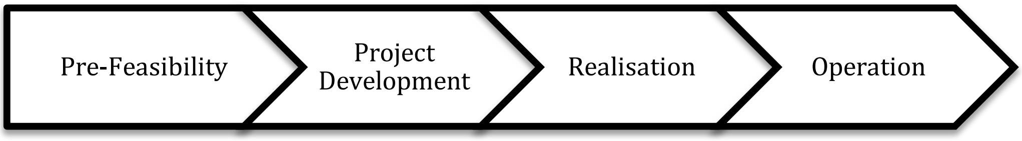

Figure 9: Major Phases of the Wind Energy Project Life Cycle (adapted from [43])

Figure 9 illustrates the four phases, which describe the entire life cycle from cradle to crave. In each phase different stakeholders are involved and different parties have different responsibilities. The project developer initiates the project and develops up to the realisation phase. Often the project is sold by the project developer at FC. An EPC (Engineering Procurement Construction Contractor) builds and commissions the project and is involved until COD is reached. The operational phase starts at COD, from then on electricity is generated for the duration of the PPA.

With regards to WFM, the project development phase sets the basis of the framework for future operations. During the contracting the technology is selected, whereby *'Turbine Supply Agreements'* (TSA) are pre–negotiated, *'maintenance and service agreements'* are outlined for the first period of the operational lifespan. Knowledge regarding operations of WTs is vital for the long-term success of the project. [43] Following aspects should be considered regarding future operations by the developer:

(i) Budgeting for Wind Farm Management
(ii) Technology Selection / WT Selection
(iii) Maintenance Contract Structure

(iv) Interface between OEM and Wind Farm Management

(v) Access to SCADA and CMS Data

(vi) Economic Development Obligations

Due to the nature of project finance any matters not allocated during the financial modelling and tariff calculation will have an impact on the future earnings of the project.

2.5 WIND ENERGY IN PROJECT FINANCE

Project finance can be defined as capital raising for a defined project, which is separable from its owners. [44] The National Treasury describes the objective of using project finance to raise capital for a bankable investment, which is aligned with the investor's interests. Risks may be diverted to external parties who are specialized in order to reduce the risks for the shareholder. For each project a new legally independent vehicle is formed, for which the funds are raised. All expenses (cost of capital, operating expenses) and dividends are derived from the revenue stream of that project. [45]

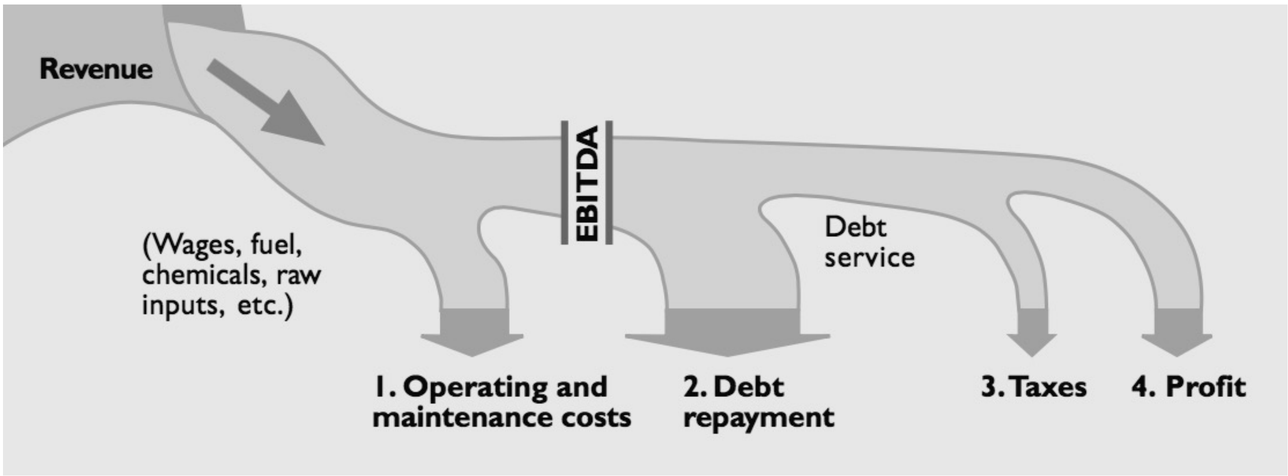

Figure 10: Revenue Waterfall Wind Energy Projects [45]

The difference to conventional corporate lending is that the balance sheet and the overall financial resources of the borrowing entity cannot be taken into account as a possible source for the debt service. The financing is structured around a single project; thus lenders have a non or only limited recourse of a project developer / borrowing entity. A project failure would therefore result in significant financial loss for the lender. [44]

Project finance provides a great option for wind energy project developers to realize a project based on future cash flow.

Figure 11 illustrates the contractual structure of a project financed wind energy project. In South Africa wind energy projects use the legal form of a Special Purpose Vehicle (SPV). The project operates independently from lenders and owners. Revenue is solely generated by electricity sales for the duration of the PPA. The revenue is paid to the owners and lenders after costs. Figure 40 describes in more detail how the structure can be applied for WEFs in South Africa based on the case study.

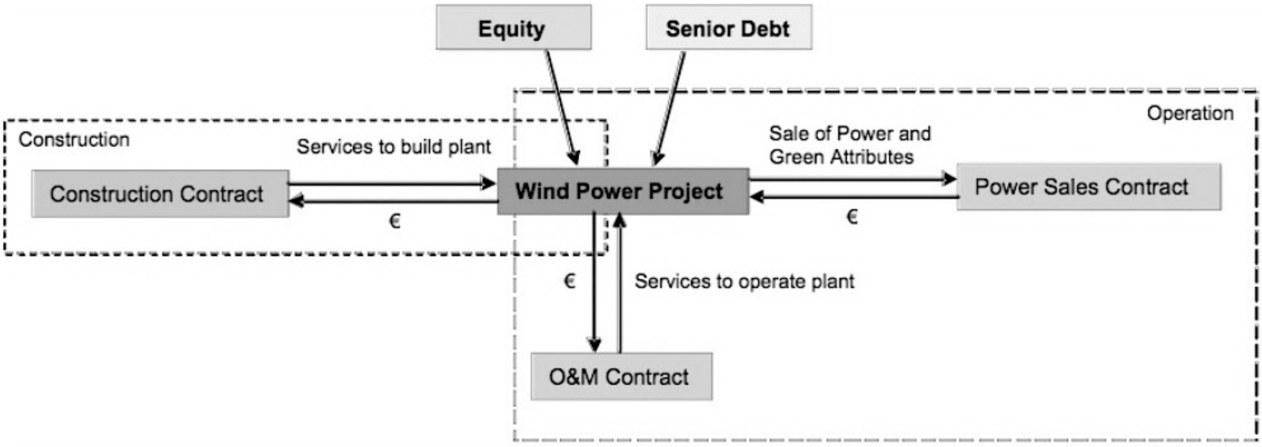

Figure 11: Structure of a Project Financed Wind Energy Project [46]

2.5.1 Wind Energy Value Chain

The importance of understanding the wind energy value chain is highlighted by the following statement:

> *“From the definition of project finance, it is clear that the biggest single risk is that the anticipated cash flows to and from the project is not realized.”* [44]

This poses the question: how does a wind energy project generate revenues and what are the major drivers of the Cost of Energy (CoE)?

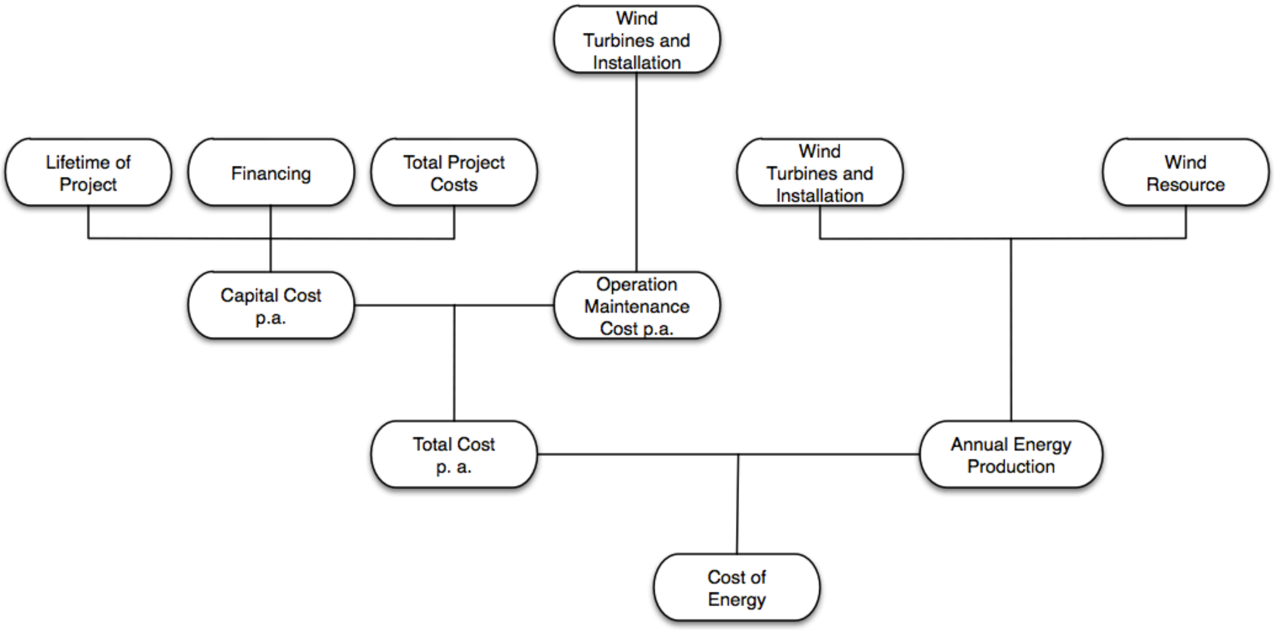

Figure 12: Cost of Energy (adapted from [47])

Figure 12 highlights the most important influence on the CoE as well as cash flow. The income is represented by the product of the AEP and the tariff, which is, in South Africa, set for the duration of the PPA. The expenses are the combination of operational and capital related expenses, where the capital expenses are determined by the total investment, expected lifetime of the project and the profit expectations of owners and lenders and additionally the associated discount rate (see 3.2.1 and 4.1.3 for detailed information). [48]

2.5.2 Importance of Operation & Maintenance in the Context of Project Finance

For a vital wind energy project the project developer has to match the way of financing the project and the operation and maintenance structure. [48]

The operation and maintenance costs are especially important for project-financed projects, which are *'off balance-sheet'*, hence electricity sales are the sole source for repayment of the debt. For the financial model of the project it is favourable if the operational expenses are predictable. A good operation and maintenance contract or strategy is therefore pivotal for the bankability of a project. It helps not only reduce insurance costs by lowering the risk but makes the project attractive for investors who seek safe investments. [49]

WTs are designed to operate up to 20 years. The first phase after commissioning of a WEF is in literature often referred to as *'teething'*. [50] For project financed WEF, the first years of operation are critical, as the project carries a high interest burden (see Figure 38 and Figure 39), while at the same time organisational structures need to be established. Full service contracts covering the minimum first five years, or rather up to half of the operational phase, are for new markets without an established industry a good choice to reduce the associated risk for owners and lenders. For later stages of the operational phase, more cost efficient solutions may be investigated by the owners, while an overview of different maintenance and service contracts are presented in the latter.

2.6 MAINTENANCE FOR WIND ENERGY FACILITIES

Maintenance for WTs is a crucial topic as the selected maintenance regime is decisive for the long-term success of a wind farm. The following paragraphs provide an overview, focussing on maintenance strategies and maintenance contracts. Regarding WFM, the interactions with the maintenance provider (OEM, Independent Service Provider (ISP)[9] or in-house department) is one of the cornerstones of the daily work routine. Where the WFM represents the project's owners, it is driven by the long-term success of the project. The maintenance provider's interests on the other hand are often driven by short- to medium-term goals (fulfilment of the contract to a minimal cost), which are not necessarily in alignment with the owners' interests.

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[9] *Independent Service Provider (ISP) is used in this research paper in the context of maintenance of WEF*

2.6.1 Introduction Maintenance for Wind Turbines

WT are able to operate remotely as opposed to conventional power stations. Additionally, the operating conditions are rather harsh, loads vary due to daily and seasonally changes in wind speeds, turbulences and temperatures. These factors combined result in highly variable operating conditions and high mechanical stress on the entire structure. [51]

The costs for maintenance and service for WTs are decreasing as the technology advances. When referring to the CoE, maintenance accounts to between 20% and 25% of the COE and up to 35% at the end of the WT life. [52] [53]

$$CoE = \frac{ICC\ x\ FRC + AOM}{AEP} \qquad (I)$$

The formula above provides a simplified approach to calculate CoE. *'Initial Capital Cost'* (ICC) and *'Fixed Rate Charge'* (FRC) are fixed. The *'Annual Operation & Maintenance'* (AOM) and the AEP are variable. [10] During the end of the life cycle the AOM normally increases and the AEP decreases. [54]

The demand for maintenance correlates with the accumulation of failures. The '*O&M Best Practices Guide*' describes this dependency, where the failure rate is pictorially represented over the entire product lifespan as a *'bathtub'*. [55]

Figure 13 shows the so-called '*Bathtub Curve*', which represents failure rate (λ) vs. time (t) in mechanical systems. This model can be applied for both single components as well as for the entire system. The model is based on the assumptions that the failure behaviour is predictable. [55]

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[10] *Sample values for clarification of the COE calculation: ICC: 40mio Rand 2MW WT, FRC: 13%, AOM: 1mio Rand per annum including spares, AEP: 5mio kWh @30% Capacity Factor.*

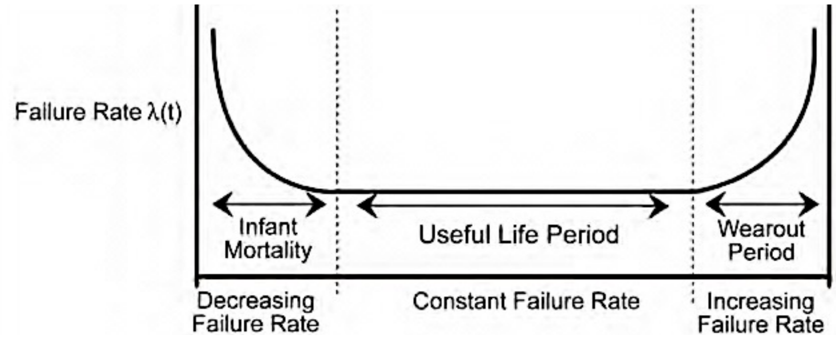

Figure 13: Component Failure-Rate over Time – 'Bathtub Curve' [55]

A study on over 1500 WTs in Germany analysed the frequency of failures in more detail and grouped them accordingly. One of the outcomes of the study is that the five most frequent failure groups account for three quarter of the total failures. [56]

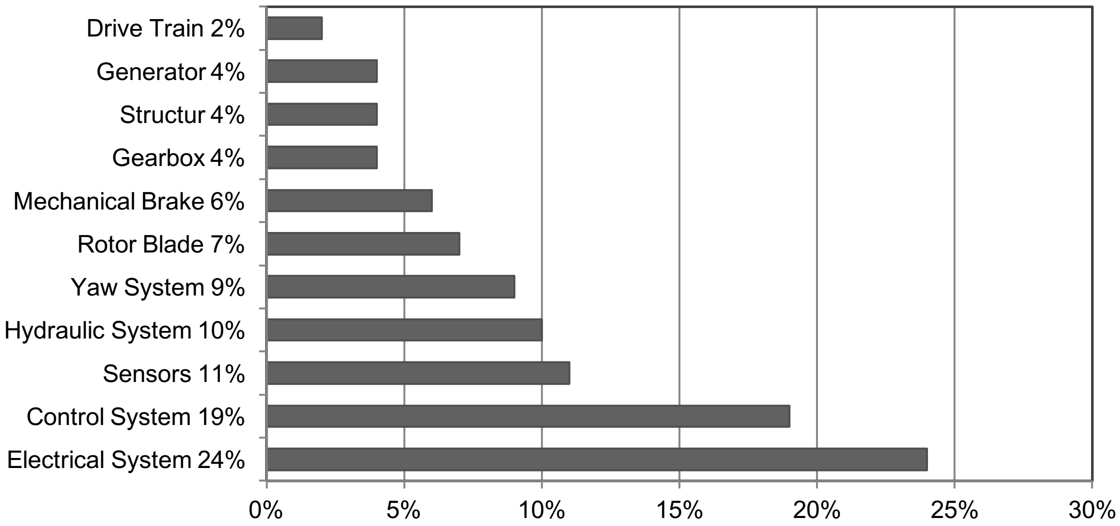

Figure 14: Failure Allocation per Subsystem [56]

The groups with the highest failure occurrence are namely the electrical system, the control system, sensors, hydraulic system and yaw system as shown in Figure 14. The impact a failure causes on the operation and profitability of the project does not correlate directly with failure-frequency, aspects such as resulting downtime, lead time, costs for replacement or repair should be taken into account. Figure 15 illustrates the relationship between failure rate per WT per year and the resulting downtime based on two studies over a period of 13 years (LWK represents

5’800 WTs, WMEP represents 15’400 WTs). It is important to mention that the failures which are least frequent (inter alia: rotor blades, gearbox, drivetrain) result in rather high downtimes. [56] - These findings should be kept in mind when setting up the maintenance strategy.

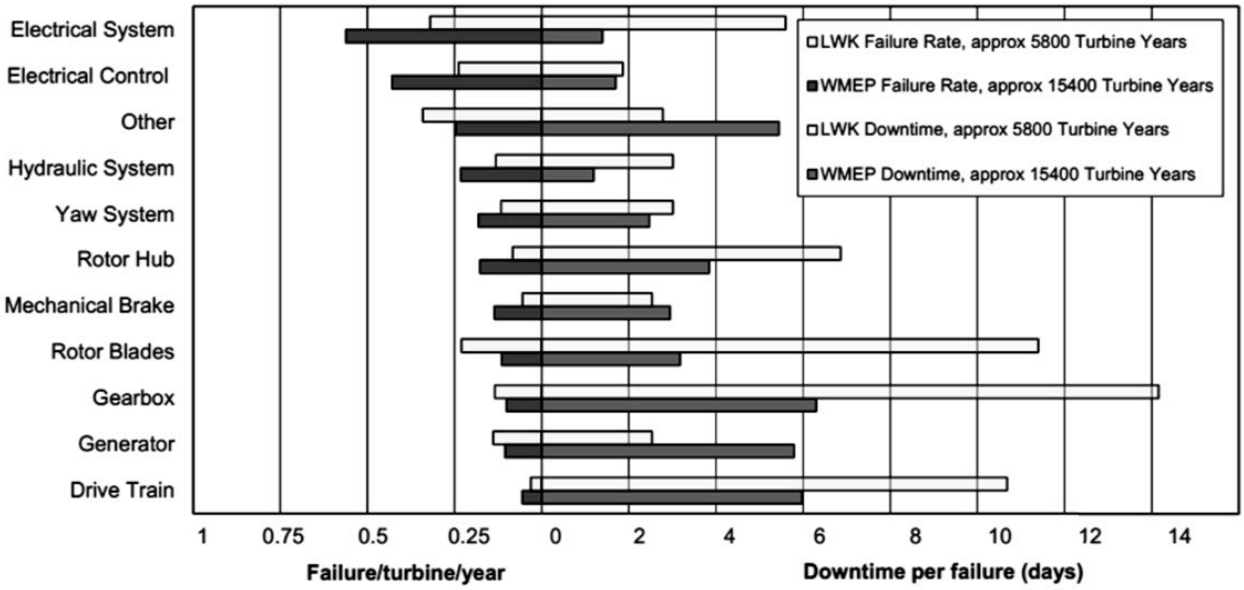

Figure 15: Relationship: Failure-Rate and Downtime of European WTs over 13 Years [56]

2.6.2 Maintenance Approaches

Figure 16 illustrates the relationship between costs and number of failures. The costs are represented by two graphs. Firstly, the repair cost and secondly, the prevention cost. The total cost is the simple addition of both graphs. The different maintenance strategies, according to industrial standards can be derived as follows: [57]

(i) Reactive Maintenance or “run-to-failure”
(ii) Preventive Maintenance or “time-based”
(iii) Predictive Maintenance or “condition-based”

Reactive maintenance runs the system until failure, resulting in high cost for replacement or repair of the faulty part and secondary damages. Preventive maintenance results in high costs, as parts are exchanged before *'end of life'* is reached; this results in high downtimes and procurement costs.

The optimum trade-of between repair costs and prevention costs results in the least system costs, this optimum can be reached using condition based or predictive maintenance. Parts are exchanged / repaired based on their actual condition. In other words, no action is taken as long a safe and efficient operation is ensured. This minimises labour and procurement costs and guarantees a high uptime of the system. The prevention cost is the cost reflecting the condition monitoring effort.

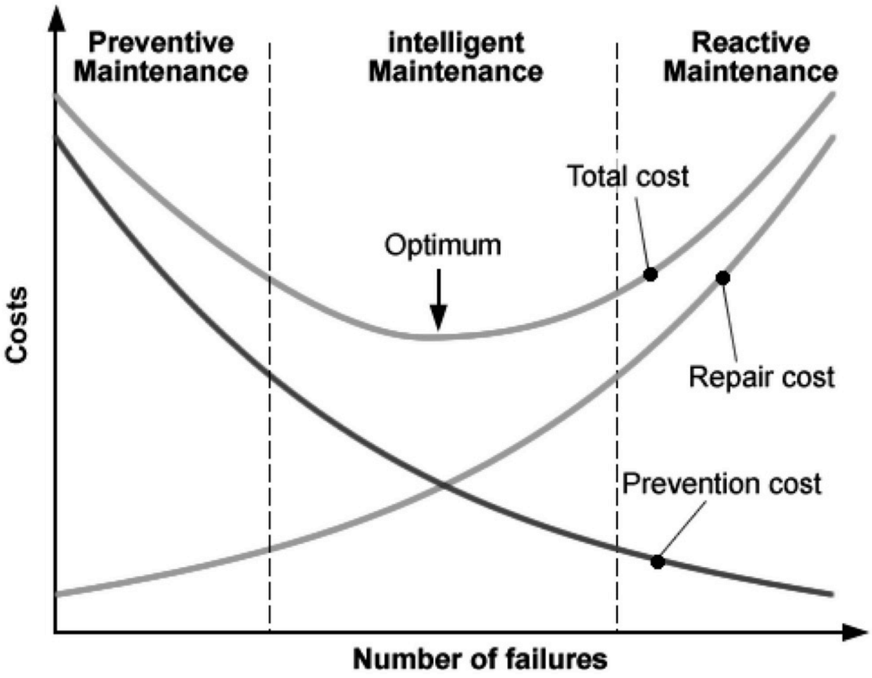

Figure 16: Three different Maintenance Strategies [57]

Reactive Maintenance can be defined as – *'run until it breaks'*. No actions are taken to keep the equipment running before a failure occurs. A special form of a corrective maintenance is reactive maintenance. WT maintenance and service providers prepare for common failures by inter alia keeping spare parts on stock. This should minimise downtime and thus the revenue. [57]

Advantages: *Low cost / Less staff*

Disadvantages: *Increased costs due to unplanned downtimes of WTs / Increased labour costs due to overtime / Secondary damages may caused by equipment failure*

If new equipment is used, one assumes a low failure rate. The use of mainly reactive maintenance is less expensive than other maintenance-models, until a failure occurs no expenses for maintenance-staff and for services arise. For WTs, other arguments have to be considered which show the disadvantages of this model. WEFs are often located in remote areas, which result in long response times for maintenance staff, acquiring of spare parts etc. The resulted downtime could occur during periods of high wind speeds and high production. Even though this way of operating could be cheaper, it decreases the overall performance, whereby production losses have to be taken into account in order to calculate the real cost. In terms of project finance, the risk of equipment failure and resulted secondary failure increases the overall project risk.

Preventive Maintenance defined according to the '*Operation and Maintenance Guide'* as *"all actions performed on a time- or machine-run-based schedule that detects, precludes, or mitigates degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level"* [55]

Advantages: *Cost effective / Increased equipment lifespan / Reduced equipment failure*

Disadvantages: *Labour intensive / Includes unneeded maintenance / Unplanned failures can still occur*

The big advantage of preventive maintenance is that the downtime is planned and service can be carried out in periods of low wind speeds, where the impact of the downtime on the energy production is minimal.

Predictive - Condition Based Maintenance represents the maintenance strategy with the least overall costs. However, it is based on additional monitoring which comes at a price and requires a vast understanding of condition monitoring and material science. Not all components can be monitored. Different parts or subsystems require different solutions for monitoring their condition. In the latter, condition monitoring is explained in more detail. In general, a condition monitoring concept for the specific WT, in conjunction with the maintenance strategy, needs to be set up.

Availability is the Key Performance Indicator (KPI) to determine reliability and correlate with the energy production. It is therefore a good measure to evaluate maintenance service providers.

$$A = \frac{MTBF}{MTBF + MTTR + MWT} \tag{III}$$

Availability[11] can be expressed as shown in the formula above by *'mean time between failures'* (MTBF), by *'mean time to recovery'* (MTTR), which represents the repair time and additionally *'mean waiting time'* (MWT) representing e.g. crane availability and work schedules. [58]

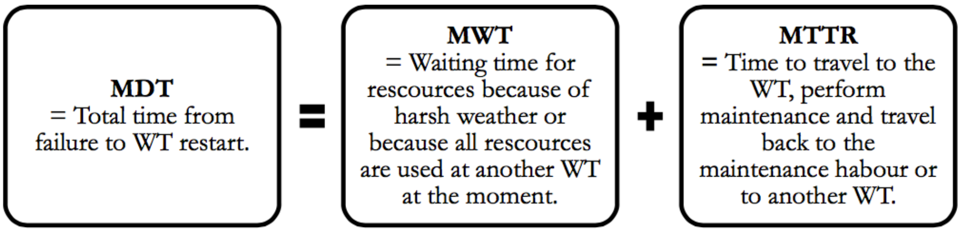

Figure 17: Explanation of Downtime [58]

The total downtime[12] (*'mean down time'* (MDT)) is the combination of MTTR and MWT as illustrated in Figure 17. According to the downtime and associated repair / replacement costs, components and subsystems, for which condition monitoring should be considered, can be identified.

According to Figure 15, gearbox faults are very unlikely (failure rate: 0,12). However, these faults can result in a prolonged downtime and high replacement costs. Based on the high overall cost

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[11] *Availability from a WFM perspective is based on different calculations, which are explained in the latter.*

[12] *Downtime from a WFM perspective is based on different calculations, which are explained in the latter.*

associated with a fault, monitoring gearboxes will most likely lead to cost reduction by optimised maintenance approach.

2.6.3 Operation and Maintenance Market

Previously in the wind industry the service and maintenance was normally carried out by the OEM. In the rapid evolving European market, ISPs joined the service sector of the wind industry with a small but growing market share. [59]

The OEMs are in an advantageous position, with the extensive knowledge of the installed WT and its technology. Maintenance and service contracts often go hand in hand with the mandatory warranty or begin seamlessly after the warranty period. ISPs contracting projects towards the end of the lifespan and through collaborating with rather bigger developers, who have a good insight into the technology and use ISPs to back up there in house maintenance department as well as project owners who want to be “in control” of their own project. ISPs are often able to offer maintenance and service as well as spare parts for competitive pricing. However, ISPs are often not prepared to offer full service contracts, which include availability guarantees and spare part provisions for a fix fee. [60]

In the European market a 70% share of the operation & maintenance is taken by the manufacturers and the ISPs increase their share on matured markets like Germany, Denmark and Spain. In other markets the dominance of the OEMs is even bigger with about 90% market share. [59] However, the decline in WT sales between 2008 to 2010 was for the OEMs a hard hit [61], due to the fact that the O&M market promises steady incomes, it therefore became more important for the OEMs.

At this time, nearly all ISPs are geographically limited. To build up a supply chain for spare parts and training staff takes time and effort. Therefore, it is more likely that the South African market will be accessed by the OEM first. The time ISPs have to settle is before the warranty period of the projects’ end in about five to ten years. [62] The immaturity of the market will be a big obstacle even in five years' time and it is more likely that the local service industry will grow when the market matures. Furthermore, lenders in South Africa often require long-term contracts with the OEM to minimize the associated risk.

2.6.4 Maintenance Contracts for Wind Turbines

The following paragraphs briefly introduce the different contractual structures of maintenance and service contracts. Manufacturer's warranties normally cover the first two, or up to five years, of the WT's lifespan. The need for seamless cover over the whole project's lifetime was discussed earlier on. [63] The *'Best Practice Guidelines'* from the Irish Wind Energy Association outlines this topic briefly. Maintenance and service contracts should be concluded with experienced affiliates. Contracts normally determine a defined duration; include performance standards and the right to replace the operator for non-performance. The performance has to be measured against a benchmark. [64]

2.6.5 Contractual Structures

Wind project developers try to find the most suitable operation and maintenance solution. To a great degree performance warranties and experience of the service provider play a role as these factors may result in lower associated risk and thus decrease the cost of capital. [62]

Matured markets were for a long time dominated by *'Cost-Plus-Fixed-Fee'* contracts. The service provider charges a fixed rate for certain services according to a term sheet. All additional labour and parts are invoiced pro rata. [65]

New markets where projects are most of the time project financed, created the need for more secure long-term contracts, which was mainly driven by lenders requirements. Full service contracts, a variation of fixed price contracts, as defined below became the standard for emergent markets.[13]

> **Fixed price contracts – Definition:** *"Contract that provides for a price which normally is not subject to any adjustment unless certain provisions (such as contract change, economic pricing, or defective pricing) are included in the agreement. These contracts are negotiated usually where reasonably definite specifications are available, and costs can be estimated with reasonable accuracy. A fixed price contract places minimum administrative burden on the contracting parties, but subjects the contractor to the maximum risk arising from full responsibility for all cost escalations."* [66]

Full Service Contracts: The performance of the service contractor is linked to disincentives - and incentives which are based on contractually agreed KPIs. These contracts are often outcome based and do not determine the exact maintenance strategy. The incentives and disincentives are rewarded by higher respectively lower payments linked to the project performance.

The actual service is measured against KPIs, which are in South Africa normally technical availability and energetic availability. *'Service Level Agreements'* define the mutual understanding of how to measure the KPIs. Full service contracts are summarised below: [67]

(i) All accruing costs are covered (e.g. regular maintenance, trouble shooting, spare parts, cranes, updates, transport etc.)

(ii) 97% or 98% guaranteed availability per year of operation. If the availability is below warranted terms, the OEM issues the customer a credit note for the yielded loss caused by the shortfall of availability.

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[13] *Based on consulting, Mike Mulcahy, Green Cape, Cape Town, South Africa, June 2013*

Availability is the most often used performance measurement and directly related to the revenue. That makes an understanding of that term essential. Technical availability and energetic availability in the context of WFM are explained in 3.2.1.3.

2.7 TECHNICAL BACKGROUND OF WIND TURBINES

This paragraph deals with the theoretical basis and general function of WTs, without going into details; a broad understanding of the technology needs to be provided as a basis for the following chapters.

WTs extract kinetic energy from the wind. The moving air slows down by passing the rotor. The air stream creates an aerodynamic lift force on the suction side of the blades when it passes the so-called rotor-swept-area.

Energy is transmitted in the form of torque through the main shaft to the rotor side of the gearbox. The gearbox translates the high torque of the main shaft (10 to 20RPM) into low torque on the high-speed shaft, which is connected to the generator (up to 1900RPM). The generator translates the torque into electrical energy. [68]

2.7.1 Available Power in the Wind

The available power in the wind is determined by air mass $\mathrm{d}m$ passing the rotor swept area A_r. In a certain time-step $\mathrm{d}t$, assuming the wind moves with constant velocity v in $\mathrm{d}t$ by $\mathrm{d}s = v \cdot \mathrm{d}t$ with a volume $\mathrm{d}V = A_r \cdot \mathrm{d}s$. Based on the specific air density ρ the mass stream passing the rotor is: $\mathrm{d}m = \rho \cdot A_r \cdot v \cdot \mathrm{d}t$. The power of the wind in this incremental time-step is $P = dE/dt$. [69]

$$E = \tfrac{1}{2} dm \cdot v^2. \qquad (III)$$

$$P_{Wind} = \frac{dE}{dt} = \frac{1}{2}\rho \cdot A_{rotor} \cdot v^3 \qquad (IV)$$

The formula describes the available power in the wind. Not all the power can be absorbed by the WTs, as this would result in slowing the wind speed down to zero velocity. In other words, bringing the airflow to a standstill. Betz described the maximum of the extractable energy in the power coefficient C_P also known as the *Betz Limit* $C_p = \frac{16}{27} = 0.593$. [69]

Modern WTs are further developments of the so-called Danish-Design[14]. The Danish-Design categorises WTs, which can be described as, upwind, horizontal axis, three-bladed and fix-speed. The drivetrain consists of; rotor, main-shaft, gearbox and generator. This type of WT makes use of the stall-effect for the power regulation[15]. [70] As the technology matured, the requirements of this technology evolved inter alia grid code requirements became more sophisticated. Variable speed concepts were implemented to fulfil the newly set standards, which led to the development of modern WTs. Two design concepts have proven themselves to be suitable for a large-scale application of the gearbox-concept and direct drive concepts without gearbox. The major difference to the Danish-Design is the type of power regulation, which is for modern WTs realised by pitch-control,[16] instead of the stall effect. [70]

2.7.2 Power Regulation

Power curves of both concepts are compared in Figure 18 In general, power curves of WTs can be described by three values; cut-in wind speed (v_c), the minimal wind speed required to start operation, rated wind speed (v_r) the wind speed required to generate rated power output and the cut out wind speed (v_f). If wind speed exceeds this value, operation is stopped, the nacelle yaws

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[14] *WTs used at the Darling Wind Farm are designed according to the Danish-Design. Furhländer FL1300*

[15] Stall regulated WTs have the rotor blades mounted onto the hub at a fixed angle. The blades are designed that once the maximum wind speed is reached, the turbulences on the trailing edge of the blade increase and thus prevent an increase of the lifting force acting on the rotor. [109] This results in a constant rotor speed at rated capacity.

[16] *Electronic control systems measure the power output of the WT constantly, if the power output exceeds the rated capacity, the blade pitches incrementally out of the wind and vice versa once the power output decreases. Thus the rotor speed can vary by constant power output. [109]*

out of the wind to minimise loads on the structure. Modern WTs operate between 3m/s and 25m/s and reach rated power at about 12m/s. The ramp up to v_r reflects the cubical relationship between the power in the wind and the wind speed as described in the previous paragraph. WTs optimized for low wind speeds perform closer to the theoretical power in the wind during the ramp up. [71]

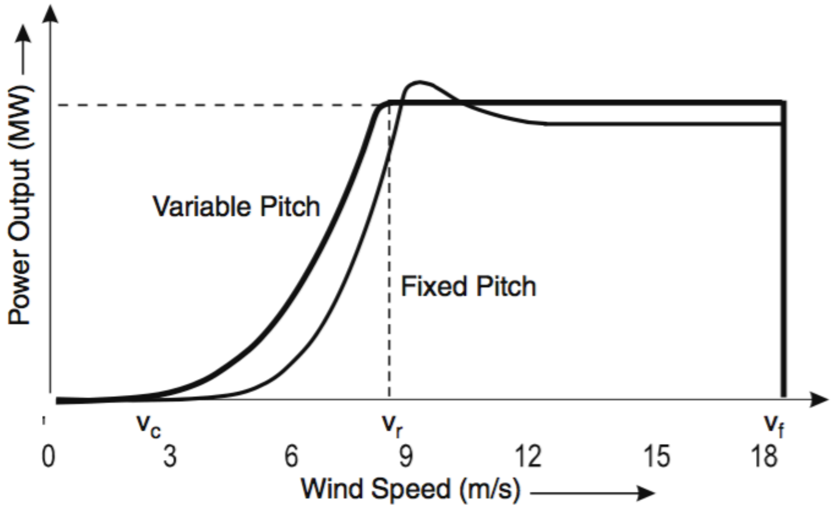

Figure 18: Power Curves of stall regulated and pitch controlled WTs [71]

Pitch-controlled (variable speed) WTs are able, due to the active power regulations, to perform close to rated power until the wind speed reaches the '*cut-out speed'* and the nacelle turn out of the wind. Stall-regulated (fixed speed) WTs have a distinctive power curve, which decreases slightly once rated power is reached by increasing wind speed. The major difference in performance can be seen by low and medium wind speed, where variable speed WTs are able to extract more energy out of the wind, due to favourable blade geometrics and optimal control strategy. [72]

At this stage all WTs successfully procured in South Africa make use of the modern WT's design with gearbox, thus this study focuses on this type of design.

Modern WTs similar to the ones procured in South Africa are illustrated in Figure 19. To summarise the WTs used are: upwind, three bladed, gearbox, pitch regulated on a hub height between 80m to 100m and a total height (ground – blade tip) up to 160m. The capacity ranges between 1,8MW to 3MW.[17] In the latter the different drivetrain concepts for modern WTs are explained.

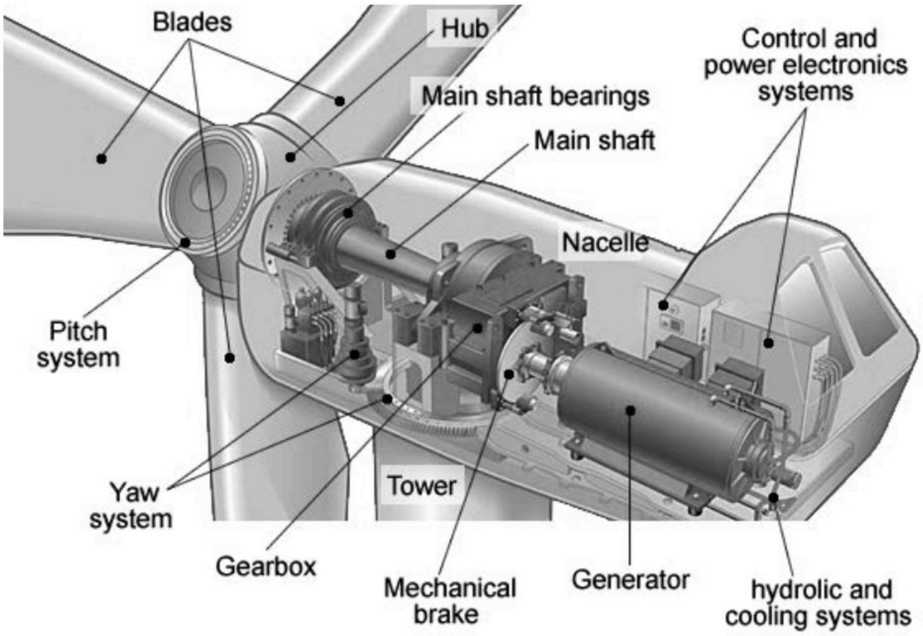

Figure 19: Modern Wind Turbine and its Components [53]

2.7.3 Modern Wind Turbine Concepts

The electro-mechanical design of WTs was constantly improved in the recent past. Two major designs are generally accepted and represent the majority of new installations. The general concept is to extract energy from fluctuating wind stream and transform this kinetic energy into electrical energy according to grid requirements (AC / 50Hz / 690V). Modern designs can be categorised into two major concepts partially and fully inverted systems. Partially converted systems use inverters scaled to about 30% of the rated power, which brings a price advantage over fully inverted systems. Fully converted systems are superior regarding grid compliance. [73]

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[17] *Based on the excessive analysis of the 'NERSA consultation process' for REIPPPP (accessed online under: http://www.nersa.org.za/Admin/Document/Editor/file/Consultations/Electricity/Presentations).*

2.7.3.1 Double Fed Induction Generator Concept (DFIG)

The DFIG Concept (Figure 20) consists of a gearbox, asynchronous generator and a power converter. The power converter performs the reactive power compensation. The speed range which the WT can perform is interlinked with the scale of the power converter. The inverter is normally scaled to about a third of the nominal power, which allows the WT to perform at +/- 30% of the rated speed. [74] Small converters, compared to synchronous machines have rather simple asynchrony generators, making this concept economically attractive.[18] [74]

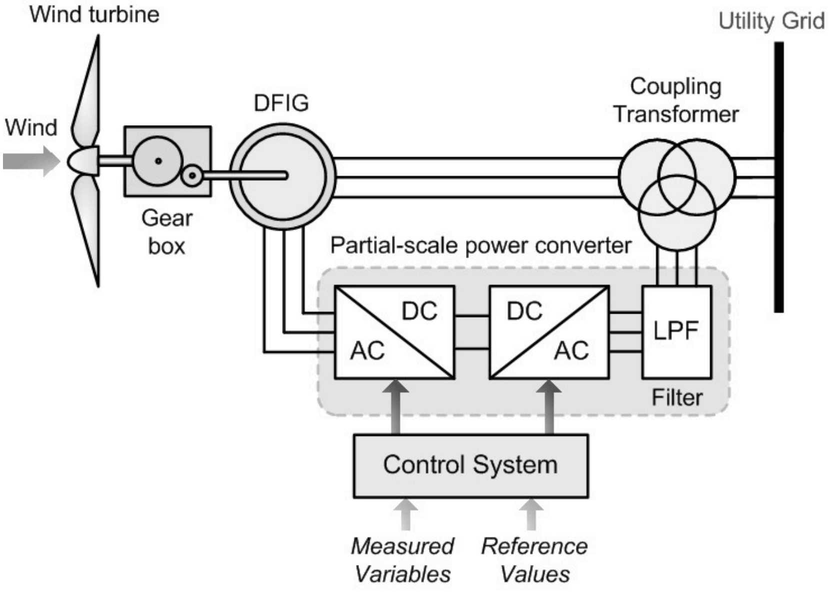

Figure 20: Modern WT using DFIG – Partially Inverted Drivetrain Concept [75]

Asynchronous Generator

DFIG are the most common generators used in WTs. The technology is robust and simple. The drawback is that the stator needs a reactive current for magnetising, therefore slip-rings are required. The excitation current is normally supplied by the grid, which results in the consumption of reactive power. [74]

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[18] *The DFIG Concept is used by many OEM, e.g. Vestas, Nordex, Suzlon, Senvion. The specification of a MM82 are an example for this concept: Generator voltage: 690V Generator speed range: 900–1800 rpm Rotor speed range: 10–20 rpm*

2.7.3.2 Fully inverted concept

The fully inverted concept (Figure 21) makes use of inverters scaled to the nominal capacity of the generator. The entire power output is converted to direct current and is converted back to alternating current. This concept works with both asynchronous wound rotor induction generators (WRIG) or synchronous generators, which can either, be a permanent magnet synchronous generator (PMSG) or an electrically excited wound rotor synchronous generator (WRSG).

The full power control of fully inverted concepts disconnects the relationship between the rotor speed and the grid frequency, thus the WT can nearly operate at any given rotor speed. Thus gearbox-less (‘*direct-drive*’) WTs are based on this concept. Direct drive WTs make use of large scale multipole generators[19]. [74] Further, according to Ackermann, the power converter acts as a buffer for gusty winds and transients on the grid side.

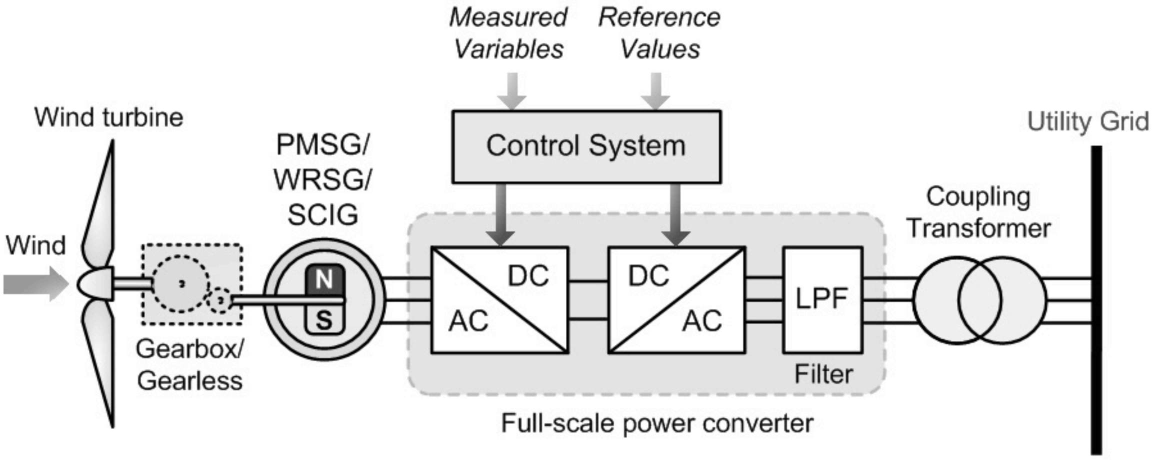

Figure 21: Modern WT using SG– Fully Inverted Drivetrain Concept [75]

Synchronous Generators

Synchronous Generators (SG) are more complicated and expensive compared to asynchronous induction generators. The advantage is that SGs do not draw reactive power to magnetise the

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[19] *Enercon can be used as an example for direct driven fully inverted WT using WRSG multipole generators. The shape of the nacelles is distinctive, compared to the DFIG concept.*

stator field. The magnetic fields can be established by either conventional field windings or permanent magnets. SGs can be used for direct-drive and gearbox concepts as illustrated in Figure 21. PMSG and WRSG represent the majority of SGs used in the wind energy industry. [74]

2.8 CONCLUSION

This concludes the research foundation. The nature of the TEFS required the research background to include market, regulatory, technical as well as financial aspects.

In this chapter firstly the energy and policy background of wind energy in South Africa was introduced, which outlines the scope of the market but as well the political motivation, which stands behind including renewable energies in the South African Energy Mix. Energy production on utility by IPPs in the not yet liberated market is a novelty, in combination with the REIPPPP, which outlines the regulatory framework for WEF, the challenge is to manage a new technology, which is not vertically or horizontally integrated at this stage. The procurement process has proven to be effective in the determination of allocation, however there is no experience regarding operations of projects developed for this competitive process and thus no precedence set how the regulatory-policy framework reacts on default or underperformance of one of the involved parties (inter alia: OEM, DoE, Eskom, grid connection, IPP, lender).

In a second step the financial and technical aspects of project financed WEFs are discussed. This sets a sound research basis in order to investigate the scope of work for WFM and how WFM can influence minimize the operational risk and the profitability of wind energy projects, which is discussed in details in the following chapter.

CHAPTER THREE:

DEVELOPING A FRAMEWORK FOR WIND FARM MANAGEMENT

The previous chapters dealt with the background of technical, financial and further aspects of the research foundation. Therefore one can derive what needs and requirements are essential in order to effectively implement independent Wind Farm Management of WEFs in South Africa.[20] This chapter provides firstly an introduction of WFM and secondly outlines the requirements based on local conditions.

3.1 INTRODUCTION TO WIND FARM MANAGEMENT

Figure 22: Main Elements of Wind Farm Management (author's compilation)

WFM is derived from the general understanding of operations management, which is commonly related to goods producing plants. However, the overall definition is applicable to WEFs:

> *"Operations management refers to the administration of business practices to create the highest level of efficiency possible within an organization. Operations management is concerned with converting materials and labour into goods and services as efficiently as possible to maximize the profit of an organization."* [76]

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[20] *The requirement analysis and its underlying assumptions are based on job shadowing of daily processes and tasks at an established WFM service provider in Germany (Energy Consult GmbH for TOM and BGZ Fondsverwaltung for BM, brands of WKN AG). A detailed timetable of the contact period (2014/06/24 – 2014/07/08) can be found in Annex VI.*

In order to have a better understanding of the role operations management plays for WEFs, it is required not only to have an understanding of the framework, but as well of the WT's technology. This has been briefly outlined in previous chapters.

In South Africa, WEFs are mainly project financed. Debt (lenders) and equity providers are driven by Internal Rate of Return (IRR) and Return on Investment (ROI) and often do not have a greater understanding of managing the technology. The role of WFM is to ensure the shareholders expected returns are met by firstly, overseeing / monitoring the technical operations of the plant, and secondly by managing the project finance structure and its contracted parties. On the highest-level, operations management can be seen as the link between the finances and the technology.

Figure 23: Stakeholders of Wind Energy Projects (author's compilation)

Figure 23 provides an overview of the different stakeholders in a WEF. During the lifecycle, each stakeholder requires a different level of attention and information. The WFM entity acts as the link between all the parties involved and acts in the owner's interest, with the aim to operate the

WEF as efficiently as possible. As illustrated in Figure 22, WFM can be subdivided into two fields. BM and TOM are both explained in the latter paragraphs.

3.1.1 Business Management

The function of BM, or so-called ‘*SPV-Management*’, is to represent the shareholders and to engage with all contracted parties and stakeholders. The monitoring of the performance of the equipment and the contracted parties is substantial for the success of a project financed wind energy project. The BM unit is in full control of all accounting related matters. In addition, it organises annual general meetings, audits and supports in all taxation matters.

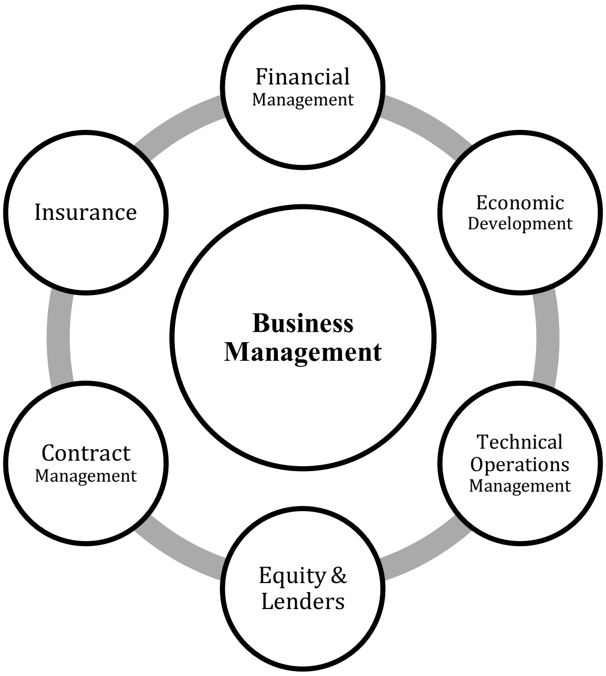

Figure 24: Business Management in Context (author’s compilation)

In other words, the BM team is well informed of the entire project’s financial and technical aspects, its past, current and planned status.

The technical reports are provided by the TOM and form the basis together with the financial information for the informed decision-making. The BM reports directly to the owners and lenders.

3.1.2 Technical Operation Management

The TOM unit calculates and verifies the reports (maintenance, availability, etc.) of the service company. A daily interaction with the service company is a normal procedure. The core of TOM is the remote monitoring of the overall plant's and the single WT's performance. This is done in aid of a powerful software tool (Technical Operations Management System), which allows one to trace and analyse all the data sent by the WTs.

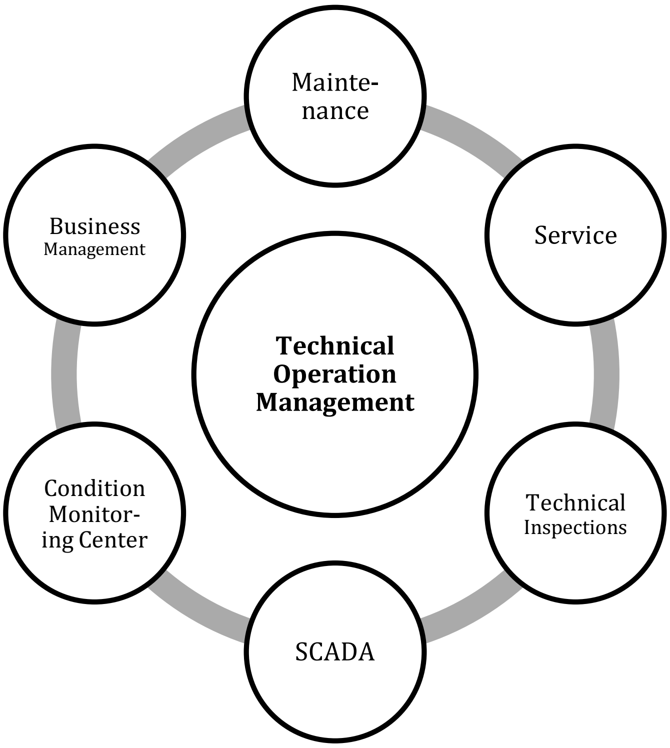

Figure 25: Technical Operations Management in Context (author's compilation)

All technical information is gathered and evaluated by the TOM. Information, that is relevant for decision-making, is reported to the BM unit. In order to monitor the performance of the WEF and its maintenance provider, additional information gathered from technical inspections, SCADA[21] and condition monitoring are utilised.

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[21] *SCADA (supervisory control and data acquisition) is a system, which provides control of remote equipment through dedicated data channels and defined status codes.*

3.2 REQUIREMENTS ANALYSIS

In order to operate a WEF efficiently and to maximise IRR, proper TOM is crucial. The technical operator's aim is to increase availability through forward-looking action.

In contrast to other power generation assets, the maintenance and operation of WTs and WEFs is often subcontracted to third parties (OEMs or ISPs). Financial and institutional investors are often purely interested in the returns and not in the management aspects of the project. Often monthly reports reflecting the financial, technical status and production figures are sufficient for the owner as opposed to investors who focus on power generating assets of so-called utilities or IPPs.[22]

As shown in the previous chapter, the market in South Africa is split on the one side between local or institutional investors and on the other side European utilities. All projects are in need of proper WFM. However, the starting conditions are fairly different. IPPs often finance on balance sheets (*'corporate lending'*) and have vast in-house knowledge and capacities in asset management of energy producing facilities (not necessarily for WEF). Institutional investors have to work in the boundaries of project finance. The main drivers for all investors are IRR and ROI, utilities however could have secondary drivers, namely: obligations to balance their overall carbon emission of their energy generating fleet.

The requirement analysis is based on project financing of wind energy projects owned by institutional investors.

3.2.1 Understanding the Wind Energy Value Chain

The wind energy value chain as described in the previous chapter is based on WFM for projects developed under the REIPPPP. In order to analyse the requirements for WFM, the key is to draw

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[22] *In the South African market active utilities are amongst others: Enel, EnBW, Building Energy [1]*

up and analyse the project's specific value chain, including restraints regarding technological, economical and policy aspects as outlined in the framework in the previous chapter. A generalised approach is illustrated in Figure 27 (the specific application is illustrated in chapter 4.1.3).

The aim of the WFM is to act in the owner's interests. This includes meeting the assumed energy production and financial targets. The WFM strives to produce sustainable high returns by minimising expenditures and maximising energy production. During the project development phase, extensive modelling and scrutiny was used to put together a viable, competitive project proposal which satisfies investors and lenders. A few specific drivers determine the IRR of a wind project due to the nature of the project finance and the REIPPPP. Most of the key factors are fixed over the entire project's lifespan or at least are *'locked-in'* for the first years of operation.

The competitive aspect of the REIPPPP creates a trilemma for the project developer: The tariff should be '*low'* in order to win the bidding process; the IRR should be *'high'* in order to compete with alternative investment opportunities. This contradiction may affect the technology selection (WT make and model). The technology selection in the South African market is generally a turnkey solution consisting of turbine supply, installation, commissioning and subsequent long-term full service contract. In projects where the project developer exits by reaching FC, the developer has no direct financial benefit of choosing the most suitable technology and / or negotiating the contractual framework according to long term asset management aspects.

This trilemma emphasises the need for checks and balances during the operational phase. Stringent contract management and technical health management by the WFM should be implemented to counter any gaps in the contractual framework and to safeguard the shareholders' interests.

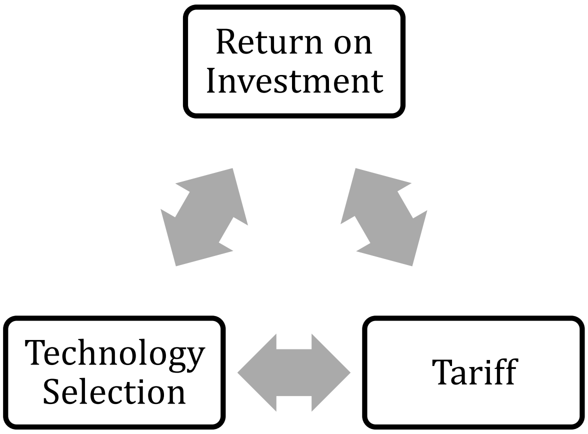

Figure 26: Project Development Trilemma (author's compilation)

Figure 27 illustrates key drivers, which have an impact on the IRR of a wind energy project. The wind farm management works in this given framework: in which the key drivers cannot be influenced, (e.g. '*Tariff*' and '*Wind Resource*') or are *'locked-in'* over a certain time duration (e.g. maintenance contract).

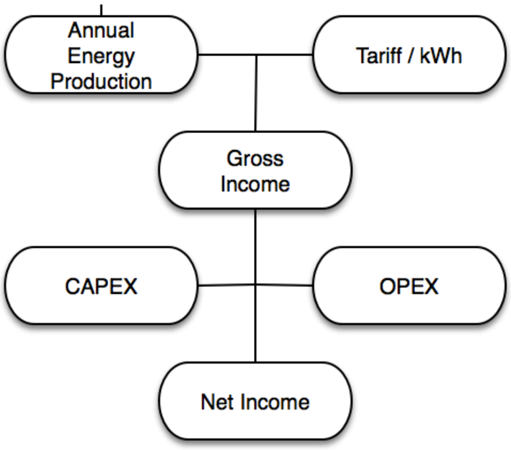

Figure 27: Simplified Wind Energy Project Value Chain (author's compilation)

The net income can be described by variable and fixed factors. The AEP represents the variable part of the gross income of a WEF. Figure 28 illustrates the variable factors. The objective of the WFM is managing these variable factors in a way that maximises profit and minimises OPEX (CAPEX is assumed to be fixed according to the upfront financial modelling).

The AEP is based on the available *'Wind Resource'* and technology or more specifically generating capacity (represented by *'Power Curve')* and system *'Availability'*.

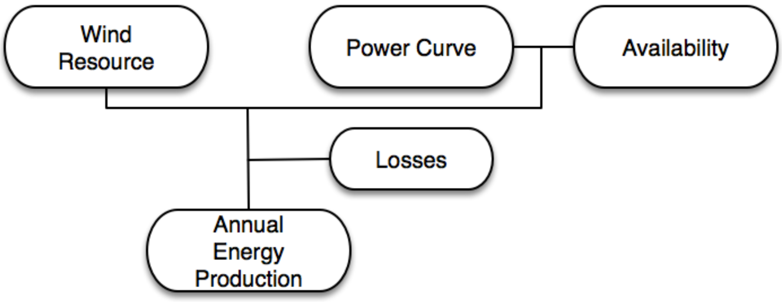

Figure 28: Variable Influences on the Net Profit of WEF under Full Service (author's compilation)

The relationship between wind resource, power curve and AEP is illustrated in Figure 29. The wind resource is represented by the Rayleigh Distribution outlined by the dashed line. Most of the hours per year the wind speed lays in the range between 4m/s and 8m/s. The power curve of the WT is drawn in black and the energy output is represented in MWh by the green bins. The WT operates on partial load, most of the hours per year. The largest amount of energy is produced between 10m/s and 12m/s. This is due to the fact that the amount of hours above 12m/s is rather limited, where the WT could produce on rated power.

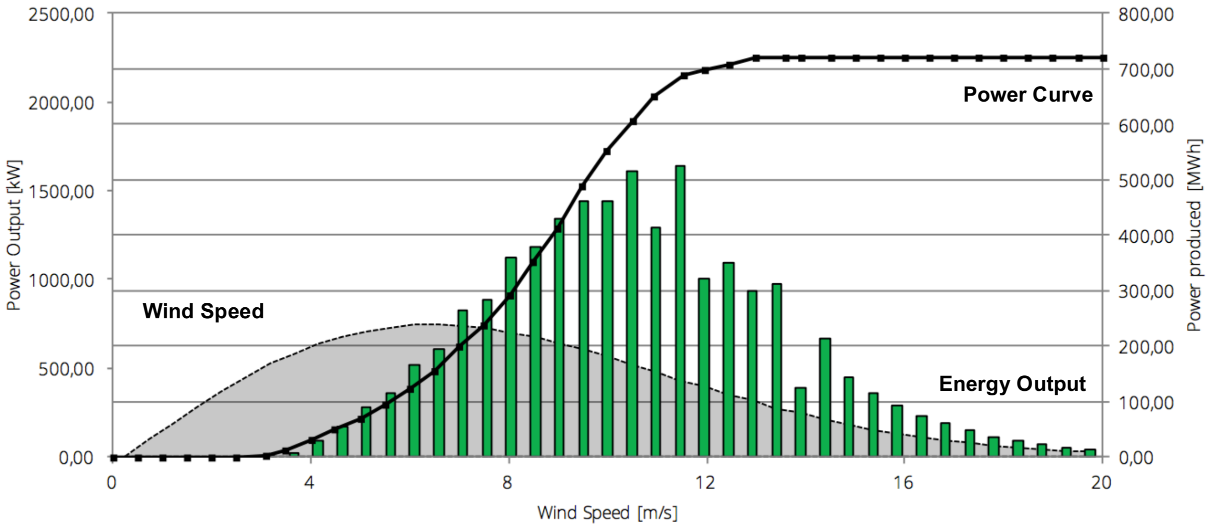

Figure 29: Relationship between Wind Regime, Power Curve and resulting AEP [77]

In the following, the different key factors influencing AEP are analysed regarding contractual obligations and are set within the context of the value chain.

3.2.1.1 *Wind Resource*

Wind projects in South Africa require a wind measurement campaign conducted of at least 2/3 of hub height of the WT's covering seasonal variation, thus at least over a period of 12 months. [37] The lenders however push for higher standards, depending on topographic site conditions and proposed size of the WEF. Most of the preferred bidders gathered 24 to 36 months of continuous wind data on hub height from at least two masts.[23]

The WFM continuously needs to evaluate the actual data against the assumption and adapt the financial model if needed. Further the maintenance strategy should be adapted to the wind regime. The aim of the WFM is to schedule planned downtimes of low wind speed periods and reduce downtimes during periods of high wind speeds.[24] The influence WFM has on the maintenance and service work depends on the contractual arrangements with the service provider. The WFM needs to analyse and understand the local wind regime with its seasonal patterns and align the service work accordingly if possible, or advise the service contractor to do so. The technical operators therefore require a certain understanding of wind data and wind measurements.

3.2.1.2 *Power Curve*

The power curve describes how much electrical energy a specific WT can generate at a certain wind speed. The OEM normally warranties the power curve during the first years of operation as agreed upon in the TSA. [78] The wind farm manager needs to be aware of the exact contractual arrangements and monitor the power curves accordingly (site specific power curve, mean power

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[23] *Based on consulting Cape Africa (Pty) Ltd, Wayne Flint, Cape Town, South Africa. June 2013*

[24] *Conclusion based on [116]*

curve, WT specific power curve). A power curve assessment based on IEC61400-12-1/2[25] [79] ,or variations thereof, exceeds the scope of work and requires the assistance of independent external consultants in order to claim for compensation. [80] A SCADA based evaluation of the power curves should be conducted periodically for a target-actual-comparison in order to identify underperforming WTs and document temporary de-rating[26] of WTs by the service provider. [80] In-depth monitoring of the power curves is especially by use of *'Lost Production Factor'*[27] (LPF) (see 3.3.2.3) driven service and maintenance contracts important.

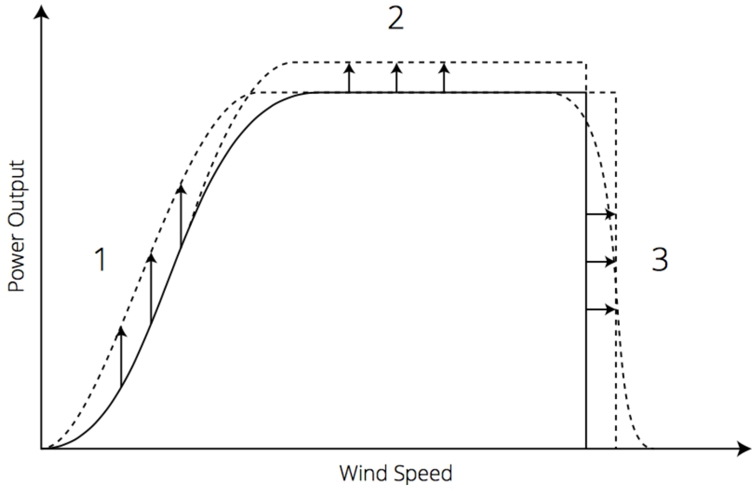

Figure 30: Power Curve Optimisation [77]

In general, the first objective of the WFM is to meet the warranted power curve or if possible to claim compensation for underperformance. The second is to optimise the operational parameters to the site characteristics and climatic conditions, with the third being to evaluate the cost-benefit of *'turbine upgrades'*. Figure 30 shows the impact of optimisation on the power curve: (1)

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[25] *IEC61400 is the overarching international standard for wind energy, the standard describes several relevant aspects, such as power curve measurements, design guidelines, etc. [114]*

[26] *temporary de-rating of wind turbines in order to i.e. reduce loads see (See Annex III, Figure 54)*

[27] *LPF represents the difference between the actual produced energy and the potential energy output assuming the ideal scenario: all WTs assumed to be available and produce according to the warranted power curve.*

adaption to site conditions (e.g. yaw or pitch parameters) (2) up-rating and (3) cut-in and cut-out wind speed optimisation.

In South Africa generally, with few exceptions, the first ten years of operation are covered by full service contracts. During this period the focal point lies on the monitoring instead of optimisation. Homogeneous large-scale wind farms provide a good economic basis for power curve optimisation, which can be utilised in collaboration with the OEM or once the full service contract has ended.

3.2.1.3 Availability

WEFs can only produce electrical energy when the WTs are in an operational state, the wind speed is within the operational range of the WTs and the grid is available. These dependencies lead to various options to calculate the actual availability (see 3.3.2.2 and 3.3.2.3).

3.2.2 Service and Maintenance Agreements

As described in 2.6.5 full service contracts are the preferred choice for WEFs in South Africa. Lenders particularly push for this option due to the minimal experience of this technology in the country on large scale application. Full service[28] contracts shift the operational risk partly from the project company to the service company / OEM. The large roll-out of this contract type across all OEMs is a novelty compared to that of matured wind energy markets, driven by the specific requirements of the REIPPPP.

Generally the fee structure consists of two components, a so-called fixed-, minimum- or base-fee,[29] as well as a performance based component. The performance component is two-fold. If the warranted target is exceeded, a performance bonus is paid to the contractor. On the other hand,

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[28] *Full service contracts such as Vestas AOM4000 and AOM5000 [115] p.18 pp.*

[29] *The base fee in, some cases, may as well depend on the produced electricity.*

for underperformance, liquidated damages are paid to the project company by the contractor. Compensation payments are normally based on annual averages of the entire project's performance. [78]

The performance bonus is generally an upside share, which is determined in the contract. In other words, if the target is exceeded it is beneficial for both parties.

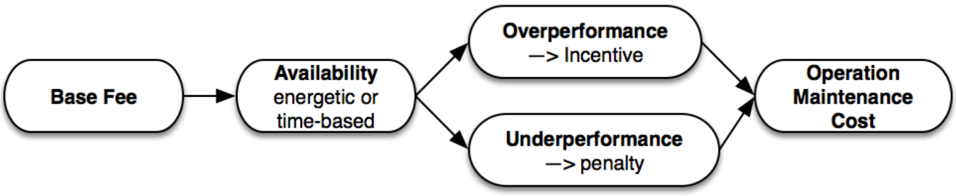

Figure 31: Operation Maintenance Costs (author's compilation)

The KPI to determine the performance is named *'availability', a certain level of availability is warranted by the maintenance contractor in performance based full service contracts. This level is referred to as 'warranted availability'.* In the South African market, the type of availability used for this performance measure is mainly *'technical availability'* but as well as *'energetic availability', to a small extent.* [78]

3.2.2.1 Technical Availability Calculation

The technical availability is based on the time the WT is in an operational state. The warranted technical availability $A_{technical\_warranted}$ is based on the overall WEF's performance. The actual technical availability $A_{technical\_actual}$ is based on the actual technical availability of the individual WT $A_{technical\_actual\_i}$.

$$A_{techncial\_actual} = \frac{1}{n}\sum_{i=1}^{n} A_{technical\_actual\_i} \qquad (V)$$

Service contracts make provision for a certain amount of hours per year allocated for scheduled maintenance work $T_{maintenance}$. During this maintenance work the WTs can be in a non-operational state, which does not negatively affect the availability. Non-operational statuses caused by the contractor are reflected in T_{OEM}. The total time of the measurement period is T_{total}. [78]

Compensation Payments: The performance bonus is calculated based on the warranted technical availability $A_{technical\_warranted}$ for the entire WEF and the actual technical availability $A_{technical\_actual}$. This is the case if the actual technical availability exceeds the warranted availability ($A_{technical\_actual} > A_{technical\_warranted}$).

Further the bonus is based on the actual annual energy production AEP_{actual}, the tariff T and the factor for the upside sharing I.

$$Performance\ Payment = \left(\frac{A_{technical\_warranted}}{A_{technical\_actual}} - 1\right) x\ AEP_{actual}\ x\ (-T)\ x\ I \qquad (VI)$$

If $A_{technical\_actual} < A_{technical\_warranted}$ the project company is compensated by the contractor. Liquidated damages are calculated in a similar manner like the performance payments.

$$Liquidated\ Damage = \left(\frac{A_{technical\_warranted}}{A_{technical\_actual}} - 1\right) x\ AEP_{actual}\ x\ T \qquad (VII)$$

3.2.2.2 Energetic Availability Calculation

Energetic availability is in contrast to technical availability based on energy output. It describes the relationship between the actual energy production AEP_{actual} and the potential energy production $AEP_{potential}$.[30]

$$Energetic\ Availability_{energetic} = \left(\frac{AEP_{actual}}{AEP_{potential}}\right) x\ 100\% \qquad (VIII)$$

---

[30] *Adapted from [110]*

The key is to determine the potential energy production or in other words, the loss of production. Different options are based on reference WTs, nacelle mounted anemometer, hub height anemometer at nearest met mast, average production for WTs of the same model and with the same configuration. [81]

3.2.2.3 Comparison of Technical Availability and Energetic Availability

A distinction must be made between warranted availability, technical availability and energetic availability. Both types of availability (energetic and technical) normally warrant 97% or 98% availability. In general, energetic availability should be preferred above technical availability. Technical availability considers the time a WT is in an operational state versus a non-operational state. It does not differentiate between unavailability during periods of high wind speed and periods of low wind speeds. The maintenance provider therefore has no direct incentive to schedule the maintenance work in low wind speed periods. Energetic availability aligns to a certain extent the interest of maintenance provider and WEF owner. [82]

3.2.3 Resulting Tasks

The scope of work for managing WEFs depends strongly on local requirements, as well as on the chosen technology and the point in time within the project life cycle. Figure 32 illustrates the operational phase of a wind project and the different levels representing different contracts and milestones. The tasks of the WFM will vary during the different times of the lifespan.

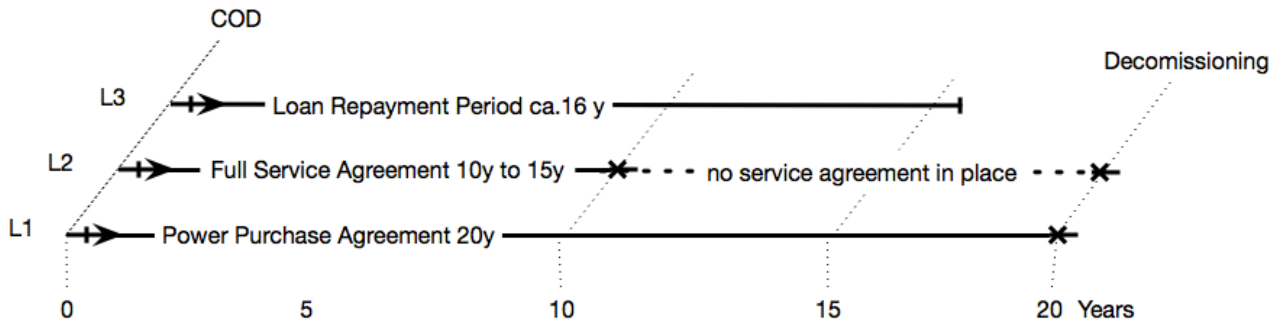

Figure 32: Contract Levels during WEF Operations (author's compilation)

The full service agreement '*L2*' covers at least the first half of the project's lifespan. During this period one of the key tasks is the monitoring of the service agreement. At the same time a comprehensive life cycle documentation of all the assets needs to be established and kept up to date in order to have a vast database as preparation for the second half of the lifespan, after the full service contract. Full service contracts cost a premium, which is normally linked to the age of the assets. In depth-knowledge of the technical condition of the assets leads to cost-efficient operation after the end of the long-term maintenance and service agreement. '*L3*' shows the timespan for the loan repayment. After the full repayment of the debt, the economically most lucrative phase of the project is reached. This is based upon the assumption that major failures in the last years of operation can be kept to a minimum. Big component failure during this time may surpass the future earnings of a WT until the end of the operational life is reached, and thus poses the question of cost-benefit of component replacements / repairs or early decommissioning.

Continuous monitoring and life-cycle-analysis sets the basis for informed decision making. In general, it can be said that for the first years of operation a fix structure is handed over to WFM, which was defined in the project development process. During the operational phase, the role of the wind farm manager may shift from passive (monitoring, advising) to active asset management, if the required knowledge base was built at this time.

The objective of this chapter is to develop a framework, which builds up the needed knowledge base, thus enabling the WFM to shift to active asset management in the second half of the operational lifespan.

3.2.4 Key Activities Wind Farm Management

The key activities of managing a wind energy project are described below [83]. In a second step the tasks are listed in detail according to both sub-categories of WFM: Technical Operation Management and Business Management. Table 9 list the tasks for BM and Table 8 respectively for TOM.

(i) Key Tasks

a. **Communication:** The WFM functions as the central point. It is the first point of contact for landowners, OEM, maintenance providers, local authorities, technical inspectors, etc.

b. **Collaboration with Maintenance Provider:** For projects under full service contracts interaction between WFM and maintenance providers is necessary. The technical manager has the best overview of the entire project and the technical background to liaise with the maintenance provider and to improve the performance.

c. **Monitoring of Operational Data:** Monitoring of the operational data allows the technical operator to find patterns in error codes and suggest possible optimisations opportunities. The information flow improves if '*alarms*'[31] are forwarded by the WFM directly to the service team on-site, thus response times are minimised. Maintenance activities can be scheduled into periods of low wind speeds or aligned with other periods of downtime.

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[31] *Events which trigger a shutdown of the WT as well as warning due to operational parameters outside a set range.*

d. **Reporting:** The vast amount of data needs to be analysed and illustrated by the technical managers in monthly, quarterly and annually reports. These reports need to reflect the current technical state and production figures**.** Reports are based on KPIs of the WEF and its WTs, but as well the interface with the financial reporting, budget reports, and expenditure . Activities which affect future earnings (e.g. scheduled downtimes) need to be presented to shareholders, lenders. Further REIPPPP outlines specific reporting requirements namely: wind forecast, energy forecast, maintenance forecast, EDO fulfilment, the WFM needs to report on the implementation of these to DoE respectively Eskom [37]

e. **Wind Turbine Inspections:** Periodical visual inspections form part of WFM. The scope of the inspection includes the entire machinery, with the aim to gain an overall impression of the WTs. Obvious damages (e.g. oil leakages, cracks, missing bolts) can be detected and compliance with OHSA can be checked. [84] These inspections do not determine the cause of a failure and do not replace independent unbiased technical inspections.

f. **Site Management:** Given that WTs are automated and can be controlled remotely, they do not necessarily require a full time presence on site. The large-scale wind farms in South Africa are located in rural areas and therefore permanent on-site presence of the owner’s representatives is imperative (minimised response times, relatively low cost for installed capacity). The site management includes the inspection of balance of plant (BoP) (electrical infrastructure, roads, fences, gates) and engagement with local service teams, which often are based on overseeing the site staff and site security, as well as engaging with local communities (to a certain extent).

(i) **Technical Operations Management:** The German Wind Energy Association GWEA describes the key responsibilities for TOM, which can be amended for the South African framework. [83] Table 8 outlines the tasks describing TOM for South African WEFs.

Monitoring of Service & Maintenance Agreement

Permanent remote monitoring of operational data

- Operation Data (SCADA)
- Environment (Met Mast)

Monitoring Technical Health of WT and BOP[32]

- Periodic visual inspections
- Online condition monitoring
- Independent technical inspection

Life Cycle Documentation of all WT and subsystems

- Documentation errors, incidents and faults
- Documentation of service and maintenance records
- Operational Reports
- Internal to Business Management Unit

Reporting according to REIPPPP

- Wind forecast
- Energy forecast
- Maintenance forecast
- EDO fulfilment

Claim Management

- Warranties
- Production Losses

Site Management

- Site Security
- OHSE Management
- Infrastructure Management (BoP)
- Environmental Management

Stakeholder Management

Table 8: Key Tasks Technical Operation Management[33]

(ii) **Business Management:** In the following the scope of work for the BM unit of WFM is outlined. Table 9 lists an overview of the scope of work of BM for WEFs.

- Accounting and book-keeping for all on-going activities
- Invoicing for exported power, power distribution
- Liquidity control and planning
- Shareholder management
- Lease accounting
- Manage and Report on post-construction responsibilities (e.g. Bird and Bat monitoring Trust)
- Contractual management and negotiations with banks, landowners and authorities
- Monthly / Quarterly reporting (REIPPPP)
- Economic Development Reporting and
- Managing insurance and claims for damages
- Invoicing to South African standards
- CDM Management
- Economic Development Reporting
- Social-Economic Development (SED) Spending Management and Reporting
- Support and optimisation of finance and financial restructuring, if necessary
- Compilation of annual and business reports

Table 9: Responsibilities Business Management[34]

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[32] *Balance of Plant in the latter referred to as BOP*

[33] *see Footnote 20 as well as [37]additional information were acquired by consulting Kai Nohme, Husum, Germany, June 2013*

[34] *see Footnote 13*

The scope of work for the business related matters of WFM are to a great extend congruent with BM of any project financed public private partnership. Figure 40 illustrates the contractual framework using the example of the case study, BM operates in the set boundaries of the project specific framework.

3.3 RESULTING REQUIREMENTS

The tasks for WFM in the South African context are wide spread. In order to execute the tasks, requirements can be derived from those described and analysed in the following paragraphs. (i) Human Resources, (ii) Technical Operations Management System, (iii) Condition Monitoring Concept (iv) and Technical Inspection Regime. These four categories embrace all key tasks, which were identified in the previous paragraph, in the latter these categories are explained in detail.

3.3.1 Human Resource

WFM relies largely on highly skilled staff due to the infancy of the industry in South Africa. It may be challenging to find experienced staff; therefore, provisions should be made for skills-transfer or training.

Further, each project of the REIPPPP has certain ED commitments, which inter alia outline the job creation obligations during the '*Operation Measurement Period'* (OMP). These commitments of the project's company are passed onto the contracted parties in the form of 'person months'. [37]

> *"'**Person Months**' the total number of Employees in each of the Contract Months, within the Construction Measurement Period and the Operating Measurement Period, where applicable, which are adjusted to the actual working time, compared to the normal working time;"* [37]

The Framework distinguishes between Construction Measurement – and the Operation Measurement Period.

> ***"'Construction Measurement Period'*** *(CMP) the period commencing on the Effective Date and ending on the day immediately preceding the Commercial Operation Date;"* [37]
>
> ***"'Operating Measurement Period'*** *is the period commencing on the Commercial Operation Date and ending on the Termination Date;"* [37]

The job creation obligation impacts the organisational structure and the economic feasibility, which to a great extent depends on human resources.

WFM for a single wind project would result in the direct adoption of the project's EDO. The moment a WEF's portfolio should be managed; economies of scale would lead to cost-efficient management solutions and thus cost reductions per WEF.

Figure 33 and Figure 34 show two possible structures. Firstly, a lean approach and secondly, an alternative option providing more person-months on the management level, which may be required by some projects. The additional layers illustrate how the structure could be applied for portfolio management.

The structure is divided into two streams: analogue to different scope of work of BM and TOM. The BM stream consists of the financial director and additional accountants, if required by the workload.

The TOM stream is subdivided into a dedicated site-office and the actual operations centre, which may be based in a central location in proximity to all WEF of the portfolio. The extent to which additional site staff is required depends for e.g. if the maintenance of BoP is included in the maintenance and service agreement or if it is handled in-house.

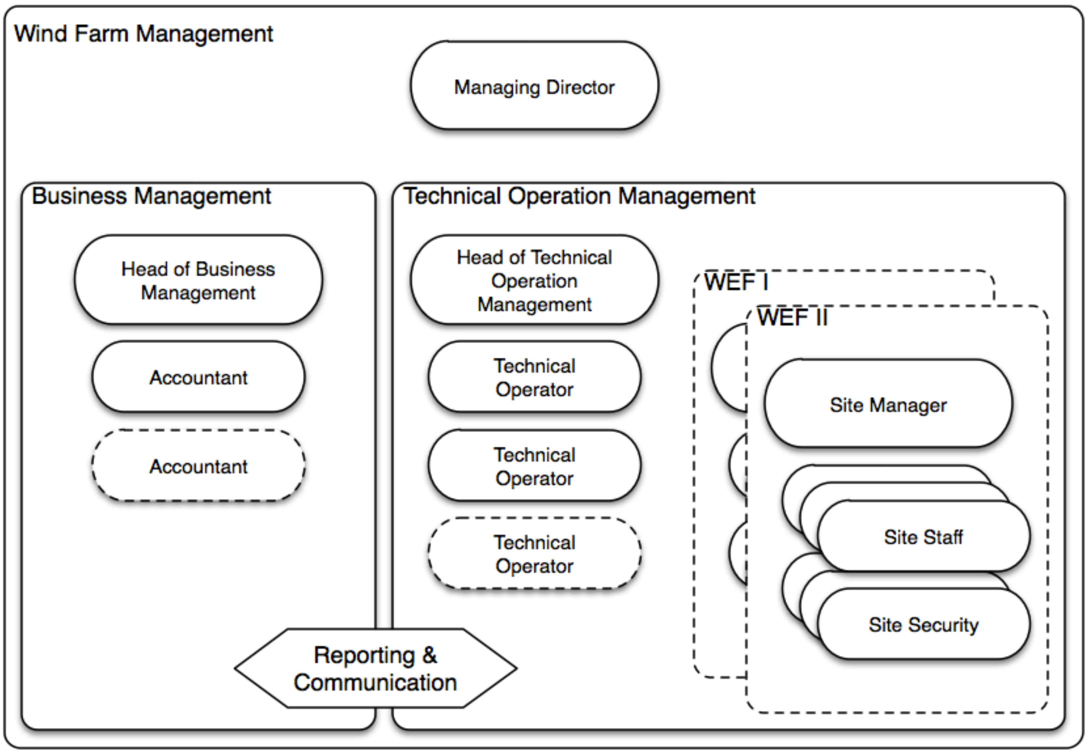

Figure 33: Organisational Structure for WFM - Option A (author's compilation)

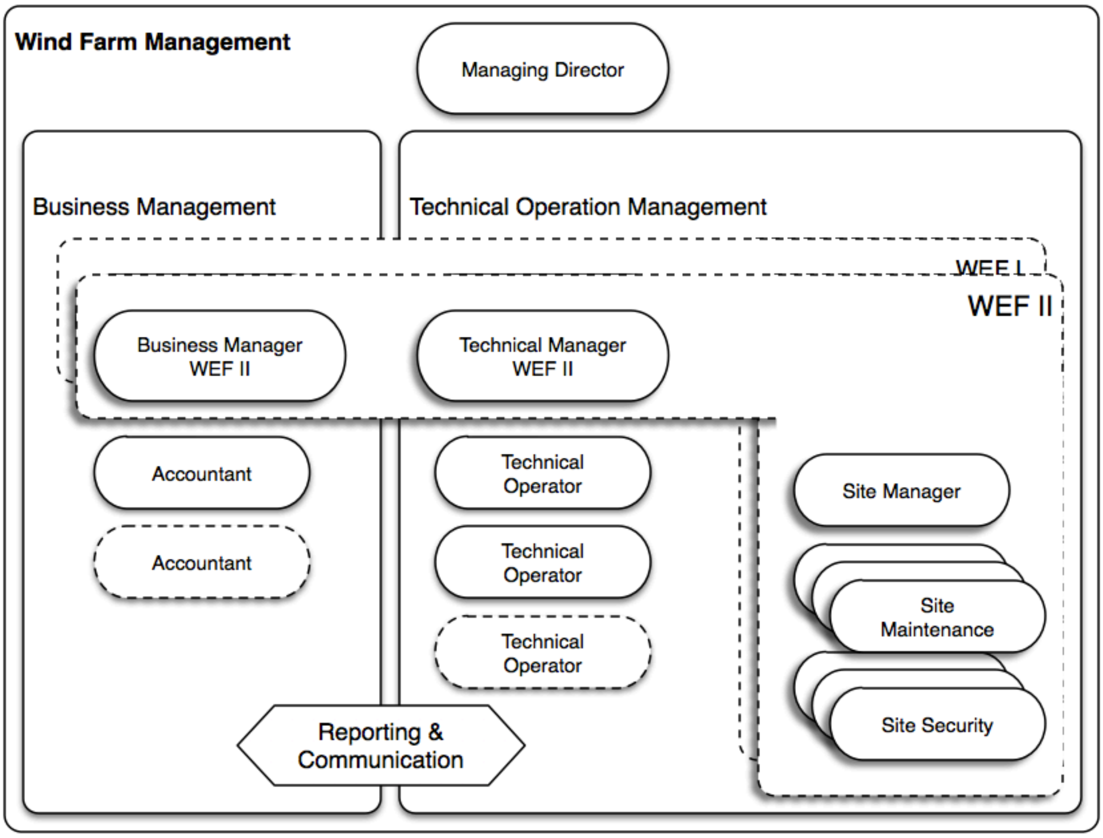

Figure 34: Organisational Structure for WFM - Option B (author's compilation)

The key staff is made up of the: Managing Director, Business Manager, Technical Manager, Technical Operator and Site Manager. The staff should be selected according to relevant experience and skills but as well as fulfilment of the job creation obligations. The mentioned obligations measured in 'person months' are subdivided as illustrated in Table 10.

i. RSA based Employees who are black[35]
ii. Skilled Employees
iii. Skilled Employees who are black
iv. RSA based Employees who are citizens from local communities

Table 10: Categories for ED Job Creation Obligations [37]

The importance of the EDO is crucial, as non-compliance may ultimately result in the termination of the PPA. [37] Temporary shortcomings may be counterbalanced over the OMP of the project; this however would lead to higher expenses at a later stage. Periodical reporting on the ED of the entire project and its subcontractors falls within the scope of work of WFM.

3.3.2 Technical Operations Management System

The TOMS is the central point where operational data, technical information and additional data (e.g. warranty periods, inspection intervals) come together. The TOMS consists of software solutions optimised for WFM. The ability to access directly the unfiltered operational data (SCADA) is one of the key requirements. The data is filtered, visualised and fitted for TOM. In contrast to Computerised Maintenance Management Systems (CMMS), the TOMS is set-up to monitor and report on the maintenance regime of the OEM and important KPIs of single WTs and the fleet. The in-depth assessment of the SCADA data is not part of the daily tasks, however the

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[35] *Definition of BBBEE Act applies / Broad-Based Black Economic Empowerment Amendment Act 46 of 2013. "Black people" means African, Coloured or Indian persons who are natural persons and are citizens [112]. Definition applies to all further references in this document*

TOMS documents and archives the necessary data, in order to allow for case-by-case assessments of the relevant data. The key requirements are listed below:

(i) High level analysis of SCADA Data and visual interpretation of KPIs
(ii) Compare measured KPIs to warranted KPIs
(iii) Track warranties
(iv) Log and classify operational events
(v) Create monthly reports according to reporting regime
(vi) Establish Life Cycle Documentation

Table 11: Requirements TOMS (author's compilation)

The TOMS is continuously monitored by the technical operators, all operational events are logged and classified continuously. The tracking of operational data and activities is the only way to detect underperformance against performance warranties where one is able to claim liquidated damages from the OEM or maintenance provider. Calculation of KPIs for liquidated damages is explained in the latter.

Figure 35 illustrates the information flow of the TOMS, where the core is the direct access to the operational data of the WEF and met masts. Further inputs are service reports of the maintenance provider (for the first 10 years the OEM) and periodic visual inspections of the WTs and site infrastructure.

External input is provided by the condition monitoring centre on a monthly basis, but also in the event of the CM data analysis, showing the need for immediate action. Independent experts provide reports on the technical condition according to the inspection regime of the WEF, following up on the findings of the analysis of CM- and operational data. The use of independent experts, especially for claims and insurance purposes, is preferred for conflict resolution as only unbiased reports are valued by all contractual parties.

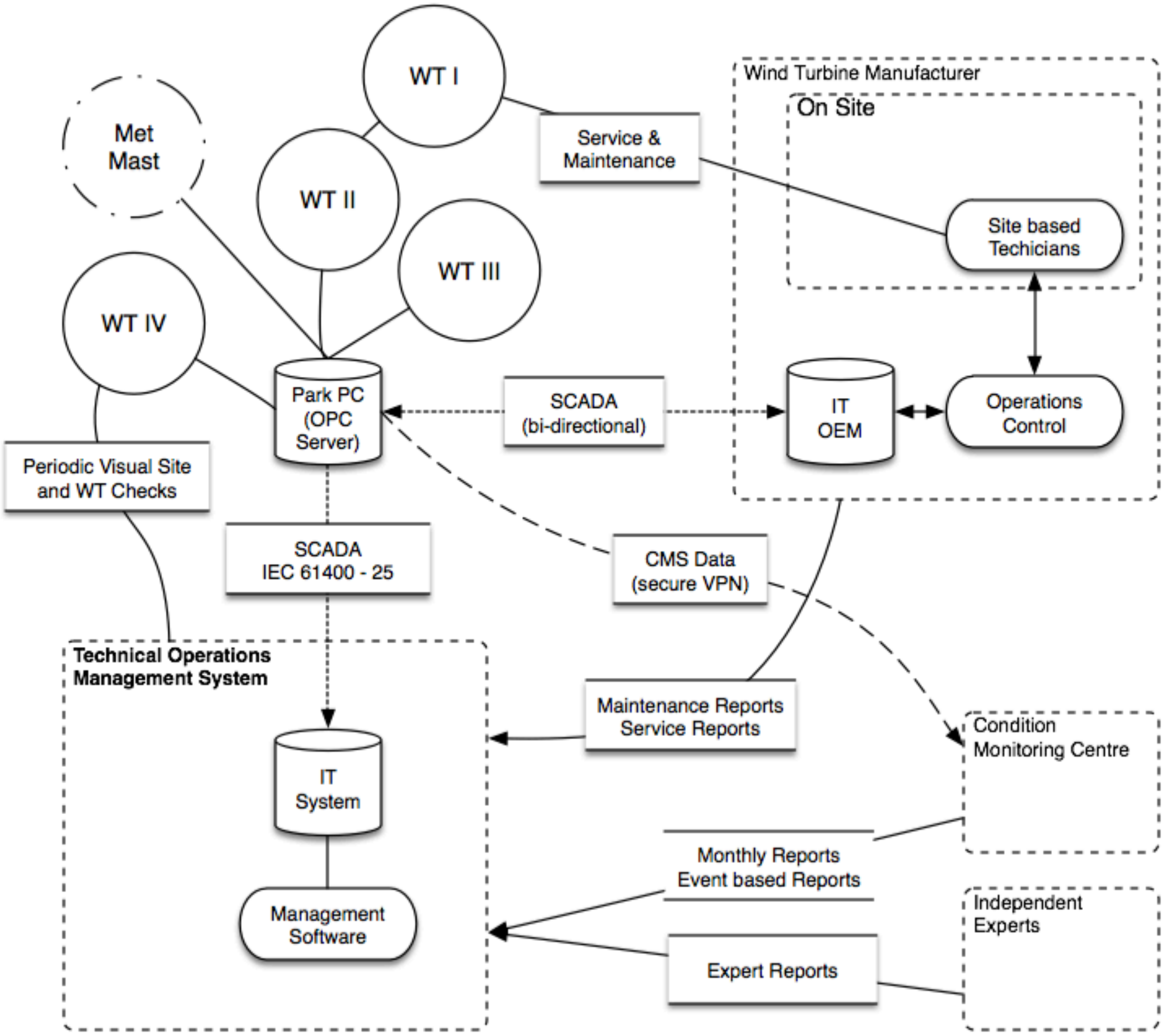

Figure 35: Information Flow Technical Operation Management System (author's compilation)

Reports (1/2)	**Reports (2/2)**	**Online / Historic Data**
▪ Availability	▪ Expected Production	▪ Operations Snapshot
▪ Alarms	▪ Failure Statistics	▪ Production Summary
▪ Production & Wind Statistics	▪ Key Performance Indicators	▪ Master Data •
▪ Alarm Handling Statistics	▪ MTBF & MTTR Report	▪ Turbine Data List
▪ Alarm Response Statistics	▪ Settlement Data	▪ Error Code Classification
▪ Export/Import Energy	▪ Stopped Turbines	

Table 12: Operator Requirements on TOMS [85]

The technical manager needs a system, which provides a holistic overview in order to have a sound basis for informed decision-making. Table 12 provides an overview of the operator's requirements. [85] The key prerequisites for this are explained in more detail in the following paragraphs.

3.3.2.1 SCADA DATA

The OEM has full access to the SCADA and full remote operational control of the WTs. In order to monitor the operational activities, the WFM needs to access the 'Park-PC', the central point where all the data of the WTs are collected. The access to the raw data on the OPC allows real-time access to the operational activities. In order to limit information-overload some data is averaged over 2-minute or 10-minute intervals (e.g. wind speed) [86]. For some analysis a higher resolution data is crucial. This applies mainly for the optimisation of the operational parameters set in the control system, such as yaw parameters: *To what extent of time is the turbine position not in line with the actual wind direction, can the time the blades are exposed to inclined flow be minimized and thus energy output be maximized.*

The pure access to data does not in the first instance add any value, only after filtering the relevant data for certain aspects and applying the right methods, intelligent connections can be made. A tailored software solution and application of industry standards assist in this process. It provides the option to improve the performance, minimise errors and allows to adapt the WT to specific site-conditions, thus availability and economic efficiency can be improved.

The GWEA describes the key components for TOMS as follows [83]

(i) Recording of operating data (e.g. output, performance curves)
(ii) Recording of operating parameters (e.g. component temperatures, max output)

The SCADA Data includes a broad amount of information, inter alia operational parameters and status codes. IEC 64100-25 standard defines is the interface for communications for monitoring and control of wind power plants. The TOMS should function according to this guideline to allow the integration of WTs of all manufacturers. Further, the norm sets the standard for the first instance of the data interpretation e.g. it regulates according to which criteria mean and aggregates of the data are calculated. A common understanding of the data interpretation is important to be able to compare reports created by OEM and WFM. [85]

Several sensors collect data, which is logged and processed in the WT control system and sent as operational parameters to the 'Park PC'. Table 13 shows a selection of these parameters.

- Wind Speed
- Wind Direction
- Nacelle Position
- Ambient Temp.
- Blade Pitch Angle
- Power Output
- Power Factor
- Grid Voltage
- Current
- Temp. Generator Bearings
- Temp. High Speed Shaft
- Temp. Main Bearing
- Oil Temperature
- Generator Speed
- Reactive Power
- Rotor Speed
- Operational Status

Table 13: WT Operational Parameters (selection)

Besides operational parameters the control system creates status codes, errors and alarms. The status codes reflect the current operational state of the single WTs, the technical operator needs to classify and categorize these codes with aid of the TOMS.

3.3.2.2 T-Classes according to IEC 61400

As mentioned in the previous chapters, availability is the key KPI to evaluate performance of WTs and of the maintenance provider. The uninterrupted logging and classification of the current technical status of the WTs is the most efficient way to compare WT performance in a fleet and to track performance warranties. A mutual understanding of the classification of the status codes between owner and maintenance provider is not always given due to partly opposing interests, but also due to the vast amount of codes created by the WT control system in combination with other factors (e.g. environmental influences)

The TOMS should provide the option of automatic categorisation and logging of the status codes according to different rules.

Mandatory Level I	Information Available (IA)											Information Unavailable (IU)
Mandatory Level II	Operative (IAO)						Non-Operative (IANO)				Force Majeure (IAFM)	
Mandatory Level III	Generating (IAOG)		Non-Generating (IAONG)				Scheduled Maintenance (IANOSM)	Planned Corrective Actions (IAONOPCA)	Forced Outage (IANOFO)	Suspended (IAONOS)		
Mandatory Level IV	Full Performance (IOAGFP)	Partial Performance (IAOGPP)	Technical Standby (IAONGTS)	Environmental Specific. (IAONGEN)	Requested Shutdown (IAONGRS)	Electrical Specification (IAONGEL)						
Time Stamps	Time Measurement											
Actual Production	Production Measurement											
Potential Production	Potential Production Calculation											
Priority	12	11	10	9	8	7	6	5	4	3	2	1

Table 14: T-Classes according to IEC61400-26, extended [87]

Table 14 illustrates a powerful system, which provides one solution to sort the status codes according to so-called T-Classes. This system is described in the IEC61400 standard. The idea behind classification of the operational statuses is: [87]

(i) to allocate a time period to a certain operational status;

(ii) to classify according to agreed rules into technical-available $\boldsymbol{T_{avail}}$ or technical-unavailable $\boldsymbol{T_{unavail}}$ or to exclude the event from availability calculations, these parameters need to be aligned with the contractual agreed parameters $\boldsymbol{T_{OEM}}$ and $\boldsymbol{T_{manufacturer}}$ (see 3.2.2.1)

(iii) to the calculate the production-loss for time periods, where the WTs are not fully operational (de-rated) or where the status was logged as technical-unavailable.

Further IEC61400 prioritises logged events from 1 to 12, which allows for unambiguous classification by simultaneous occurrence of status codes (e.g. temperature is out of operational range and grid is not available). [87]

3.3.2.3 Key Performance Indicators

The classified status codes and the operational parameter are used to calculate KPIs in order to determine over- or under-performance, calculation of incentive- or compensation-payments

(i) **Annual Energy Production:** Is calculated for a single WT or averaged for the entire fleet, it should however be differentiated between calculated $AEP_{calculated}$ and measured values AEP_{actual}.

$$\boldsymbol{AEP_c = installed\ capacity\ x\ \ CF_i\ x\ total\ hours\ per\ year} \tag{IX}$$

(ii) **Capacity Factor:** Provides a simplified approach to compare the performance of different WT models on the same site or to compare different sites with each other. CF includes the technology component and is therefore more accurate than $mean\ wind\ speed$ for site comparisons

$$\boldsymbol{CF = \frac{P_{actual}}{P_{rated}}} \tag{X}$$

$\boldsymbol{CF}\ Capacity\ Factor, \boldsymbol{P_{actual}}\ actual\ power\ output, \boldsymbol{P_{rated}}\ rated\ power$

(iii) **Production Factor:** Is a performance indicator used to compare different WTs in a fleet over a certain time period. It compares the actual power to the potential power for a certain time period. For the calculation of the potential power excluding events should be recognised and be kept in mind for comparison.

$$CP = \frac{\sum_{i=1}^{n} P_{actual\_i}}{\sum_{i=1}^{n} P_{potential\_i}} \; x\,100 \qquad (XI)$$

CP $Production\ Factor$, P_{actual_i} $actual\ power\ for\ interval\ i,$

$P_{potential\_i}$ $potential\ power\ for\ interval$

(iv) **Availability:** Based on the allocation of time periods to certain T-Classes (IEC-61400) and classification according to contractually agreed operational statuses. Time Based and Energetic Availability can be calculated:

a. **Time Based Availability:**

$$A_{technical} = \left(1 - \frac{T_{unavail}}{T_{avail} + T_{unavail}}\right) x\,100 \qquad (XII)$$

$A_{techical}$ $technical\ availability,$ $T_{unavail}$ $unavailble\ time,$

T_{avail} $availbale\ time$

b. **Energetic Availability:**

$$A_{energetic} = \left(1 - \frac{P_{lost}}{P_{actual} + P_{lost}}\right) x\,100 \qquad (XIII)$$

$A_{energetic}$ $energetic\ availability,$ P_{lost} $lost\ production,$ P_{actual} $actual\ production$

$$P_{lost} = P_{potentiol} - P_{actual} \qquad (XIV)$$

$P_{potential}$ $potential\ production$

(v) **Potential Power:** Potential Power can be calculated using different approaches or the combination thereof. Different approaches are based on the warranted power curve or a selected reference WT, historical power curve of the WT, nacelle mounted anemometer or the on-site met mast.

$$P_{potential} = \left(\frac{1}{n}\sum_{i=1}^{n} PF_i\right) x\,P_{rated} \qquad (XV)$$

PF_i $power\ factor\ for\ turbine\ i$, P_{rated} $rated\ power$

(i) **Power Factor:** The calculation for the power factor is similar to the capacity factor in a WEF. Each WT can be assigned a primary and a secondary reference WT, in order to estimate potential power production (e.g. for non-operational periods). The correlation between a WT and its reference WT should be as high as possible, a correlation factor could be incorporated into the following equation.

$$PF_i = \frac{P_{actual\_i}}{P_{rated\_i}} \tag{XVI}$$

3.3.2.4 Life Cycle Documentation

Life cycle documentation is the key to an efficient operation in the long-term. The owner, respectively the wind farm manager, needs to keep their own records independent of the OEM. According to GWEA, life cycle documentation for condition based maintenance should at least cover the following [83]:

(i) List of all maintenance and repair activities

(ii) Records of periodic checks / inspections

(iii) Operating Data

(iv) List of failure events (error codes, frequency of occurrence of fault and error code) with information on cause and repair

Over and above this, the life cycle documentation should cater for tracking overall warranties and warranties of replaced components and the condition monitoring reports. This provides the WFM to go back to the operational history in order to investigate e.g. root causes for failures and detect failure patterns or re-evaluate the work carried out by the maintenance and service provider.

3.3.3 Condition Monitoring for Wind Turbines

Condition Monitoring (CM) is widespread in the power generation industry. Increasing WT capacity increases the magnitude of downtime on the financial viability of wind energy projects. CM quickly became a mandatory requirement by insurers of wind energy projects in matured markets e.g. Germany. The unique characteristics of WTs led to the development of more and more sophisticated Condition Monitoring Systems (CMSs) and specialised independent CM service providers in the recent past. [88]

The aim of condition monitoring is manifold. System- and component-failures should be prevented by detection of initial damages. The diagnosis of damages sets in motion an optimised workflow for the rectification of the findings at the point of the lowest system cost. Depending on the structure of the specific wind energy project, different aspects will be focused on,[36] overall CM provides a deep technical understanding of the drivetrain condition, which sets a base for informed decision-making regarding maintenance and other operational aspects.

Condition Monitoring can be described as a *“means to prevent catastrophic failure of critical rotating machinery”.* [89] The necessity to implement condition monitoring may have different angles, which vary during the lifetime of the project. OEMs who offer long-term full service agreements, usually make use of CM as a maintenance tool in order to reduce the risk of big component failures during the period of the full service contract. Access to information by the WFM is often limited and the analysis of the data falls within the responsibility of the OEM. Condition Monitoring as a part of Wind Farm Management aims to detect initial faults as early as possible over a scope of the entire operational phase and to ring-fence the owner’s interest in case of disputes with OEM, maintenance providers and other component suppliers. This often results in the installation of a secondary retrofitted, more sophisticated and fine-tuned condition monitoring system, where the project owner has the full data sovereignty and ownership of the CMS.

The basic objectives for Condition Monitoring can be narrowed down to three [90]:

(i) **Detecting** a symptom, deviation of the established baseline

(ii) **Diagnosing** the root fault (type and location) responsible for the observed symptom.

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[36] *OEM CMS and retrofitted solutions by independent CM service providers inherent different benefits for the project’s owners.*

(iii) **Forecasting** the remaining useful life of the component based on the diagnosis.

The following paragraphs provide a brief overview of state of the art CM technology, the application thereof on WTs, as well as the interface with WFM and a brief cost analysis.

3.3.3.1 Technology overview: Wind Turbine Condition Monitoring

Condition Monitoring hardware for WTs consists of several sensors collecting physical data from the main components of the drivetrain: rotor, main bearings, gearbox, generator as well as from subsystems, e.g. pitch systems, yaw system, hydraulic systems, cooling system etc. The data is centralised processed and analysed with the aid of mathematical algorithms by diagnostic engineers.

Figure 36 illustrates the *'P-F Interval'*, which is the time interval between the occurrence of a potential failure *'P'* and progression to a functional failure *'F'*. *'P'* describes the point in time the potential failure can be detected in accordance with different methods. Online condition monitoring provides continuous data to evaluate the health of the major components. The advantage of this is that a higher diagnostic confidence due to longer period of data collection, the risk of missing potential failures due to wrongly selected *'inspection intervals'* (*'inspection interval'* > *'P-F interval'*) is eradicated.

CMS aims to maximize the *P-F interval* using the combination of different methods and analysis techniques. A prolonged *P-F interval* widens the options on how to respond to a potential failure. Leading condition monitoring service providers offer a condition monitoring concept rather than a system. A Condition Monitoring Concept (CMC) is the intelligent connection of CMS, WT specific KPIs and information gathered from technical inspections and R&D combined in a Life-Cycle-Database, which creates a tool to increase the diagnostic confidence.

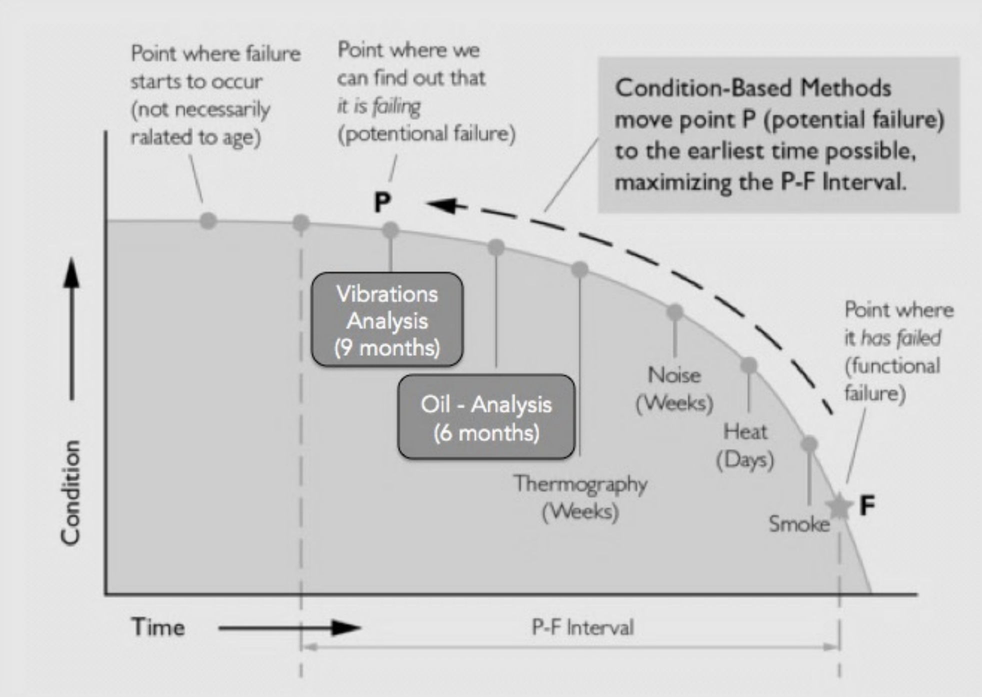

Figure 36: P-F Curve - Condition of Technical Equipment over Time (author's compilation) [91]

(i) **Data Transmission between Site and Monitoring Centre**

Professional CM consists of two parts: the installation on-site for data collection and respectively a monitoring centre for data analysis and data archiving. Figure 37 illustrates a schematic overview of the installation on the drivetrain, data transmission and the monitoring centre. Sensors are mounted on the drivetrain; the physical data of all sensors is processed collectively in the CMS unit. In order to allow a deep analysis of the data as a function of the rotational speed and current power output, it is crucial to collect the data time synchronous and include clean measurement of the actual rotational speed[37] as indicated in the figure. The data transmission in-between the site location and the monitoring centre is done by a communication unit for either single WTs or the entire fleet, depending on the site infrastructure. Secure VPN tunnel is

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[37] *Time-synchronous measurements depending on the current RPM of the high-speed-shaft is mandatory to perform a Fast Fourier Transformation FFT, this algorithm can only be applied on "standing" systems. Keeping in mind the eigenfrequenz of oscillating components. Thus the vibration level does not linear correlate with the rotational speed of the system.*

established in between the monitoring centre and each WT, in order to avoid interference with other devices (e.g. control systems) on the internal network. The data is archived and backed up in the monitoring centre, where diagnosis engineers monitor and analyse the measurements.

(ii) **Condition Monitoring System**

Condition Monitoring is a powerful method to gain a deep understanding of the current health of WTs. The monitored components respectively the amount of sensors need to be analysed on a case by case basis. Different WTs require different level of attention and different drivetrain-concepts require different monitoring concepts. The monitoring of 'major components' forms the basis of a monitoring concept. These components have the characteristic of a low failure rate (high MTBF), which would result in high system cost due to replacement and downtime (high MTTR). These components are normally the main-bearings, gearbox, and generator. The monitoring concept can be extended to nearly all subsystems based on number of input channels and interfaces on the CMS unit.

As illustrated in Figure 37, the CMS consists of several sensors on the drivetrain. A basic concept consists of 8 or 9 vibration transducers, which are placed on the major components. A list of sensors and placements in the nacelle is listed below.

(i) Vibrations transducer
    a. 1x Main Bearing
    b. 5x Gearbox
    c. 2x Generator
(ii) Optical / Inductive RPM Sensor
    a. 1xHigh Speed Shaft
(iii) MEMS - Tower Oscillation & rotor unbalances
    a. 1x X / Z Axis of Tower
(iv) Oil particle counter (optional extension)

Table 15: Basic Monitoring Concept

Online oil quality measurements and laser rotor blade monitoring are system extensions, which exceed a standard condition monitoring concept and are thus only applied in special cases.

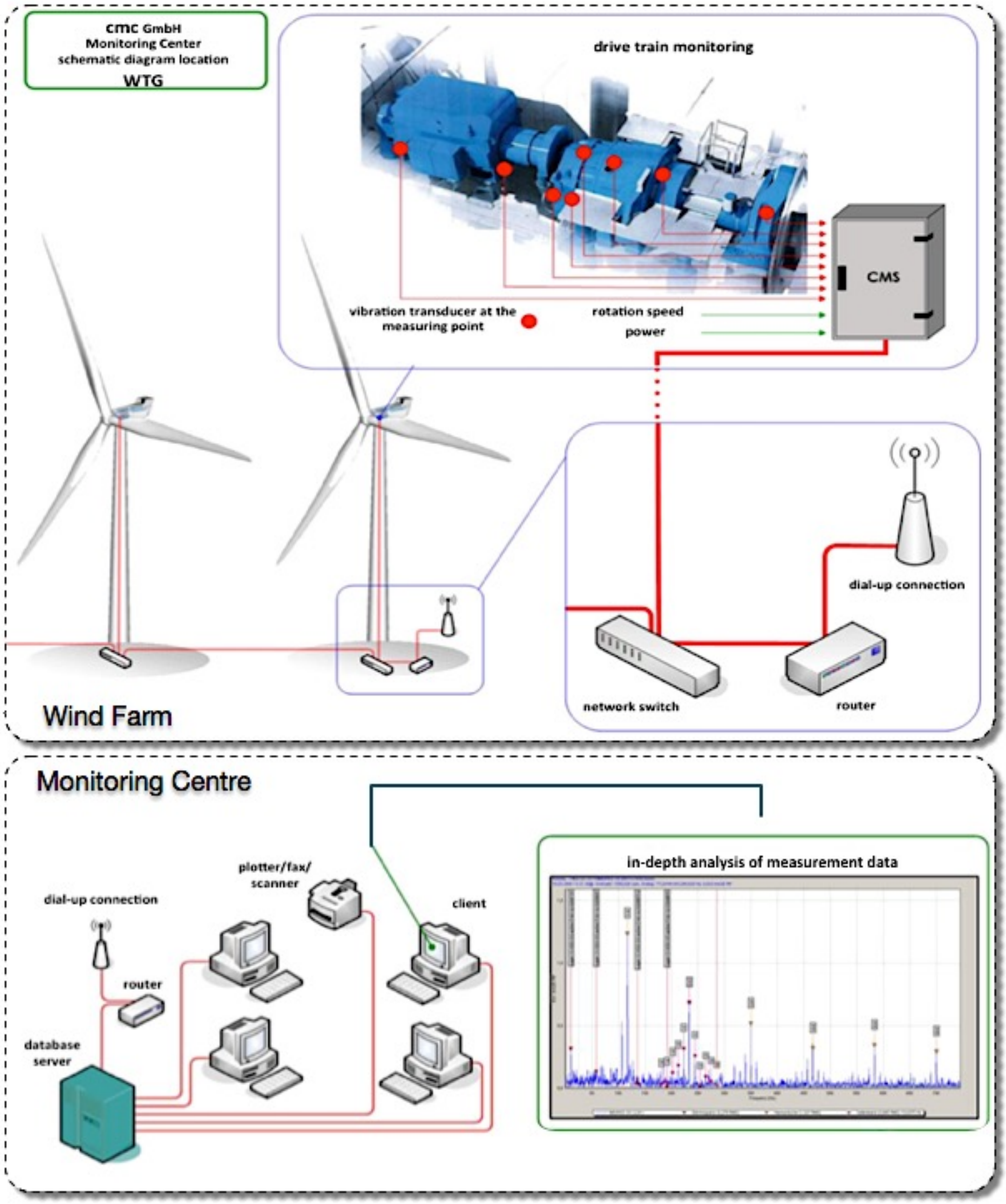

Figure 37: CM Installation and Monitoring (courtesy of cmc GmbH)

3.3.3.2 Diagnostic Method

Vibration Analysis is the most established form of assessing the condition of a wind turbine drivetrain of wind turbines. This diagnostic approach makes use of the fact that damages in rotating machinery lead to a deviation of the vibration baseline and that each rotating unbalance can be identified by its unique vibration pattern. [92]

The analysis can be categorized in to three levels: Level 1 is based on the monitoring of the vibration severity. This broad band approach makes use of the international standard ISO 10816-3, which classifies the frequency (10Hz to100Hz) as a function of the actual power output of the WT. Level 2 analysis is band-selective, specific parameters are tracked at fixed- and variable speed. If certain limits are reached frequency or order based Fast Fourier Transformation (FFT) are performed on the measured data. The FFT results in a plot of amplitude of the vibration signal over the frequency. This allows to allocate certain frequencies to rotating machine components such as gear mesh or bearing race or roller pass frequency. Conclusions regarding the deterioration can be made by monitoring the change in the amplitude over time. [92] [93]

Level 3 analyses may be described as the in-depth assessment of historic events based on i.e. envelop-spectra, amplitude-spectra. [93]

3.3.3.3 Cost Analysis Condition Monitoring

A study including 200 WT (1,5MW) of three European IPPs investigated the cost-benefit of condition monitoring on modern WTs. [94] The cost savings are based on estimates and do not include loss of production during the downtime. The costs for repairs and procurement of the faulty components are based on the German supply chain and underlying its relatively high spare part availability and short procurement times.

	Juwi Management	e.disnatur	Envia M
Amount of WT	**59 WT**	**130 WT**	**15WT**
Measurement Period	**3 years**	**5 years**	**5 years**
Total Cost CMS[38]	**472’000€**	**1’300’000€**	**150’000€**
Detected Damages	**20 x Gearbox**	**12 x Gearbox**	**3 x Gearbox**
Repair without CMS[39]	**2’811’000€**	**4’620’000€**	**405’000 €**

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[38] *Total cost for Hardware and monitoring services*

Planned repair (with CMS)[40]	**702’750€**	**1’155’000€**	**101’250€**
Estimated Savings	**1’636’250€**	**2’165’000€**	**153705€**

Table 16: Cost Saving Potential of Online CMS [94]

To quantify the benefits and potential savings from a WFM perspective, different aspects have to be taken into consideration: First half of the operation life is covered by a full service contract; no indication for lead times of big components (e.g. gearboxes) for the second half of the operational life span.

(i) Failure rate increases with age of components, thus failures in the second half are more likely.
(ii) Lead times for components will most likely be higher compared to the German market.
(iii) Crane availability and remote locations of WEFs will lead to prolonged downtimes even if spare parts are available.

3.3.3.4 Need for independent condition monitoring approach in South Africa

Condition Monitoring services are based on a combination of several aspects and experience. Specialized CM service providers are to be preferred over a stand alone solution, which purely work on algorithms without evaluation of the data by diagnosis engineers. Cmc GmbH describes the requirements on the CM provider as follows[41]:

(i) CMS Hardware
(ii) CMS Software
(iii) WT specific CMS application
(iv) Diagnostic experience

---

[39] *Estimated replacement cost: €150,000 for gearbox, €38,000 for a generator and €25,000 for a main bearing (DEWI)*

[40] *Costs for planned repair < 30% for unplanned replacement (DEWI)*

[41] *Based on consulting Roman Wolff, cmc GmbH, Schoenkirchen, Germany*

(v) Know How of drivetrain design

(vi) Know How of WT operations

(vii)IT infrastructure

This goes hand in hand with the misconceptions that an installed CM system generally provides benefit to the owner. Only thorough analysis and communication with the WFM results in benefits to the project's owners.

Further benefits of implementing independent condition monitoring during the full service period, is to gain an in-depth understanding of the WTs and establish a gapless life cycle documentation, which brings the wind farm manager, respectively the owner in a position to move to active asset management and to take on more responsibilities for the operations of the WEF (this could result in a shift away from full service contracts to more cost efficient ways to operate the WEF).

Warranties especially towards the end of the full service contract must be monitored. Initial damages 'P' are documented which may result in a failure 'F' which occurs after the end of the warranty period. Without independent CM the owner has no legal means to claim for damages after End of Warranty (EoW).

For the second half of the operational life-span active asset management can be implemented. The longer the data collection is before the shift to active asset management, the higher the diagnostic confidence will be.

3.3.4 Technical Inspections for Wind Energy Facilities

The following paragraphs outline an inspection regime for WEF and common analysis methods for WTs in order to determine the condition of the structural integrity, electrical, mechanical and hydraulically components. Most of the components of the drivetrain and of the subsystems can be found in various industrial equipment and thus standard state of the art analysis methods can be applied.

An inspection regime consists of two parts, firstly inspection of the entire wind farm according to key events in the WT's life cycle and secondly condition based inspection, which on a case by case basis investigates events triggered by analysis of the operational data or to act in order to verify findings based on analysis of the CM data.

(viii) (ix

(x) **(i) Inspection Regime according to Wind Farm Life Cycle**

(xi)
    a. Technical Inspection and Technical Acceptance after commissioning (x

(xiii)
    b. Periodical Inspection according to local regulations

(xiv)
    d. End of Warranty Inspection

(xv) **(ii) Condition based Inspection / Case by Case**

    a. Inspection of entire WT and its structural integrity
    c. Inspection of entire drive-train and components thereof:
        i. Video endoscopy of generator and main gear-box
        iii. Vibration-measurements and analysis
        v. Oil analysis
        vii. Life Cycle Analysis and comprehensive inspection of drivetrain
    e. Blade inspections using rope access

Table 17: List of Technical Inspection for WTs (author's compilations)

The most common inspections are explained in the following paragraphs.

3.3.4.1 Inspection of an entire WT and its structural integrity

This inspection is conducted to ensure an overall structural integrity and a safe operation of the WTs, which is often a mandatory requirement from the insurer of the WEF. [83]

The scope includes the WT's documentation (including maintenance reports), foundation, tower, welding seams and bolt connection of structural and safety relevant components, electrical components, mechanical components incl. visual gearbox inspection, hub-systems, obstacle lights as well as functional test incl. safety-chain of the WT. [83]

Comprehensive tests are performed regarding the WT’s functions including safety processes, but as well as integral components e.g. by bolt connections are checked acoustically on tightening torque.

3.3.4.2 Gearbox Inspection

The gearbox is one of the most expensive components of a WT, the technical health is crucial to the WT’s viability and must therefore be assessed thoroughly.

The torque from the slow turning rotor is transmitted through the gearbox onto the high-speed-shaft, which drives the generator. The frequent load changes on the entire drivetrain cause wear and tear on e.g. gears, slow and fast running bearings.

The gearbox analysis exposes eventual damages or reports the absence thereof. This can prevent major breakdowns and thus avoid costly repairs, but as well as repairs can be scheduled with regards to weather conditions, component and crane availability.

State of the art gearbox inspections are based on a threefold approach, consisting of video endoscopy, vibration analysis and lubrication analysis.

(i) Gearbox Video Endoscopy

Gearbox video endoscopy makes it possible to access and inspect visually, otherwise not accessible areas and components of the gearbox e.g. gears, hollow spaces and bearings. The visual inspection is the most suitable way to determine and record wear, tear and damages or certifies the absence thereof.

The focus of this inspection is the assessment, of, internal components and areas of the gearbox, which are visible from the service lid e.g. the planetary stage; its sun gear and planetary gears bearings, planet carrier bearing.

The accessible components of the gearbox should be examined using a state of the art industrial video-endoscope. Gears and bearings are inspected visually; pictures are taken of anomalies and areas of significant wear or damages of the accessible components. The inspection will be carried out without dismantling the gearbox, bearing-covers or reduction of the oil level.

(ii) Gear Oil Analysis

The oil analysis provides valuable information to assist in determining the condition of the gearbox and of the oil itself. In the course the dipstick-magnet and gearbox-oil-filter is checked visually for debris and particles.

A gear oil sample is taken according to best practice procedures during the inspection of the WT. It should be ensured that the sample will not be contaminated and that the sample is taken in a manner, which is reproducible at any given time in the WT's life. The sample is analysed at laboratory, which works according to international industry standards.

3.3.4.3 Rotor Blade Inspection

The rotor blade inspections are conducted in order to ensure that the current condition of the blades ensure safe operation, as well as being in accordance with the provided documentation. All found anomalies and defects should be documented.

The outer surface and structure of the blades are inspected to determine defects and anomalies e.g.: cracks, wear, delamination, cavities, erosion, which are marked on the surface, and then captured photographically. The interior inspection of the blade includes the accessible part of the blade as well as the blade-hub-connection. The lightning-protection-system is tested on conductivity in between the lightning receptors, located on the outside, and the connection of the lighting protection system situated at the root of the blade.

3.3.4.4 Expert Reports

Technical inspections by independent experts result in expert reports for the wind farm owner. These reports document all found defects or the absence thereof. The deficiencies are evaluated according to best industry practice. If serious defects are found, e.g. damages to gear teeth (cracking, brake outs), or bearings, appropriate recommendations regarding continued operation are made. The reports form an essential part of the life cycle documentation. The aim of the report is to detect initial damage in order to prevent secondary damages.

Reports by independent experts are unbiased and can therefore be used for mitigation between OEM and wind farm owners.

3.4 SUMMARY OF DEVELOPED FRAMEWORK

In summary of the developed framework, the requirements were firstly analysed on the basis of the wind energy value chain and its variable influences were identified, which are: wind resource, power curve and availability. Operational expenses are linked to the availability for WEFs, which are under full service contracts. In the second step the scope of work for BM and TOM was deduced from the named variable influences as well as from the research foundation set in chapter two.

WFM can be subdivided into two streams, which are BM and TOM, as mentioned previously the focus is on TOM, due to the vast experience in South Africa with '*Public Private Partnerships'* and financial management. Both streams may work independently from one another, besides the regular reporting. The BM unit is in the decision making position and is the first point of contact for the owners and lenders, TOM on the other hand is the first point of contact for all technical related matters. During the period of the full service contract the main objective of TOM focuses on the monitoring of the technical performance of the WTs as well as the monitoring of performance of the maintenance provider. In addition, the TOM entity functions as an advisor to the maintenance provider in order to prolong MTBF and reduce MTTR, based on the constant analysis of all gathered data and thus optimises the performance of the WTs.

The resulting requirements can be deduced from the scope of work. Four key requirements (human resources, TOMS, CM and technical inspections) were identified and how they interact in the South African context was looked at. The economic aspects and feasibility will be discussed in the following chapter.

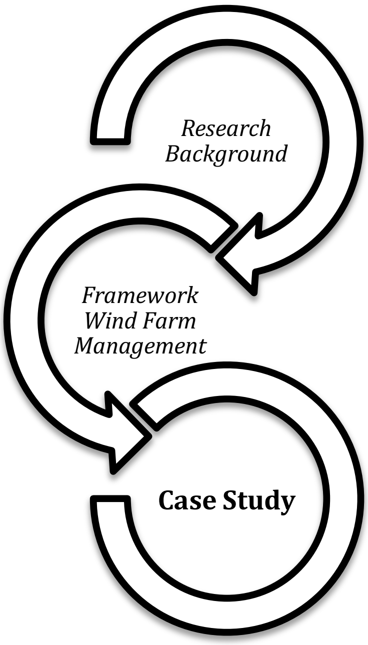
Due to the infancy of the South African industry, there is currently a lack of knowledgeable experts who can provide this type of service. These experts require vast experience within CM and technical inspection services and therefore it may be better advised to subcontract those services to overseas based companies until the local knowledge base is more established.

This chapter answers the technical research question and it is followed by the financial analysis that is based on a case study.

CHAPTER FOUR:

APPLICATION OF FINDINGS ON CASE STUDY

The case study represents a wind project (Alpha Energy) developed according to the local requirements (REIPPPP). The project outline is based on industry insight and conclusions drawn from successful projects of the previous bidding rounds (BW1 to BW4). The objective of the case study is to test if the framework for independent WFM developed in this paper is applicable and economically viable for local wind projects.



4.1 OUTLINE CASE STUDY – ALPHA ENERGY

'Alpha Energy' represents a successful project of the REIPPPP. It consists of 41 WTs of 2.4MW capacity each, totalling to 98,4MW installed capacity. A capacity factor of 36% is assumed, which is high in international comparison, this however represents a realistic value for wind projects in South Africa.

Project Company:	Alpha-Energy SPV
Installed Capacity:	98MW
Wind Turbines:	Nordex N117 / 2400

Amount WT	41
Tariff:	0,85 Rand / kWh
Capacity Factor	36%
AEP (P75):	307'126MWh
Electricity Sales	261'057'7168R

Table 18: Project Details Alpha-Energy WEF[42]

The tariff is based on a rounded average of previous successful projects (BW2 to BW4), excluding the *'high tariffs'*[43] of the BW1 projects. The technology selection reflects the current market situation[44] (2MW to 3MW, gearbox-driven, DFIG). The turbine manufacturer Nordex offers a wind turbine on the market, which meets the mentioned criteria: Nordex N117 / 2400 is a WT optimised for low wind sites[45]. [95], further technical information to be found in Annex II.

4.1.1 Financial Assumptions

Alpha Energy reached COD in 2015. Figure 38 provides a high-level overview of the financial model of the WEF. The electricity sales start in 2015 for a 20-year period until 2035. The tariff is indexed by CPI and therefore increases gradually over the entire lifespan. The assets are written off in a straight-line to zero over 20 years. After about ten years of operation, the first taxable income was generated, represented by the jump in tax payments illustrated in the figure.

The debt equity split of the project is 70/30. The debt service illustrated in Figure 39 composes of the interest and principal payments. For the first ten years the debt service is relatively consistent and increases towards the end of the payback period. The entire loan is paid back after 16 years of operation in 2031, which will result in a jump of free cash for the last years.

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[42] *Based on rounded average values of BW2 to BW4*

[43] *Due to under subscription off the BW1 the selection was not competitive, which resulted in the acceptance of high tariffs.*

[44] *See Footnote 17*

[45] *Sites are classified according high (IEC1), medium (IEC2), low wind speeds (IEC3). In South Africa most utilised sites are categorised as* IEC2 / IEC3

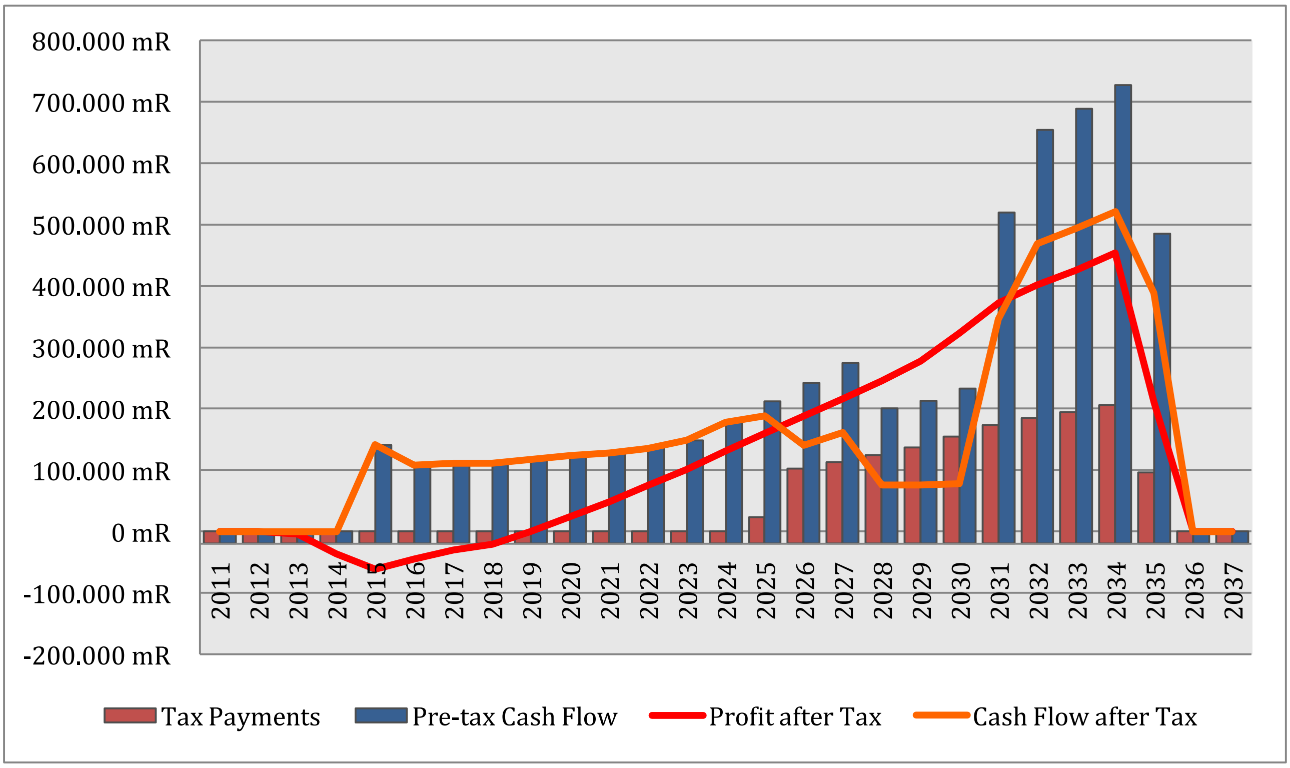

Figure 38: Alpha Energy Financial Forecast – Equity Returns

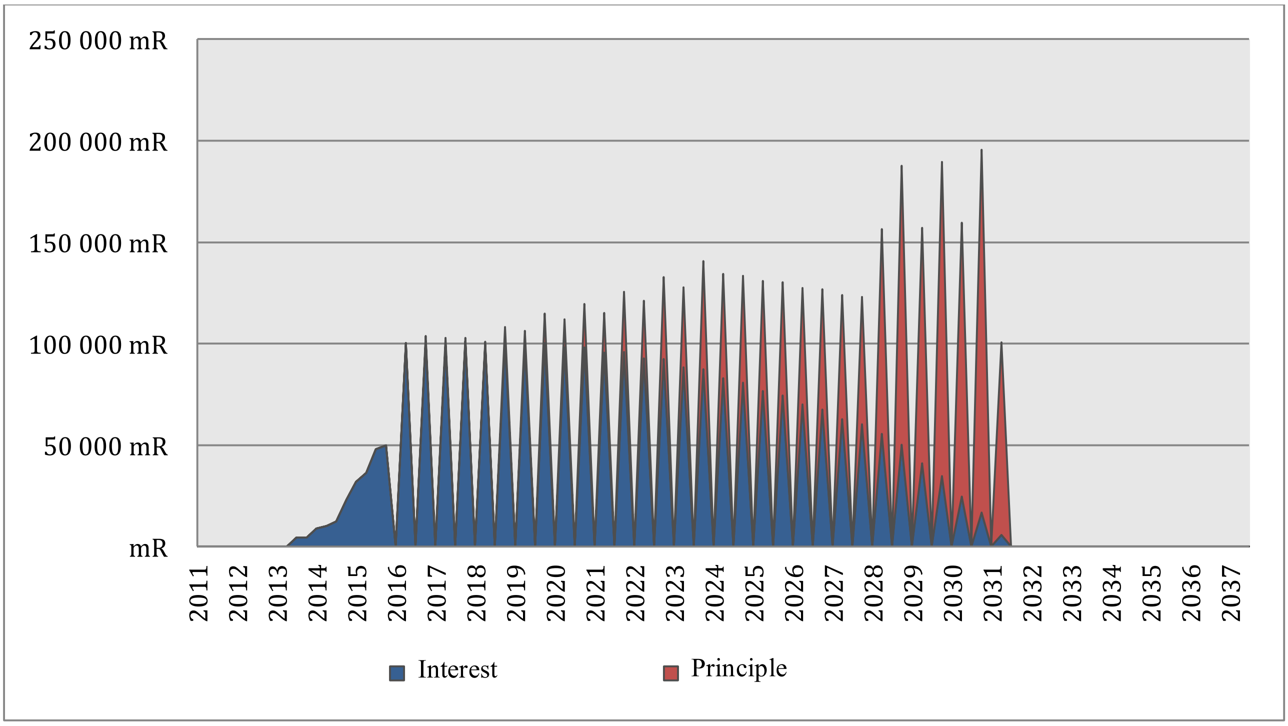

Figure 39: Debt Service Alpha Energy

4.1.1.1 Budget Requirements

The budget for WFM needs to fit the financial model of a wind project. Based on international experience, basic WFM is budgeted to about 4% to 6% of the annual turnover of a wind farm, of which about 1% to 3% is allocated for TOM and 2% to 4% for BM[46]. Large projects in South Africa result in a lower workload per installed MW as well as lower costs than that of international counterparts, due to economies of scale. The workload can be subdivided into work per WT and activities for the project at large. The fact that all WTs of the WEF are consisting of the same model and that the amount of shareholders is limited allows to offer the service for a reduced rate compared to the European markets. In discussion with financial managers and project developers, the budget for this illustrates an average South African wind project, which is set to 3,25%[47] of the annual electricity sales. The budget is therefore dependent on the AEP of Alpha Energy which incentives the WFM to increase the turnover by minimising the downtimes and maximising the energy output. In the same token a fee structure linked directly to the electricity sales is aligned with the financial model of Alpha Energy.

Percent	Budget per WT		Total Budget	
1,00%	64.157	R	2.630.445	R
2,00%	128.314	R	5.260.889	R
2,50%	160.393	R	6.576.111	R
3,00%	192.472	R	7.891.334	R
3,25%	**208.511**	**R**	**8.548.945**	**R**
3,50%	224.550	R	9.206.556	R
4,00%	256.629	R	10.521.778	R

Table 19: Project-Outline Alpha Energy – Budget for WFM as fraction of project turnover

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[46] *according to Kai Nohme, Energy Consult GmbH, Husum, Germany July 2013*

[47] *according to David Wolfromm, Windcurrent Pty Ltd, Cape Town August 2013*

4.1.2 Alpha Energy Contractual Framework

The contractual framework and the associated stakeholders are illustrated in Figure 40. The stakeholders are subdivided into three groups, (i) mandatory government institutions and REIPPPP contracts (grey filled), (ii) project specific stakeholders (grey stripped) and (iii) wind farm management.

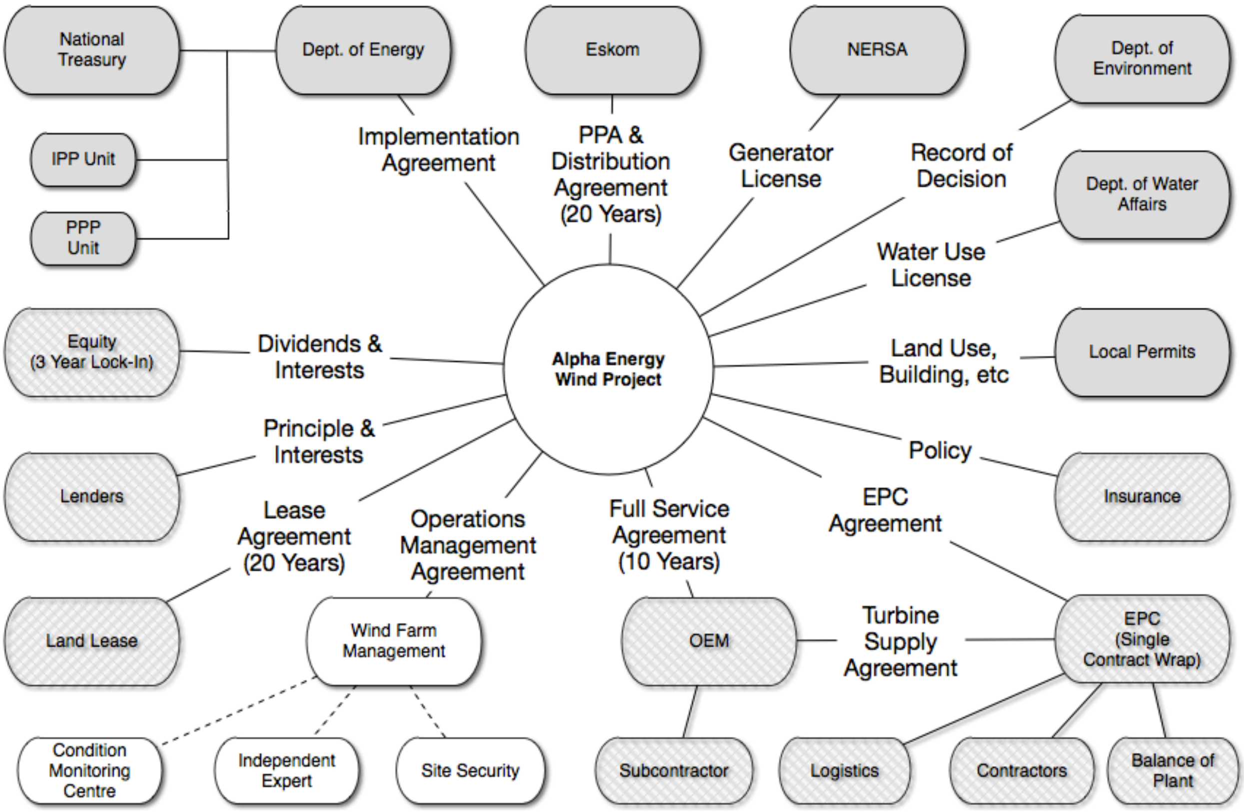

Figure 40: Contractual Framework Alpha Energy WEF adapted from [96]

The contractual framework sets the basis for the BM for *'Alpha Energy'* stakeholders and contracts need to be managed and reported in accordance with the agreements.

4.1.3 Project Specific Value Chain Analysis

The project specific value chain is derived from the contractual framework (Figure 40) and the project outline (Table 18). Figure 41 illustrates the value chain for Alpha Energy. Based on the wind regime, availability and losses of a single WT and the overall WEF losses, the AEP is calculated. The AEP in conjunction with the set tariff per produced kWh (fixed for the duration of the PPA) builds the gross income of the wind energy project. In order to determine the net income two major expenditures need to be taken into consideration, firstly the capital expenditures (illustrated by the grey fields) and secondly the operational expenditures (OPEX). The OPEX may be subdivided into two categories according to the different contractual structures, where the operation and maintenance is incentivised by mean technical availability (light blue) of the entire wind turbine cluster the land lease and the wind farm management are directly connected to the gross income (light orange).

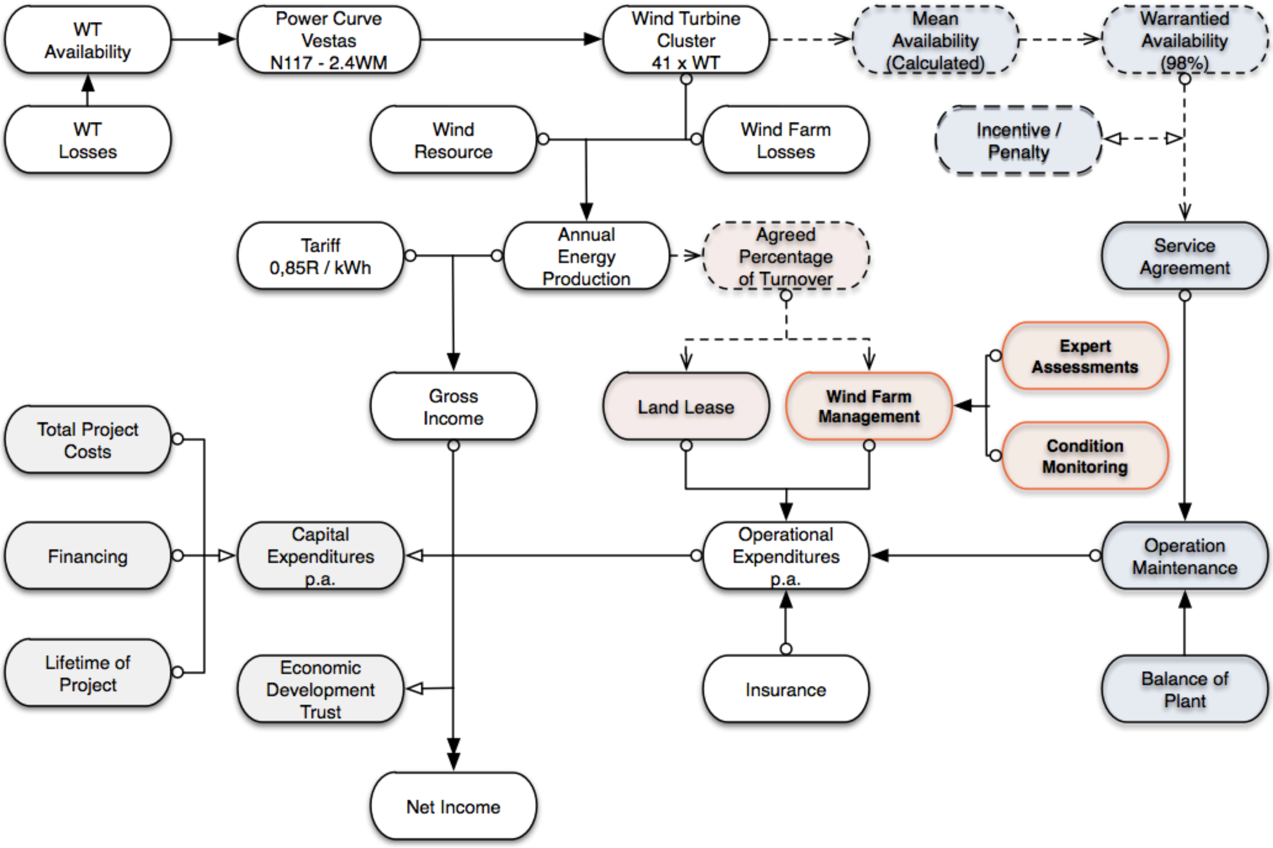

Figure 41: Alpha Energy Value Chain (author's compilation)

The difference between technical availability and AEP was pointed out in previous paragraphs. The incentives of the WFM and the owners / investors in Alpha Energy are therefore directly aligned. The aim of the WFM of Alpha Energy is to monitor all service activities and to make recommendations for optimisation in order to achieve the highest possible energy output for the current technical availability.

4.1.4 Maintenance and Service Contracts

Full service contracts for the first ten years of operations are contracted to the OEM. Technical availability of 98% is warranted for the duration of the contract. The contract includes Balance of Plant (BOP) maintenance for the first five years of operation. Downtime for scheduled maintenance per WT (40h per annum) and BOP (41h per annum) is part of the agreement.[48] These figures reflect average time allocation for service for WTs of the class and size such as the selected Nordex N117/2400.

4.1.5 Economic Development Obligations

For operations management, EDOs are important from two different perspectives. On the one hand the job creation commitment of the project company is partially passed onto the operation management division and has to be adhered to. On the other hand the operation management is the representative of the project, which is obliged to monitor and report on the level of performance of all contracted parties.

Job Creation during the Operating Measurement Period	***Total Jobs created***	**Person Months**
Total RSA Based Employees jobs created	8	1920
RSA Based Employees who are Citizens	8	1920
RSA Based Employees who are Black People	5	1200
Skilled Employees	5	1200
Skilled Employees who are Black People	3	720
RSA Based Employees who are Citizens from Local Communities	4	960

Table 20: Job Creation Obligation, OMP, Overview

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[48] *According to Kai Nohme, Energy Consult GmbH, Husum Germany, June 2013*

Table 20 lists the requirements for the OMP in *'person months'*. The WFM takes over the responsibility to fulfil the obligations, therefore the need arises to structure the organisation accordingly.

4.2 WIND FARM MANAGEMENT FOR ALPHA ENERGY

The WFM for Alpha Energy should follow the framework outlined in the previous chapter (see 4.1.1.1) for a budget, which is for the project sustainable. As outlined previously the budget for WFM should be correlated directly with the success of the overall wind energy project. A fraction of 3,25% of the turnover of the WEF reflects this scenario. This results for the outlined case study Alpha Energy in an annual fee of about R200'000 per WT per year (according table Table 19). For this fee the entire WFM and the work of the specialist companies should be realised. In accordance with the developed framework the following four areas of the WFM entity are applied on the Alpha Energy case study, where each will be further investigated.

(i) Humans Resources & Organisational Structure
(ii) Technical Operations Management System
(iii) Technical Inspection Regime
(iv) Condition Monitoring Concept

The final step combines the financial assumptions of the four key drivers in a financial model and tests the economic feasibility.

4.2.1 Organisational Structure & Human Resource

The internal organisational structure of the new entity is important, as one has to outline the positions to be filled and to determine the responsibilities. According to the responsibilities the organisation is subdivided into BM and a TOM. The work of the managing director falls into business management; however the responsibility of the position includes both units.

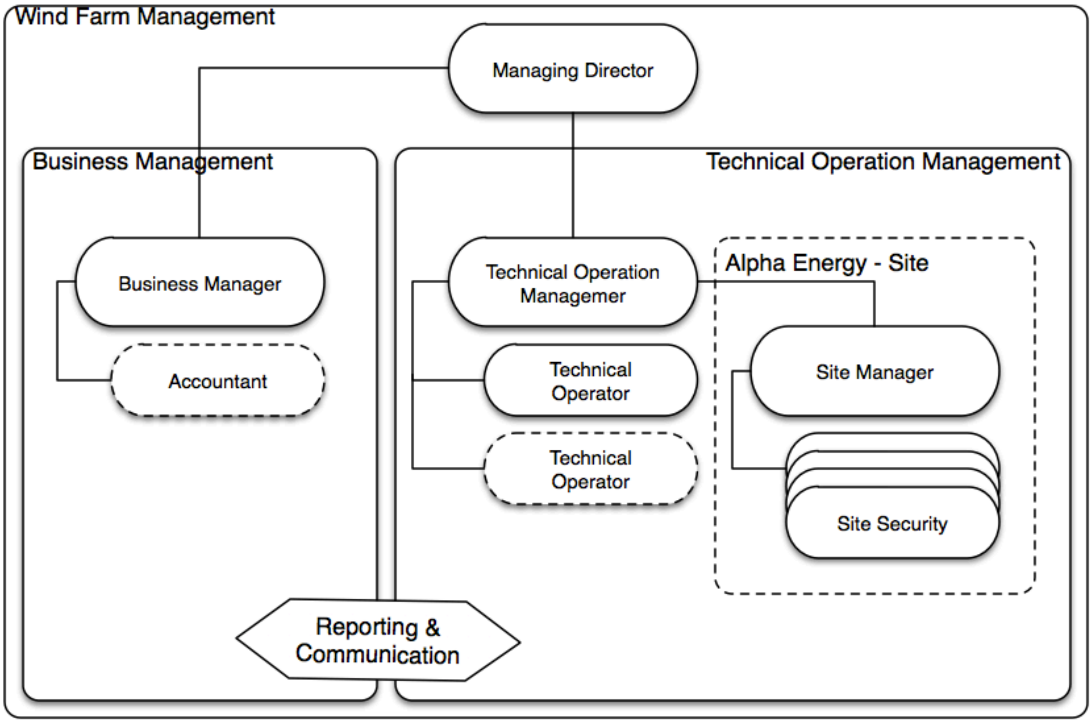

Figure 42: Organisational Structure Alpha Energy

In accordance with the EDOs five skilled jobs need to be created (Managing Director, Business Manager, Technical Operations Manager and Site Manager), three of which need to be filled by *'black persons'* according to the BBEEE definitions.

Job Creation during the Operating Measurement Period	***Skilled***	**Black**	**Local**	**RSA based & citizens**
Managing Director	X	X	O	X
Business Manager	X	X	O	X
Technical Operations Manager	X	O	O	X
Site Manager	X	X	O	X
Technical Operator	X	O	O	X
Site Security	O	O	X	X

Table 21: Possible Staff Placement Alpha Energy

The site security should consist of at least four *'black persons'* from the area of the project. At least eight jobs need to be created in total. The proposed scenario creates nine jobs; the obligations are exceeded by twelve person months per year. This can be used to ease the obligations at a later. Table 21 shows a possible solution for the staff placement according to the EDO. The obligated person months are compared to the actual job creation in Table 22.

Job Creation during the Operating Measurement Period	***Actual Job Creation***	**Obligation**
Total RSA Based Employees jobs created	2160	1920
RSA Based Employees who are Citizens	2160	1920
RSA Based Employees who are Black People	1440	1200
Skilled Employees	1200	1 200
Skilled Employees who are Black People	720	720
RSA Based Employees who are Citizens from Local Communities	960	960

Table 22: Actual Job Creation in Person Months vs. Obligations according to proposed Structure

4.2.1.1 Cost Assumptions Humans Resources

Human Resources are one of the most crucial aspects of the implementation of WFM. The key positions require highly skilled staff members. The skills shortage in South Africa combined with the EDOs and the infancy of the industry may result in a challenging task for acquiring suitable staff for the job.

Position	**Lower Limit**	**Upper Limit**
Managing Director	1’000’000 Rand	1’250’000 Rand
Business Manager	800’000 Rand	850’000 Rand
Technical Manager	750’000 Rand	850’000 Rand
Accountant	360’000 Rand	480’000 Rand
Technical Operator	340’000 Rand	500’000 Rand
Site Manager	650’000 Rand	800’000 Rand
Site Maintenance	Minimum Wage	120’000 Rand
Site Security	Minimum Wage	100’000 Rand

Table 23: Salary Assumptions Wind Farm Management[49]

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[49] *Based on consultation with Altgen Pty Ltd, Sean Gibson, Stellenbosch, South Africa June 2013*

Salary assumptions were investigated with input from renewable energy specialist recruitment companies and are listed in the following table. The respective job descriptions of the key staff are listed in Annex IV.

The cost-to-company remuneration rate includes all costs associated with the employment. This includes the gross salary and the employer's contributions. The net salary is derived after the portion of deductions is removed from the gross salary.

4.3 TECHNICAL OPERATION MANAGEMENT SYSTEM

Different TOMS have different pricing models. A modern cloud based system is selected for *'Alpha Energy'*. The advantage of this system is that no in-house IT for TOMS is required. For the system integration a once off installation fee is charged, and for the continuous SCADA monitoring of the WT an annual subscription fee.

The system fulfils the outlined requirements of the framework and works according to IEC61400 standard with regards to data communication and data classification. For the data communication an OPC Server for real-time data and an ODBC Server as a back-up solution for 10-minute average data is required. The selected WT Nordex N117 and its control system '*Nordex Control 2'* work on the same server set-up, which allows system integration without installing additional IT infrastructures on site.[50]

Another advantage of a cloud-based solution is that during the implementation phase, and first months of operation, if needed, login to the TOMS may be shared with experienced overseas-based service providers to train the technical operators on the job, which is favourable for a seamless integration of the TOMS starting at COD.

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[50] *Based on consultation with Greenbytes, Patrick Strom, Göteborg, Sweden, August 2015*

4.3.1 Cost Assumptions TOMS

The costs of the TOMS are illustrated in Table 24. A this stage no local software company offers a product for this application, due to that a European supplier was selected. Therefore, the charges are Euro based. The rand values are thus calculated based on today's terms[51].

Set up cost	3'000 €	42'000 R
Annual subscription per WT	600 €	8'400 R
Total subscriptions fee	24'600 €	344'400 R

Table 24: Cost Assumption TOMS[52]

4.4 CONDITION MONITORING CONCEPT

A basic state of the art condition monitoring concept for the Nordex N117 WTs is suggested, including monitoring of the entire drivetrain as outlined in the framework. Additional oil particle counters and quality measurements as well as blade monitoring may be added at a later stage if the operational data shows the necessity for that. Figure 43 illustrates the CMS in the nacelle of the N117 and the placement of the sensors on the drivetrain.

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[51] *Todays terms refer to exchange rate of 1€ : 14R (2015-08-10)*

[52] *Based on consultation with Greenbytes, Patrick Strom, Göteborg, Sweden, August 2015*

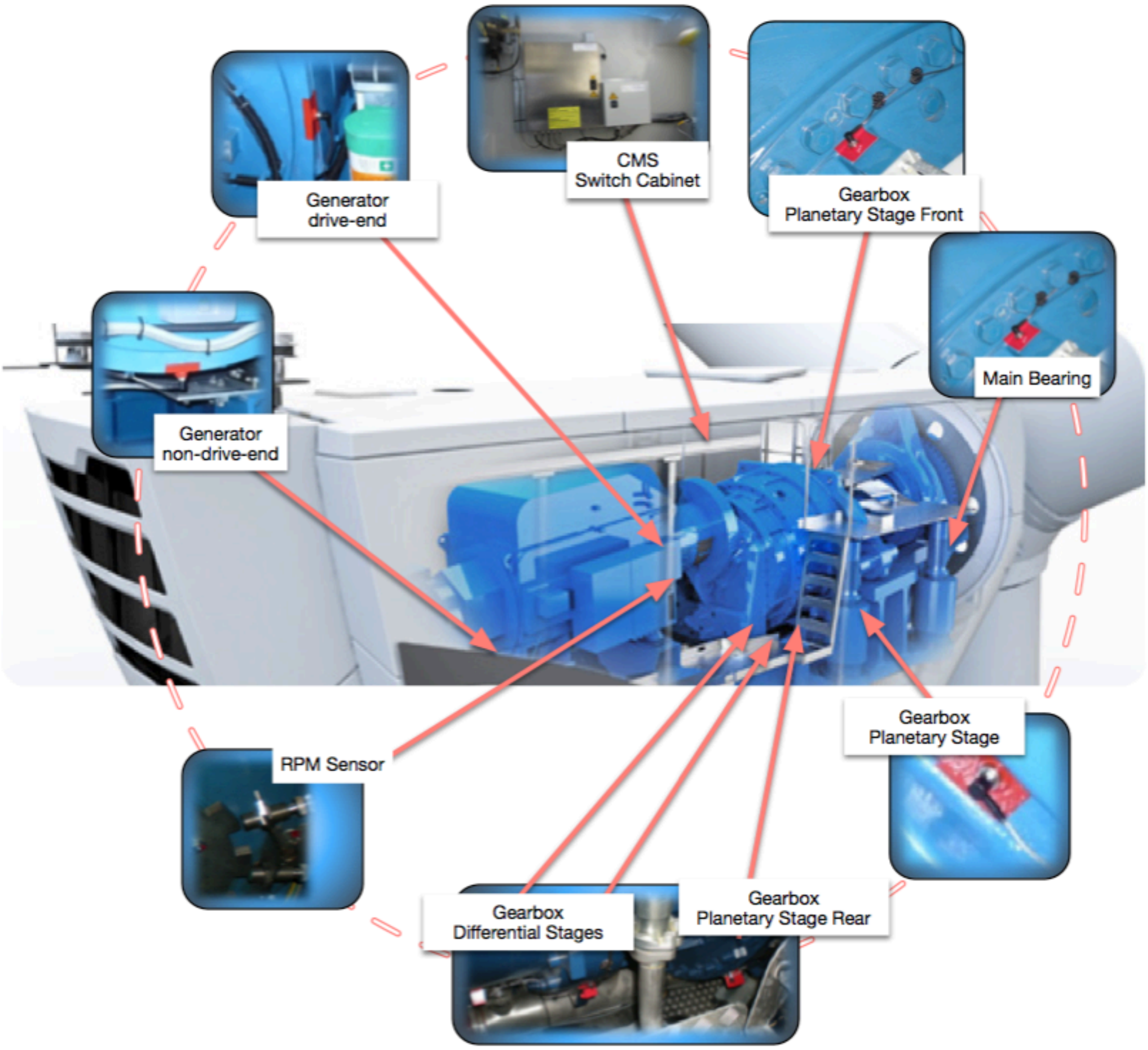

Figure 43: CMS Nordex N117

4.4.1 Cost Assumptions CMS

The costs of the CM are illustrated in Table 25. This specialised service is not available in the South African market at this stage, therefore a European monitoring centre was selected for this case study. The charges are Euro based and the rand values are calculated based on today's terms

Condition monitoring consists of two components, firstly the CMS hardware and secondly the subsequent monitoring and reporting services.

The CM hardware is bought and installed for a fixed-fee, the subsequent continuous monitoring and reporting will be charged per drivetrain per month. The cost for CMS are relatively small compared to the overall project costs and can be included in the financial modelling of the entire WEF.

CMS Cost per WT	9’000 €	126’000 R
Total CMS cost	369’000 €	5’166’000 R
Annual subscription per WT	1300 €	18’200 R
Total subscriptions fee	53’300 €	746’200 R

Table 25: Cost Assumption CMS adapted from [97]

4.4.2 Savings Potential of CMS

The following example illustrated in Table 26 places the cost for the CM hardware and monitoring services in context with other costs associated with the operations of the selected WTs for ‘*Alpha Energy*’.

CMS Hardware and Installation	126’000 R
Data analysis and reporting per annum	18’200 R
Total Life Time Cost CMS (20y)	490’000 R
Replacement Cost Gearbox	3’200’000 R
Replacement Cost Main Bearing	400’00 0R
Replacement Cost Generator	560’000 R
Production loss per day of down time[53]	17’625 R

Table 26: CMS Savings Potential N117

The total lifetime-cost of CMS is equal 28 days of avoided downtime (based on average wind days) over the entire operational lifespan of a singe WT, or avoidance of a single major damage over the WT’s lifetime. Prevention of a gearbox replacement exceeds the life cycle costs of CMS by a factor five.

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[53] *Based on 2.4MW, CF of 36% and 0,85R/kWh.*

The example is based on today’s terms and excludes other associated costs for procurement e.g. interests. The replacement costs are estimates based on the German supply chain and do not reflect additional secondary damages caused by component failure.

4.5 INSPECTION REGIME FOR THE FIRST 10 YEARS OF OPERATIONS

The inspection regime needs to be aligned with the contractual framework of *‘Alpha Energy’*. The most important contracts are illustrated in Figure 44. For the first half of the operational lifespan the OEM was awarded a full service contract.

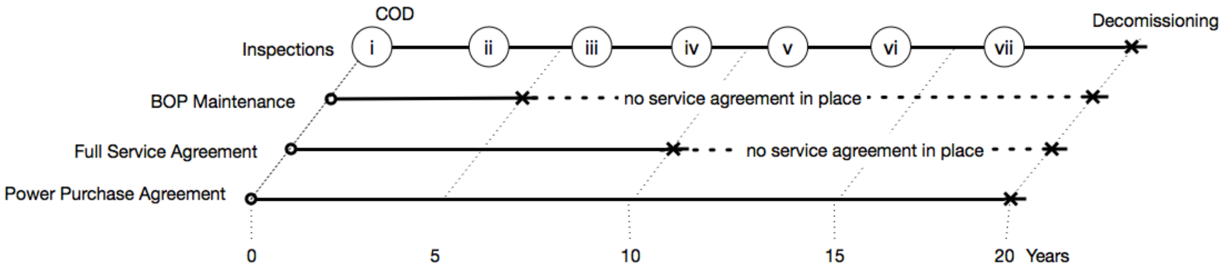

Figure 44: Alpha Energy Inspection Regime (author’s compilations)

The inspection regime for this time frame should consist of three or rather four thorough inspections. After commissioning the inspection before handover (i) is crucial. Based on exhaustive testing the single WTs and the entire WEF are accepted by the owner. It needs to be assured that all WTs are in safe operational conditions, complying with the local regulations and that all WTs and their components are in an acceptable condition. Periodic inspections (ii) and (iii) should be carried out in the fourth and seventh year of operation. Before the end of the full service contract, the most important inspection is the *‘End of Warranty’* inspection before the operational risk is shifted back to the owner of the project. All initial damages need to be documented to protect the owner against failures caused by damages, which occurred during the full service contract period.

Additional to the independent technical inspections the site manager and/or technical operator should conduct at least two visual inspections for the years without planned independent inspections, and one for the other years, in order to capture the current technical condition of the WTs in max. six months intervals.

Further inspections may be required based on the findings of the condition monitoring or for damage assessments after a defect.

4.5.1 Cost Assumptions Technical Inspection Services

The costs for the independent technical inspection services are outlined in Table 27. These specialised services are not available on the South African market at this stage and therefore a European provider was selected for this case study. The charges are Euro based and the Rand values are calculated based on today's terms[54]. The costs are based on the inspection of the entire fleet; inspection of single WTs may result in higher costs.

	Per WT	Per WT	Alpha Energy (41WT)
Handover Inspection	4'750 €	66'500 R	2'726'500 R
Periodical Inspection	3'750 €	52'500 R	2'152'500 R
End of Warranty Inspection	4'750 €	66'500 R	2'726'500 R

Table 27: Cost Assumption Technical Inspections[55]

The costs for the technical inspections occur on a regular basis every third year. It is advised to make provisions on an annual basis for the technical inspections in order to streamline cash flow.

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[54] *See Footnote 51*

[55] *Based on consultation with cmc GmbH, Roman Wolff,15 of August 2015*

4.6 FINANCIAL ANALYSIS

The financial viability of the WFM for the case study *'Alpha Energy'* is determined by relevant financial indicators such as IRR, NPV and DSCR (Debt Service Coverage Ratio). The following paragraphs discuss the financial model itself the underlying cost assumptions, input parameters and results of the financial model.

4.6.1 Cost Assumption

Based on the cost assumptions outlined in the previous paragraphs, a conservative approach was selected for the financial model. In the following, the cost for (i) Human Resources (ii) Expert Services (iii) Operational Cost and (iv) Implementation Cost are illustrated.

(i) **Human Resource (A):** *'A'* represents the largest cost allocation of WFM. The costs are subdivided into, 1.1. the staff placed at the operations centre and 1.2. the on-site staff. A lean approach is selected, which fulfils the ED obligations of '*Alpha Energy*'. The HR costs sum up to over 50% of the total available budget for WFM. The costs are inflated by CPI.

A	**Human Resource**	CTC p.a.
1.1.	**Operations Centre**	
1.1.1.	Managing Director	R 1.250.000
1.1.2.	Technical Manager	R 850.000
1.1.3	Technical Operator	R 500.000
1.1.4.	Business Manager	R 850.000
1.1.5.	Accountant	R -
	Subtotal	R 3.450.000
1.2	**Site Office Alpha Energy**	
1.2.1.	Site Manager	R 750.000
1.2.2.	Site Maintenance	R -
1.2.3	Security Guard	R 400.000
	Subtotal	R 1.150.000
Total A		R 4.600.000

Table 28: Cost Assumption Human Resource for DCF

(ii) B - Expert Service: The costs for expert services occur in Euro-terms as these services will be provided by overseas-based companies. The costs vary from year to year, due to the cost for the technical inspection services. The according to the inspection regime outlined technical inspections are scheduled four times during the ten-year period of the financial model (year 1, year 4, year 7, year 10). The costs are inflated by German CPI. The financial model makes provisions for the technical inspection services by using a reserve account to equalise the annual payments and avoid jumps in the yearly costs. The costs for the hand-over inspection in the first year of operation are covered by the initial capital outlay.

B	**Expert Services**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
2.1	TOMS	€24.600	€24.698	€24.797	€24.896	€24.996
2.2	Condition Monitoring*	€53.300	€53.513	€53.727	€53.942	€54.158
2.3	Technical Inspection	€194.750	-	-	€155.602	-
Total B		**€272.650**	**€78.212**	**€78.524**	**€234.441**	**€79.154**
B	**Expert Services**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
2.1	TOMS	€25.096	€25.196	€25.297	€25.398	€25.500
2.2	Condition Monitoring*	€54.375	€54.592	€54.810	€55.030	€55.250
2.3	Technical Inspection	-	€157.477	-	-	€201.874
Total B		**€79.471**	**€237.265**	**€80.108**	**€80.428**	**€282.624**

Table 29: Cost Assumptions Expert Services for DCF

(iii) Operational Cost (C): The operational costs reflect all other costs in order to run WFM. The expenses are estimated based on the integration of WFM in an existing structure. All costs are Rand-based and inflated by CPI.

C	**Operational Cost**	per annum
3.1.	Technical Operation Manager	R -
3.2.	Financial Advisor	R -
3.3.	Legal Advisor	R 100.000
3.4.	Auditing	R 100.000
3.5.	Insurance	R 150.000
3.6.	Cost Operational Centre	R 300.000
3.7.	Cost Site Office	R 200.000
Total C		**R 850.000**

Table 30: Cost Assumption Operational Costs for DCF

(iv) **Implementation Cost (A, B, C):** Implementation costs provide to start the operation of the WFM entity one month prior to COD of the Alpha Energy, where the first income will be generated by COD. That time should cater for the transition from the construction to the operational phase. (Cost 3.1, 3.2).

The set up cost for expert services are limited to the TOMS. The costs for the CMS hardware (cost 2.2) are carried by *'Alpha Energy'* who takes ownership of the systems. The WFM uses the system for the daily operation. Therefore, the costs are not included in the financial model. The costs for the implementation and for the first year of technical inspections are the main drivers for the required capital outlay.

A	**Human Resource**	Per annum
1.1.	**Operations Centre**	
1.1.1.	Managing Director	R 104.167
1.1.2.	Technical Manager	R 70.833
1.1.3	Technical Operator	R 41.667
1.1.4.	Business Manager	R 70.833
1.2.1.	Site Manager	R 62.500
Subtotal A		R 350.000
B	**Expert Services**	
2.1	Technical Operations Management System	€ 3.000
2.2	Condition Monitoring*	€ 369.000
2.3	Technical Inspection	€ -
	*) carried by Alpha Energy	
Subtotal B		R 42.000
C	**Operational Cost**	
3.1.	Technical Operation Management	R 200.000
3.2.	Financial Advisor	R 250.000
Subtotal C		R 450.000
Total		**R 842.000**

Table 31: Cost Assumption Implementation Cost for DCF

4.6.2 Cost Analysis

In order to compare the expenses, the average costs of the A, B and C over the ten year period are illustrated in Figure 45. The exposure to the exchange rate (Rand / Euro) is 17% which equals about 1'400'000 R on average.

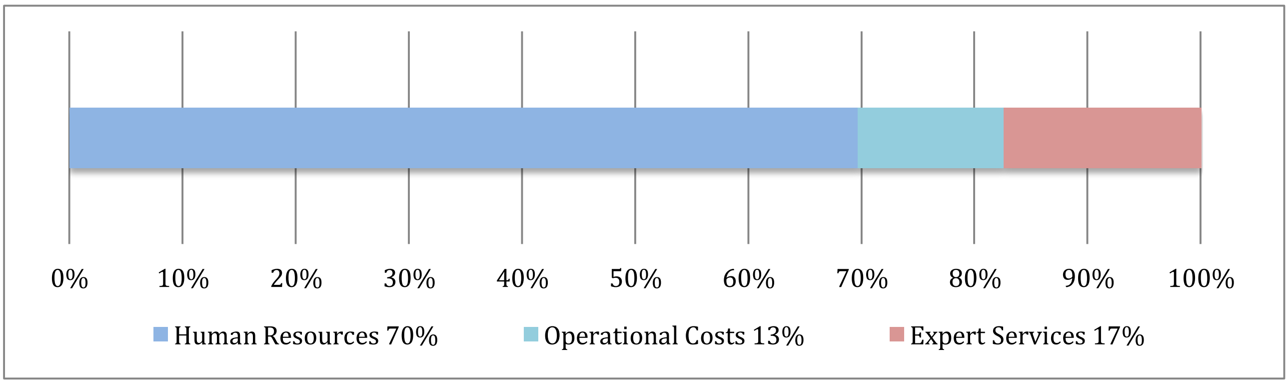

Figure 45: Cost Comparison and Exchange Rate Exposure

4.6.3 Financial Assumptions

(i) **Cost of Capital:** The analysed scenario assumes that the WFM entity is on the balance sheet of either the project developer company or of the SPV of the WEF. Thus the capital outlay is financed by a 100% parent company loan according to market related conditions. Selected interest rate: 12% [98]

(ii) **Inflation Rate:** The inflation rate is measured by the consumer price index (CPI). The 3Y average of 5.26% is used in the financial model. [99] The budget for WFM is based on the electricity sales, which are indexed by CPI. The income and expenses escalate by the same factor; therefore the risk caused by inflation is minimal. Figure 46 illustrates the CPI over the term of the last three years.

(iii) **Exchange Rate:** The expenses for expert services are Euro based and therefore are exposed to exchange rates. The relationship between the exchange rate and the interest rate is illustrated in Figure 46. For the financial modelling a fixed exchange rate of base on todays terms[56] is used.

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[56] *See Footnote 51*

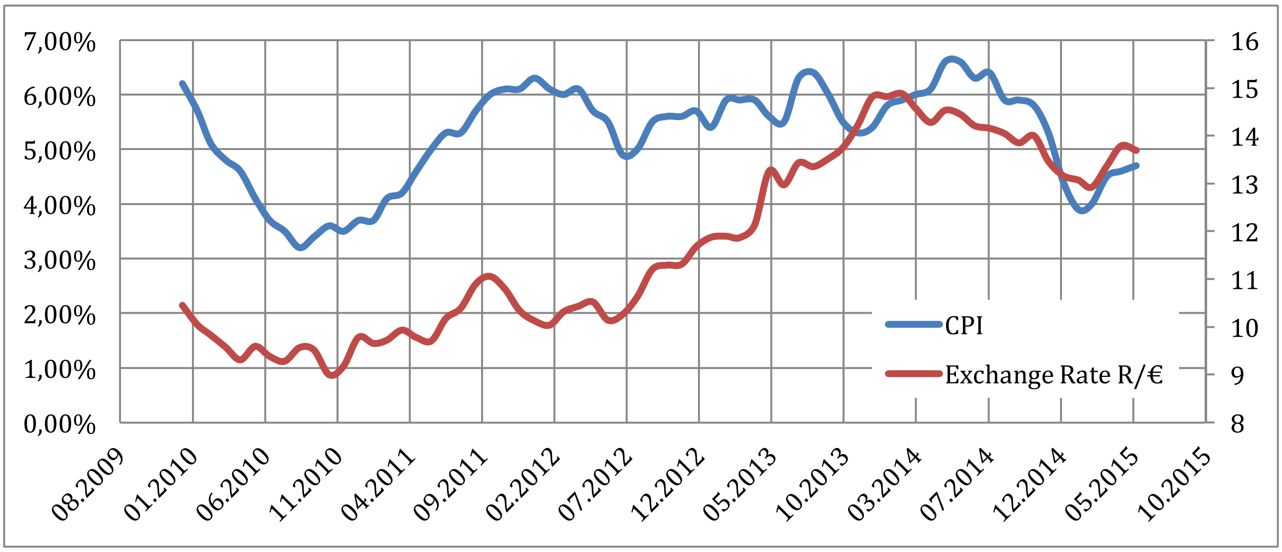


Figure 46: Exchange Rate and Inflation 3Y [100] [99]

(iv) **Capital Outlay:** The required capital outlay was structured in order to cover the cost for the implementation and the upfront cost as well as to provide sufficient free cash for operation and debt service. A debt service coverage ratio of >1.5 was used to calculate the necessary capital outlay.

(v) **Discount Rate:** The discount rate for the financial model is based on opportunity cost for long-term investments and an added risk premium. [101]

+ Risk Free Rate: 8.33% based on South African Government bond 10Y [102]
+ Risk Premium: 3,2% (estimate)
= Discount Rate: 11,53%

(vi) **Free Cash:** The free cash was calculated as shown below. Based on EBIT (Earnings before Interest & Tax), tax, debt service and the reserve account for upcoming technical inspections.

+ Earnings before interest and tax
- Reserve Account
- Corporate tax
- Interests on taxable income
- Debt repayments
= Free Cash Flow

- Dividends

= Zero

4.6.4 Financial Model

A discounted cash flow model (DCF) was applied to in order to evaluate the financial viability of WFM for Alpha Energy.

Figure 47 illustrates the inputs and outputs of the model based on the cost assumptions and financial assumptions, which were discussed in the previous paragraphs. The relation between the major inputs of the model (Net Income, OPEX, Debt, Budget) is indicated by single lines.

Based on the *'project outline'* and the specific *'requirements'* the *'initial capital requirement'* can be determined. The initial capital required need to carry the 'set-up cost', the first technical inspections as well as to provide cash flow for repayment of the loan for the first year in order to meet the required DSCR of 1,5 or greater.

The *'OPEX'* is derived directly from the '*requirements'* reflecting the three categories of the costs, *'Human Resources'*, *'Expert Services*' and *'Operational Costs'*

The *'Net Income'* is based on the allocated budget, which is directly related to the turnover of the wind farm project (AEP) as discussed in the chapter budget requirements.

In the centre of Figure 47 stands the DCF, besides the main assumption *'Net Income'*, *'OPEX'* and *'Debt'* several '*Input Parameters'* are set in order to calculate the output of the model: DCF, IRR, NPV, DSCR. The input parameters are subdivided into two categories, fix parameters and variable parameters. A sensitivity analysis tests the stability of this financial model against deviation of these parameters.

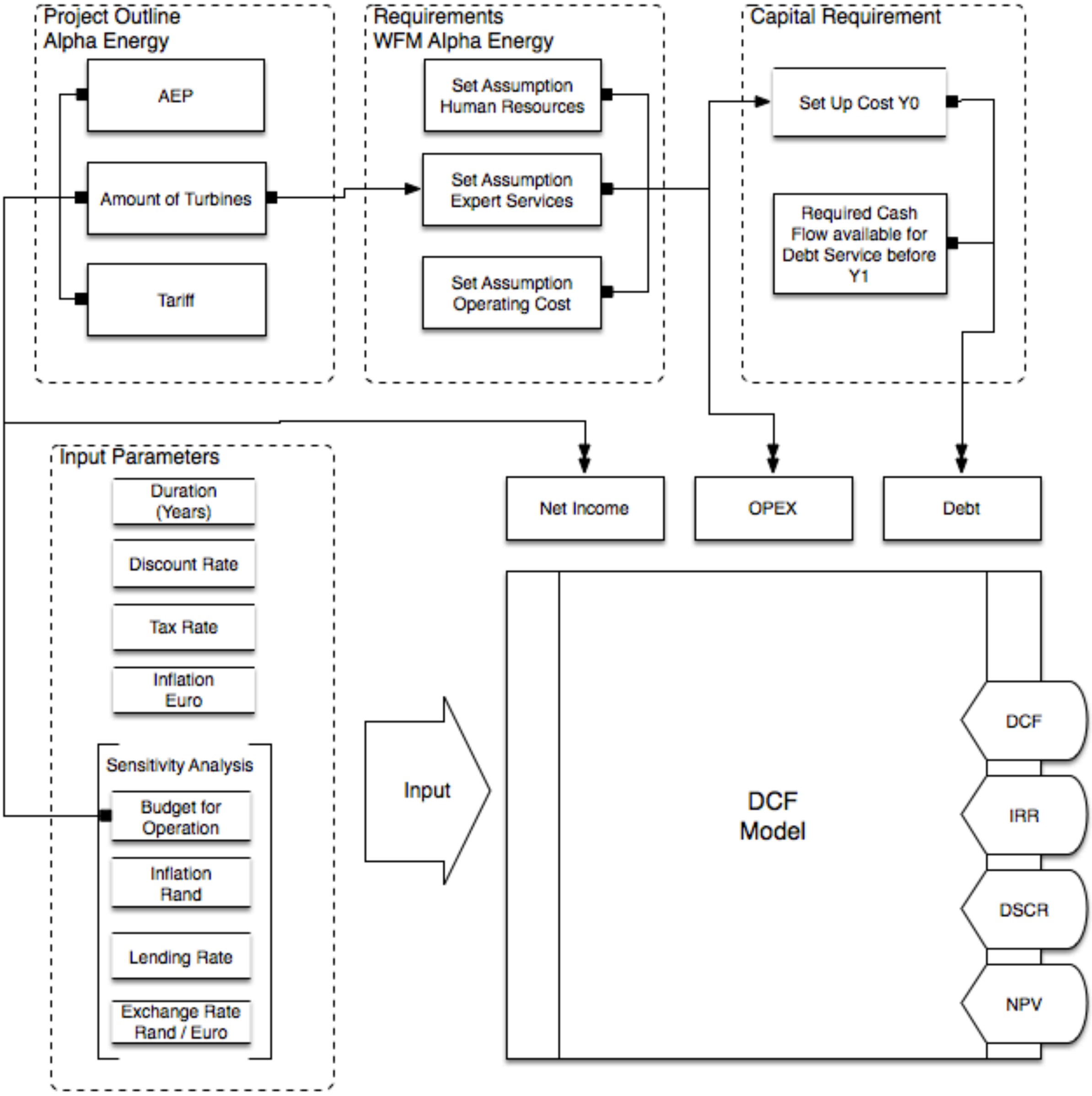


Figure 47: DCF Model Overview Input - Output - (author's compilation)

The following explains the inner workings of the financial model. Figure 48 illustrates the flow-chart of the financial model. On a yearly basis the free cash is calculated taking into account the financial parameters and basic assumptions as illustrated in Figure 47. The model follows the calculation of the free cash as outlined in the previous paragraphs. The '*EBIT'* is based on the *'Net Income'* (for the specific year) less the corresponding *'OPEX'* as well as the cash reserve. The cash reserve minimised the financial impact of the technical inspections, which occur not on a yearly basis (four times in the course of the first ten years of operation). During the payback period the interest and tax are deducted to calculate the EAT (Earnings after Interest & Tax). The cash flow available for the repayment of the loan is compared to the total yearly debt service (DSCR). A yearly DSCR of greater than 1.5 has to be achieved, if this is not achieved the initial capital requirements are revised until the criteria is met. The resulting free cash of the model is discounted over the entire project duration in this case ten year in order to calculate NPV and DCF. The results of the DCF are discussed in the in the following paragraphs. The details of the excel based model can be found in Annex V.

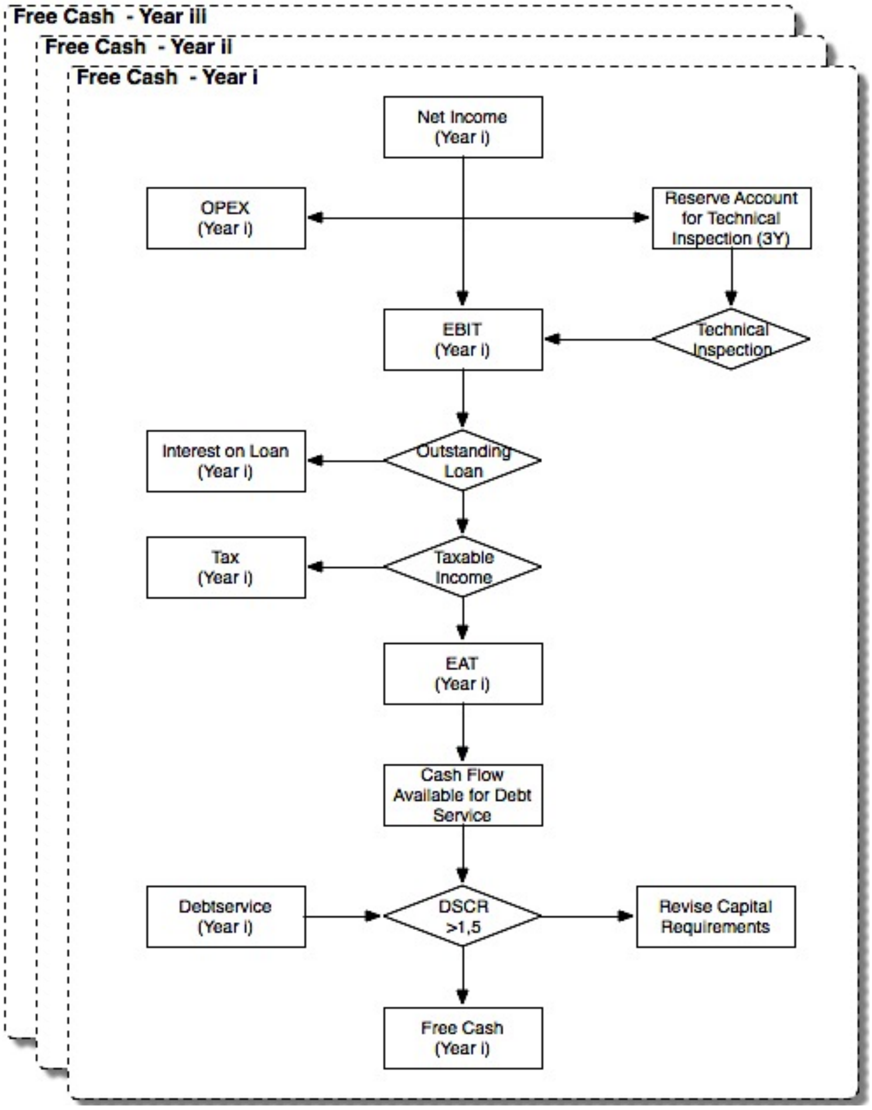


Figure 48: Flow-Chart Financial Model (author's compilation)

4.6.5 Results Analysis

The output of the financial model over the ten-year period is illustrated in Figure 49. The loan is structured over the entire period and paid in equal instalments. The actual debt per annum is represented in the figure. Tax is paid once the accumulated earnings exceed the operational loss, from then forward the relationship between EBIT, EAT and the tax payments are nearly constant. The DFC (Discounted Free Cash) is due to the negative EBIT and EAT minimal in the first year of operation, from then on forward free cash may be used for dividend pay-outs.

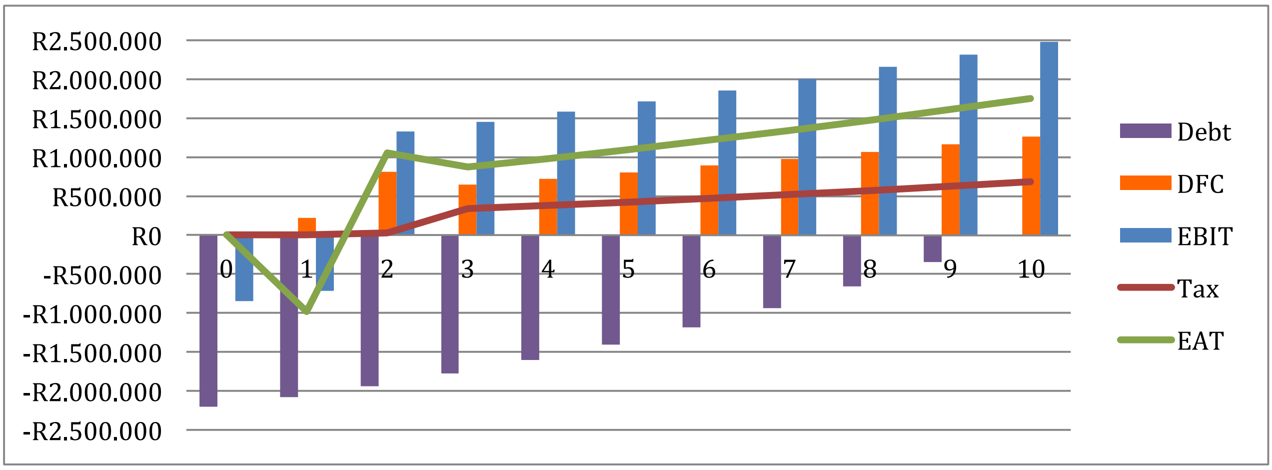
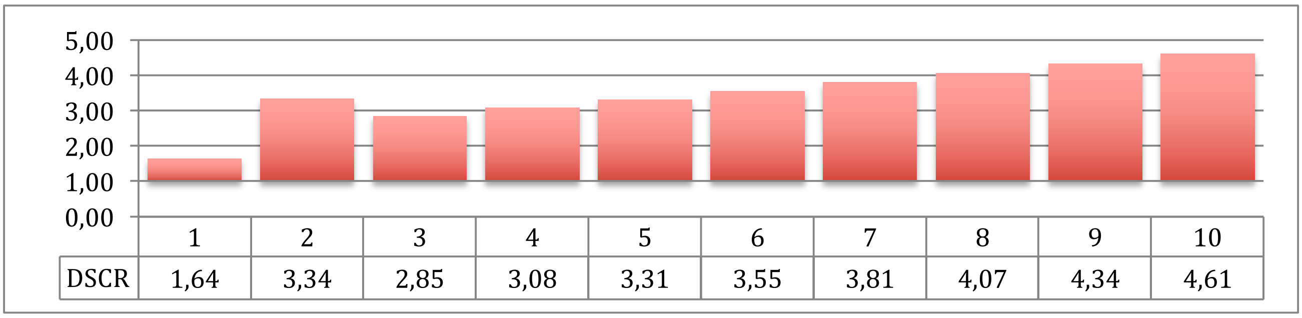


Figure 49: Overview Financial Modell WFM Alpha Energy

4.6.6 Financial Indicators

In order to get a better understanding of the results relevant financial indicators were applied to the model and are discussed below.

(i) **Debt Service Coverage Ratio:** The DSCR is a measure to define the economic stability. The ratio indicates the amount of which cash flow is available for the repayment exceeds the instalments for the debt service. The entry requirement for a stable investment was set to a DSCR of 1.5 or greater to ensure upcoming debt commitments can be met. Figure 50 shows the values over the ten-year loan period. As illustrated in Figure 49, the instalment for the first year needs to be carried by the initial capital outlay to which the loan was structured accordingly. Afterwards the free cash generated by operations exceeds the debt service more than twofold.



	1	2	3	4	5	6	7	8	9	10
DSCR	1,64	3,34	2,85	3,08	3,31	3,55	3,81	4,07	4,34	4,61

Figure 50: DSCR for WFM of Alpha Energy

(ii) **Net Present Value (NPV):** The NPV is a measure to assess the viability of an investment. The present value of the future cash inflows and outflows are represented by the NPV; in other words, it is the sum of the DFC. Therefore, the NPV is dependent on the selected discount rate. A positive NPV justifies the investment based on the selected discount rate. In order to evaluate the financial viability of WFM for Alpha Energy, a so-called NPV Evolution was established. Figure 51 illustrates the accumulation of the NPV for each year of operation. A positive NPV reached by the fifth year of operation.

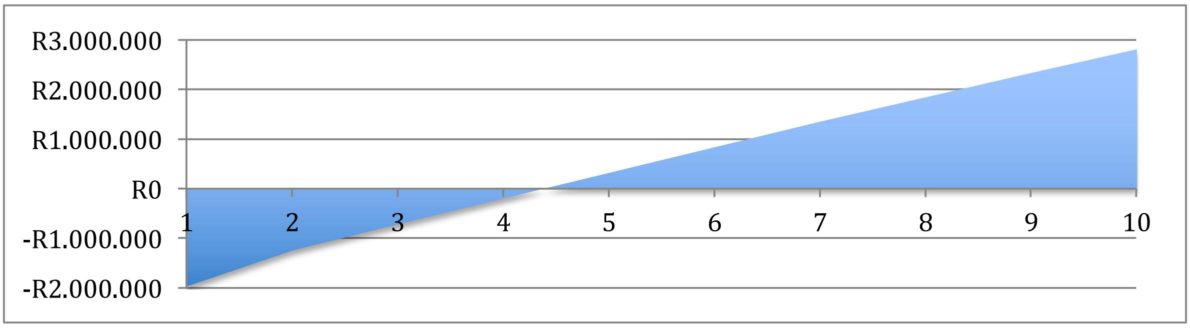


Figure 51: NPV Evolution of WFM for Alpha Energy

(iii) **Internal Rate on Return (IRR):** The IRR is another measure to assess the viability of investments. Like NPV, IRR is based on the selected discount rate. NPV and IRR are connected. The IRR of a cash flow stream is the interest rate of the investment for NPV of zero. In order to make investment decisions, the IRR is compared against a hurdle rate, which may be determined by alternative investment option of similar lengths and associated risks. The IRR of the base case of the financial model is 31.78%, which is high compared to other investments.

(iv) **Sensitivity Analysis:** The relatively high IRR needs to be tested against the change of the input parameters of the financial model, in order to cater for financial risks. Figure 52 illustrates the sensitivity of the IRR regarding following parameters: (i) budget, (ii) inflation, (iii) exchange rate Euro-Rand, and (iv) lending rate. All parameters are tested against the variation of +/- 15%, the ploted points of the single graphs represent the variation a single parameter represented by the graph's colour and illustrate the corresponding IRR.

It can be seen that the influence of (ii) inflation rate and (iv) lending rate are rather minimal. Change of the (iii) exchange rate and (i) budget (representing the income) on the other hand result in rather large changes of the IRR, which may impact the profitably.

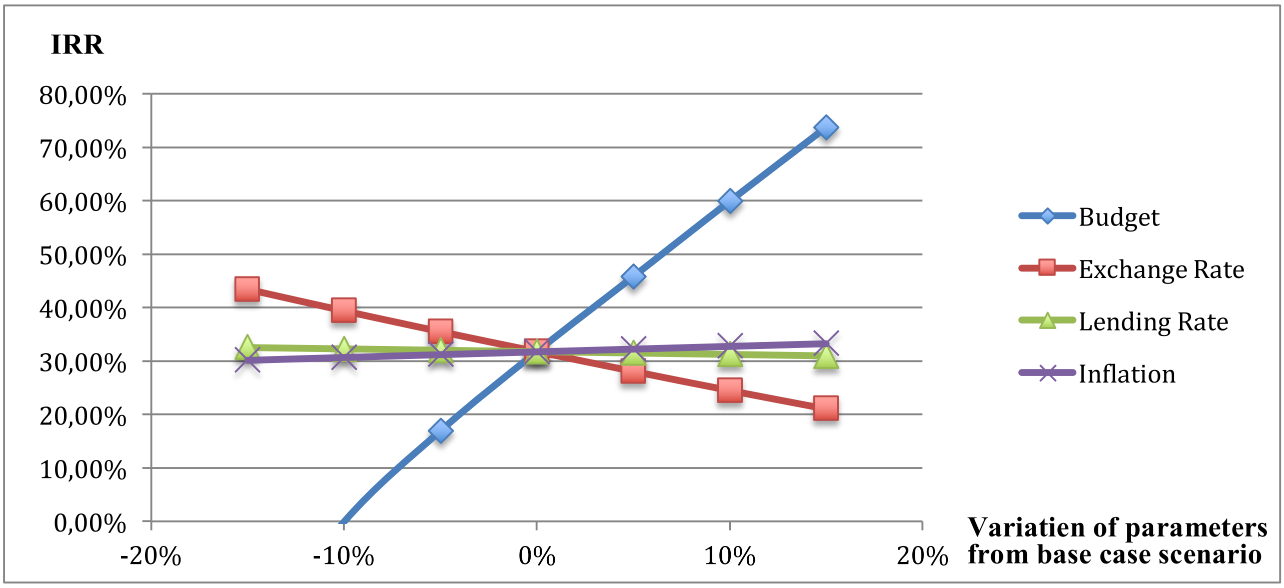


Figure 52: Sensitivity Analysis of IRR of WFM for Alpha Energy

A change of 25% of the exchange rate results in about 20% variation on the IRR. In order to protect against the exchange rate risk, the exposure to foreign services should be kept to a minimum and local service providers should be contracted once they become available on the market. Optional insurance against exchange rate risk can be taken out.

The highest impact on the financial viability is related to the budget which represents the net income. Budget variation of 5% would imply over or under performance of the Alpha Energy by the same percentage. In order to minimise the risk, the statistical certainty level of the wind resource on which the budget assumption is based, should be P75 or P90, which implies a 75% respectively 90% chance of reaching the target-level. Further, a fix rate for the first one or two years of operation should be negotiated in order to secure debt service until operational profits are made.

The AEP of a wind project is based on the wind resource and therefore attached to a certain level of uncertainty. The minimisation of operational risks by managing the variable factors of the AEP (inter alia under performance of contractors and underperforming WTs) is the key objective of WFM, therefore it is intended that the IRR of the WFM is linked directly to the overall WEF performance.

CHAPTER FIVE:

CONCLUSION AND RESULTS OF STUDY

The final chapter of this research paper presents the conclusion and discusses the findings of the Techno-Economic Feasibility Study. The chapter concludes with the recommendations for further research based on the findings of the conducted research.

5.1 CONCLUSION OF THE STUDY

The aim of the study was to test the hypothesis if "*independent wind farm management entity for WEFs in South Africa is technically and financially feasible".* Therefore a techno-economic feasibility study was conducted with the objective to develop a technical framework and test its financial viability by application to a case study.

The research foundation was built in the second chapter by discussing the technical, financial, and political aspects in which South African WEFs need to be managed. The literature shows that the success of project financed wind energy projects depend mainly on electricity sales, operational- and capital-expenditures as well as the importance of monitoring and managing these three aspects throughout the project's lifespan; the requirements for proper WFM can be derived. WFM is the tool to safeguard the investments in this technology, which is the basis for successful integration of wind energy in the South African energy mix. The vast amount of different influences as well as the unique competitive tender (REIPPPP) and its socio-economic factors (EDO) illustrate that WFM in South Africa demands a unique approach compared to matured markets.

Based on the research foundation a framework was developed in the third chapter. Firstly, the requirements for WFM in the South African context are discussed and the scope of work as well as possible organisational structures in accordance with the EDO, are proposed. Four key requirements are identified and their technical aspects are discussed namely: Human

Resources, TOMS, CM and Technical Inspections. WFM for the utility scale WEFs in South Africa need a professional physical asset management like approach in order to safeguard the owner's interests. If all four aspects are strictly applied and the generated data is collected in a life cycle database, WFM can move towards active asset management. The TOMS is the most important tool for WFM as it provides the only option to monitor the performance of the WEF and its WTs as well as the performance of the maintenance provider; thus monitors the key drivers for the financial viability of a wind energy project namely AEP and OPEX.

The developed framework was applied in the fourth chapter to a case study, which represents most WEFs in South Africa. The case study and its financial assumptions and contractual framework are introduced and explained, on the basis that the budget for WFM would be set to 3,25% of EBITDA. Based on the four key requirements identified in the developed framework and their associated costs, a financial model could be set up, taking into account the project's specific characteristics (amount WTs, EDO). A discounted cash flow approach was used to determine the financial viability of WFM based on the developed framework. Relevant financial indicators discuss the output of the model. DSCR, NPV and IRR together provide a solid picture for determining the economic feasibility. The volatility and dependency of the IRR on the input parameters of the model was further tested by use of a sensitivity analysis. The results of the financial analysis indicate that the application of the developed framework on the case study is financially viable. DSCR exceeds the set hurdle of 1.5. A positive NPV is reached after less than five years of operation. The IRR of the base case is above 30%, which is relatively high despite taken into account the sensitivity against the exchange rate and energy output of the case study.

It can thus be concluded that the developed framework is feasible for the case study. Further, the inductive conclusion can be drawn that the developed framework can be applied to WEFs in general, which were developed according to REIPPPP, based on the representative nature of the selected case study. The hypothesis can be confirmed: “An independent wind farm management entity for WEFs in South Africa is technically and financially feasible”.

Maturing of the wind energy industry in South Africa will have a positive impact on WFM, expert services can be sourced locally, once established, which reduces the exposure to exchange rates. Furthermore, when portfolios are managed as opposed to single WEFs, the human resource requirement can be reduced (depending on job creation obligations), which account for over 70% of the cost. Both will reduce risk and costs, which would lead to a reduction of budget requirements for WFM.

In order to provide coherent concept the following paragraph takes up the research questions that were possed in 1.2., which were addressed as follows:

(i) *How can the operational risk for owners of WEF be minimized?* This was one of the key questions; it was addressed in several paragraphs inter alia (2.5, 2.6.2, 2.6.4) these paragraphs dealt with the technical, financial and maintenance aspects of wind turbines and project financed WEFs. The tools for risk mitigation were discussed thereafter and the following were identified: SCADA data analysis (3.3.2.), Condition Monitoring (3.3.3) and Techncial Inspections (3.3.4.) all elements combined can be seen as state of the art risk management for the owners of WEF.

(ii) *How are maintenance and service contracts structured?* This was discussed in (2.6.4.) as well how theses contracts can be monitored (3.2.2).

(iii) *What are the requirements of WFM in South Africa?* Based on the local procurement process (2.3.) suitable strategies in accordance with the local requirements were outlined and discussed (3.3.1, Figure 33, Figure 34).

(iv) *How can the maintenance regime of WTs be monitored?* A two-fold approach was discussed to monitor the maintenance regime as well as the service provider. As this poses one of the greater risk to a WEF the same paragraphs address this research question as the one mentioned for the risk mitigation (2.5.2, 2.6.4, 3.3.2, 3.3.3, 3.3.4, 3.4)

(v) *What is the scope of work for BM of WEFs?* Based on the research foundation and on the requirement analysis in (3.2.) the scope of work was explained in *(3.2.4, Table 9).*

(vi) *What is the scope of work for TOM of WEFs?* Based on the research foundation and on the requirement analysis in (3.2.) the scope of work was explained in *(3.2.4, Table 8).*

(vii) What are the requirements for the TOM posed by the local framework? The requirement of TOM are illustrated by the case study in the fourth chapter of this study as well as in the summary of the third chapter (3.4.).

(viii) What are the main process-flows regarding TOM? The process flows are based on the WFMS, which needs to be monitored continously, in addtion (3.3.2 Figure 35) illustrates how the OEM, WFM, Condition Monitoring Centre and Independent Experts are collaborating in the process.

(ix) How can the technical condition of WTs be assessed by WFM? This is done in a two-fold approach by visual inspection by independent experts (3.3.4) on a case by case basis and by the condition monitoring centre on an ongoing basis (3.3.3).

(x) How can WFM be implemented for local WEFs? The last research question was discussed in details in the fourth chaper of this study. The Case Study shows how the framework developed according to the local requirements can be implemented on an representative wind energy project in South Africa.

5.2 RECOMMENDATION FOR FUTURE STUDIES

This paper investigated WFM for already developed wind energy projects, with a set contractual framework, which is in accordance with the current state of the industry. Future studies could investigate the impact on the associated risks for owners and lenders by using a consequent physical management approach based on PAS55[57], together with the cost-plus-fixed-fee

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[57] The objective of PAS55 is to ensure physical assets are managed efficiently over time, therefore PAS55 outlines a framework. Organisations using PAS55 develop practices for effective long-term asset management. The outlined framework of PAS55 assists an organisation to continuously improve the asset care processes. [111]

maintenance contract, as opposed to the prevailing full service contract, and a tailored condition monitoring concept.

REFERENCES

[1] Anton Eberhard, Joel Kolker, and James Leigland, "South Africa’s Renewable Energy IPP Procurement Program: Success Factors and Lessons ," Public-Private Infrastructure Advisory Facility (PPIAF) , Washington, 2014.

[2] Urban-Econ Development Economists; EScience Associates , "The Wind Energy Industry Localisation Roadmap in Support of Large Scale Roll-Out nin South Arfica," Department of Trade and Industry, Integrated Final Report 2015.

[3] Britta Rennkamp and Anya Byod, "Technological capability and transfer for achieving South Africa’s development goals," Energy Research Centre, University of Cape Town, Cape Town, Research Article 2013.

[4] Teresie Schafranek Solum Hommersand, "Pioneering Wind Energy in South Africa," University of Bergen, Bergen, Master Thesis 2013.

[5] City of Cape Town. Electricity - Citiy of Cape Town. [Online]. http://www.capetown.gov.za/en/electricity/greenelectricity/Pages/default.aspx

[6] Central Energy Fund , "Integrated Annual Report 2013/2014," CEF SOC Ltd, Johannesburg, Annual Report ISBN: 978-0-621-42997-8, 2014.

[7] Ian Smit, Riaan Smit, and Roderick Beckmann, "Eskom's First Wind Energy Experiences at Klipheuwel," Eskom, Cape Town, Conference Paper 2003.

[8] David Zach Wolfromm, "Feasibility Study for Utility Scale Wind Farm Developments in the Eastern Cape, South Africa ," Energy and Environmental Management, University of Flensburg, Flensburg, Dipl. Thesis 2010.

[9] Y. Amirat, M.E.H. Benbouzid, and E. Al-Ahmar, "A brief status on condition monitoring and fault diagnosis in wind energy conversion systems," *Renewable and Sustainable Energy Reviews* , vol. 13, June 2009.

[10] J.F. Manwell, J.G. McGowan, and A.L. Rogers, *Wind Energy Explained - Theory, Design and Application*. Amherst, USA: John Wiley & Sons, 2002.

[11] Ch. Kaminker and F Stewart, "The Role of Institutional Investors in Financing Clean Energy," *OECD Working Papers on Finance, Insurance and Private Pensions*, vol. 23, p. 37, August 2012.

[12] Sina Bernotat, Christian Lorenz, and Alexander Schiffler, "Marktanalyse – Windenergie an Land," Bundesministerium für Wirtschaft und Energie, Hamburg, Report 2015.

[13] National Treasury - PPP Unit. (2012) Introducing Public Private Partnerships in South Africa. [Online]. http://www.ppp.gov.za/Documents/Final%20Intro%20to%20PPP%20in%20SA%2021%2009%2007.pdf

[14] Raghavendra M.Vijaya and U.Ranjith Kumar, "Comparative Techno Economic Study of Energy Supply Systems in a Remote Village," *International Journal of Education and applied research*, vol. 4, no. Spl-1, p. 4, 01 - 06 2014.

[15] International Energy Agency, "Technology Roadmap Wind Energy," Paris, Report 2013.

[16] Financial Mail, *South Africa's Energy Crisis Eskom 2008-2015*. Rosebank, South Africa: Times Media Books 2015, 2015.

[17] Eskom Holdings. (2014, July) Eskom.co.za. [Online]. http://www.eskom.co.za/OurCompany/CompanyInformation/Pages/Key_Facts.aspx

[18] World Wind Energy Association, "Wind Energy International," 2011.

[19] South African National Energy Development Institute. (2011, October) SANEDI. [Online]. http://www.sanedi.org.za/archived/wp-content/uploads/2013/08/sacrm%20value%20chain%20overview.pdf

[20] Samatha Herbst. (2014, March) Mining Weekly. [Online]. http://www.miningweekly.com/article/eskom-bound-low-grade-coal-could-soon-face-global-demand-2014-03-14-1

[21] Andreas Brebøl Thomas Capral Henriksen Edward James-Smith Tina Sommer Kristensen, *Electricity from Renewable Resources in the Western Cape*., 2003.

[22] Department of Energy, "Executive Summary of the Draft Integrated Electricity Resource Plan for South Africa - 2010 to 2030 ," Department of Energy, Executive Summary 2010.

[23] Posorski/Werner, "Energiepolitische Rahmenbedingungen für Strommärkte und erneuerbare Energien 16 Länderanalysen," Eschborn, 2009.

[24] Dr. Elsa du Toit, "Context and Definitons," in *Suistanable Energy Resource Handbook*., 2010, vol. 1.

[25] Brindaveni Naidoo. (2011, October) Engineering News. [Online]. http://www.engineeringnews.co.za/print-version/wind-power-is-key-to-kwazulu-natals-green-economy-2011-10-17

[26] NERSA. (2012) National Energy Regulator of South Africa. [Online]. http://www.nersa.org.za/Admin/Document/Editor/file/Electricity/REFIT%20Phase%20II%20150709.pdf

[27] NERSA, "Review of Renewable Energy Feed - In Tariffs," 2011.

[28] DME, *White Paper on Renewable Energy*.: Department of Minerals and Energy RSA, 2003.

[29] DoE, *Executive Summary of the Draft Integrated Electricity Resource Plan for South Africa - 2010 to 2030*.: Department of Energy, 2010.

[30] Standard Bank. (2012, September) Funding projects in REIPP - lessons learnt from BD1. Presentation.

[31] Jurg van Dyke and Bianca Pollastrini. (2011, December) Mondaq.com. [Online]. http://www.mondaq.com/southafrica/x/155586/Renewables/REFIT+Gone+With+The+Wind

[32] DoE. (2011) Department of Energy, Renewable Energy Independent Power Producer Procurement Programm. [Online]. http://www.ipp-renewables.co.za/

[33] Department of Energy RSA. (2011, August) Energy.gov.za. [Online]. http://www.energy.gov.za/files/events_overview%20IPP.html

[34] Department of Energy RSA. (2014, June) Energy.gov.za. [Online]. http://www.energy.gov.za/IPP/Electricity-Infrastructure-Industry-Transformation-30June2014.pdf

[35] Department of Energy RSA. (2015, April) IPP Renewables. [Online]. http://www.ipprenewables.co.za/gong/widget/file/download/id/278

[36] Creamer Media. (2015, June) Polity.org.za. [Online]. http://www.polity.org.za/article/attention-turns-to-expedited-renewables-bid-after-13-more-projects-are-confirmed-2015-06-08

[37] Department of Energy - Republik of South Africa. (2012) RFP Documentation REIPPPP. Documents.

[38] Department of Energy - IPP Office. (2015) Department of Energy sheds light on Renewable Energy IPPs. [Online]. https://www.ipp-projects.co.za/Content/IPP%20Press/Department%20of%20Energy%20Sheds%20Light%20on%20REIPPs%20(English).pdf

[39] Department of Energy RSA. (2015, January) Energy.gov.za. [Online]. http://www.energy.gov.za/IPP/Electricity-Infrastructure-Industry-Transformation-13January2015.pdf

[40] Stuart Lowman. (2015, August) Biznews.com. [Online]. https://www.biznews.com/leadership/2015/08/06/medupi-timeline-costs-delays-spiralling-no-completion-in-sight/

[41] ESI Africa. (2014, June) [Online]. http://www.esi-africa.com/sa-renewable-energy-tariffs-cheaper-than-expected-medupikusile-generation-cost/

[42] Dr. Tobias Bishoff-Niemz, "Financial Costs and Benefits of Renewables in South Africa in 2014," CSIR, Stellenbosch, Research Report CSIR/02400/RD,.

[43] Luc Dewilde. (2011, August) Wind Energy Project Development. [Online]. http://www.tudelft.nl/fileadmin/UD/MenC/Support/Internet/TU_Website/TU_Delft_portal/Onderzoek/Kenniscentra/Kenniscentra/DUWIND/EAWE_Summer_school/EAWE-WAUDIT-3rdSchool_Project_Development_Dewilde_Oct-2011.pdf

[44] Jako Volschenk, "Environmental certificates in project finance," University of Stellenbosch, Research Report 2006.

[45] National Treasury RSA. (2001) Project Finance - Introductory Manual on Project Finance for Managers of PPP Projects. Document.

[46] Sophie Ph. D. Justice. (2009, December) PRIVATE FINANCING OF RENEWABLE ENERGY - A GUIDE FOR POLICYMAKERS. [Online]. http://fs-unep-centre.org/sites/default/files/media/financeguide20final.pdf

[47] Poul-Erik Morthorst, Shimon Awerbuch, and Søren Krohn, "The Economics of Wind Energy," European Wind Energy Association, Report 2009.

[48] Rune Moesgaard, Hugo Chandler, Paulis Barons, and Mr. G. Bakema, *Wind Energy - The Facts*.: International Energy Agency, 2010.

[49] World Wind Energy Association. (2010) www.wwindea.org. [Online]. http://www.wwindea.org/technology/ch03/estructura-en.htm

[50] Niamh Conroy, J.P. Deane, and Brian P. Ó Gal, "Wind turbine availability: Should it be time or energy based? e A case study in Ireland," *Renewable Energy* , vol. 36, p. 1, March 2011.

[51] Erich Hau, *Windkraftanlagen - Grundlagen, Technik, Einsatz, Wirtschaftlichkeit*. Berlin, Germany, 2008, vol. IV.

[52] IRENA,. Abu Dhabi: IRENA, 2012.

[53] Pierre Tchakoua et al., "Wind Turbine Condition Monitoring: State-of-the-Art Review, New Trends, and Future Challenge," ISSN 1996-1073,.

[54] L. Fingersh, M. Hand, and A. Laxson, "Wind Turbine Design Cost and Scaling Model," NREL - National Renewable Energy Laboratory , Technical Report NREL/TP-500-40566, 2006.

[55] G. P. Sullivan, R. Pugh, A. P. Melendez, and W. D. Hunt, *O&M Best Practices Guide*, 30th ed., 2010.

[56] Berthold Hahn, Michael Durstewitz, and Kurt Rohrig, "Reliability of Wind Turbines ," in *Wind Energy*. Berlin: Springer, 2007.

[57] B.S. Dhillon, *Engineering Maintenance a Modern Approach*. Lodnon / New York: CRC Press, 2002.

[58] Jeff Johanson, "Operational Validation of SIMLOX as a Simulation Tool for Wind Energy Operations and Maintenance (O&M)," KTH Industrial Engineering and Management, Stockholm, Master Thesis 2013.

[59] Philippa Jones, "How to find the right maintenance contract," *Windpower Monthly*, June 2010.

[60] Phillip Jones. (2010, June) Wind Power Monthly. [Online]. http://www.windpowermonthly.com/article/1009791/find-right-maintenance-contract

[61] Sebastian Fritz-Morgenthal, Chris Greenwood, Carola Menzel, Marija Mironjuk, and Sonntag-O'B Virginia. (2009) The global financial crisis and its impact on renewable energy finance. [Online]. http://www.unep.org/pdf/dtie/Study_Financial_Crisis_impact_on_RE.pdf

[62] Wesley Lien, Stefan Gsänger, and Everaldo Feitosa, "Operations and Maintenance for Onshore Wind Energy Systems," WWEA Background Paper.

[63] David Krüger and Carsten Bartholl, "European Wind Services Study Find out which way the wind blows," TaylorWessing & Deloitte, Hamburg; Munich, Research Report 2012.

[64] Fehily Timoney, *Best Practice Guidelines for the Irish Wind Energy Industry*.: Irish Wind Energy Association , 2012.

[65] Investopedia. (2012, Oct.) www.investopedia.com. [Online]. http://www.investopedia.com/terms/c/cost-plus-contract.asp#ixzz29LNWXye9

[66] Businessdictonary. Businessdictonary.com. [Online]. http://www.businessdictionary.com/definition/fixed-price-contract.html#ixzz29LLddj3m

[67] Maurizio D. Galluzo, "Performance base conracting - A concept for cost-effective operation and maintenance of wind power plants," Gotland University, Gotland, Master Thesis 2011.

[68] A.P. Schaffarcyk, *Introduction to Wind Turbine Aerodynamics*. Berlin, Heidelberg: Springer, 2014, vol. I.

[69] R. Gaasch and J. Tweele, *Wind Power Plants*. Berlin: Solarpraxis AG.

[70] Tony Burton, David Sharpe, Nick Jenkins, and Ervin Bossanyi, *Wind Energy - Handbook*. Chichester West Sussex, England: John Wiley & Sons, 2001.

[71] Wagner Hermann-Josef and Mathur Jyotirmay, *Introduction to Wind Energy Systems*. Bochum, Germany: Springer, 2009.

[72] National Instruments. (2008, December) White Paper - Wind Turbine Control Methods. [Online]. http://www.ni.com/white-paper/8189/en/pdf

[73] Erich Hau, *Wind Turbines - Fundamentals, Technologies, Application, Economics*. Heidleberg: Springer, 2006, vol. II.

[74] Thomas Akermann, *Wind Power in Power Systems*. Stockholm, Sweden: John Wiley & Sons, Ltd, 2005.

[75] Marcelo Gustavo Molina and Gimenez Alvarez Juan,. Orlando: InTech, 2011, p. 15.

[76] Investopedia LLC. (2015) Investopedia. [Online]. http://www.investopedia.com/terms/o/operations-management.asp

[77] Greenbyte AB. (2015) An evaluation of quantitative methods to measure effects of power performance upgrades to wind turbines. [Online]. www.breezesystem.com

[78] Clifford Chance. (2012, February) Operation and Maintenance Agreement Issues for Wind Turbines. Briefing Note.

[79] Smith Joe. (2009, October) Power Performance Testing IEC 61400-12-1 1st edition. [Online]. http://www.nrel.gov/wind/smallwind/pdfs/power_performance_testing.pdf

[80] A. Abers, "Critical limitations on Wind Turbine Power Curve Warranties," Deutsch Wind Guard Consulting GmbH, Varel, Research Report 2014.

[81] Bernardo Reyes. (2012) Modeling and Monitoring of the Operational Risk in Wind Farms - South American Experience. Conference Presentation.

[82] Kasper Dalsten. (2012, March) Wind Power Potential in Developing Countries. Presentation.

[83] GWEA Expert Consulting Committee , "Principles for condition-based maintenance of wind turbines ," German Wind Energy Association (BWE e.V.) , Berlin, Guideline 2007.

[84] Torgny Möller, Faster identification and repair of problems, November 2005.

[85] Anders Johnsson, Implementation guideline when building a set-up for monitoring wind assets , November 2014, www.use61400-25.com.

[86] Anoop Prakash Verma , "Performance monitoring of wind turbines : a data- mining approach," University of Iowa , Iowa, PhD Thesis 2012.

[87] IEC International Electrotechncial Commission , IEC 61400-26 Part 1: Wind Turbines - Time Based Availability, February 2010, Committee Draft - IEC Norm.

[88] Thomas Gellermann, "Extension of the scope of Condition Monitoring Systems for multi-MW and offshore wind turbines," in *Schwingungen von Windenergieanlagen 2012*, Bremen, 2012, pp. 1-2.

[89] Drew Robb and Lyn Harrison, Who supplies to whom - wind industry gearboxes and bearings, November 2005.

[90] Roman Wisznia, "Condition Monitoring of Offshore Wind Turbines," KTH School of Industrial Engineering and Management , Stockholm, M.Sc. 2013.

[91] Dale R Blan. (2013, Oktober) Maximizing the P-F Interval Through Condition-Based Maintenance. [Online]. http://www.maintworld.com/Applications/Maximizing-the-P-F-Interval-Through-Condition-Based-Maintenance

[92] Diego Coronado and Katharina Fischer, "Condition Monitoring of Wind Turbines: State of the Art, User Experience and Recommendations," Frauenhofer Institute for Energy and Energy System Technology - IWES, Bremerhaven, Project Report 2015.

[93] Dr. E. Becker and Paul Poste. (2009, July) Creative Condition Monitoring. [Online]. http://www.windsystemsmag.com/article/detail/24/creative-condition--monitoring

[94] R Kewitsch, Optimizing Life Cycle Cost for Wind Turbines by Implementing Remote Condition Monitoring Service, January 2011, presented at AWEA Project Performance and Reliability Workshop.

[95] Nordex. (2015, March) Nordex Online. [Online]. http://www.nordex-online.com/fileadmin/MEDIA/Gamma/Nordex_Gamma_en.pdf

[96] Mark Pickering. (2013, March) Renewable Energy: Assessing the experience of South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). [Online]. http://stias.ac.za/wp-content/uploads/2013/03/WS-06-REIPPPP-Pickering-20130305b.pdf

[97] Diego Coronado and Katharina Fischer, "Condition Monitoring of Wind Turbines: State of the Art, User Experience and Recommendations," Frauenhofer Institute for Wind Energy and Energy System Technology IWES, Bremerhaven, Project Report 2015.

[98] Rainmaker Energy Pty Ltd. (2011) National Energy Regulator South Africa. [Online]. http://www.nersa.org.za/Admin/Document/Editor/file/Consultations/Electricity/Presentations/Rainmaker%20Energy.pdf

[99] Trading Economics Inc. (2015, Aug.) Trading Economics. [Online]. http://www.tradingeconomics.com/south-africa/inflation-cpi

[100] Francois Viljoen. (2015, Aug.) Liberta.co.za. [Online]. http://liberta.co.za/blog/cpi-inflation-rate-in-south-africa-current-and-historical/

[101] Michael Power. (2004, October) Cheaper Money for Southern Africa - Unlocking Growth. Presentation.

[102] Trading Economics Inc. (2015, Aug.) Trading Economis. [Online]. http://www.tradingeconomics.com/south-africa/government-bond-yield

[103] DEAT, *Long Term Mitigation Scenarios Technical Report*.: Department of Environment Affairs and Tourism RSA, 2009.

[104] Randall Burleson and Lynn Wilson, "Incentive Contracts," Aug. 2007.

[105] AnneMarie Graves, Keir Harman, Michael Wilkinson, and Ross Walker, "Understanding Avaiability Trends of Operating Wind Farms".

[106] Vitchev, "Development of RE Efficiency and RE Bankable Projects," , 2010.

[107] Dr. Tobias Bischof-Niemz. (2015, January) Financial benefits of renewables in South Africa in 2014.

[108] Department of Energy RSA. (2013, November) Energy.gov.za. [Online]. http://www.energy.gov.za/IPP/List-of-IPP-Preferred-Bidders-Window-three-04Nov2013.pdf

[109] Hermann-Josef Wagner and Jyotirmay Mathur, *Introduction to Wind Energy Systems - Basics, Technology and Operation*. Berlin, Heidleberg: Springer, 2009.

[110] Henrik Breum. (2011, November) Creating Buisness Certainty in Wind - Catalysing Investment in Low-Carbon, Climate-Resilient Growth. Presentation.

[111] N.A.J. Hastings, *Physical Asset Management*. London: Springer, 2010.

[112] Department of Trade and Industry of the Republick of South Africa. (2003) Broad Base Black Economic Empowerment Act. [Online]. https://www.thedti.gov.za/economic_empowerment/docs/2nd_phase/Code1000Statement1000.pdf

[113] Kaminker CH Stewart, "The Role of Institutional Investors in Financing Clean Energy," OECD, OECD Working Papers on Finance, Insurance and Private Pensions, No.23, 2012.

[114] Peter Hauge Madsen. (2008, August) Power Performance Testing IEC 61400-12-1 1st edition. [Online]. http://www.windpower.org/download/461/introduction_to_the_iecpdf

[115] Vestas A/S. (2011, October) Austrian Wind Energy Association. [Online]. https://www.igwindkraft.at/mmedia/download/2011.11.02/1320229622.pdf

[116] AnneMarie Graves, Keir Harman, and Michael Wilkinson, "Understanding Availability Trends of Operating Wind Farms," in *AWEA WINDPOWER Conference*, Housten, 2008.

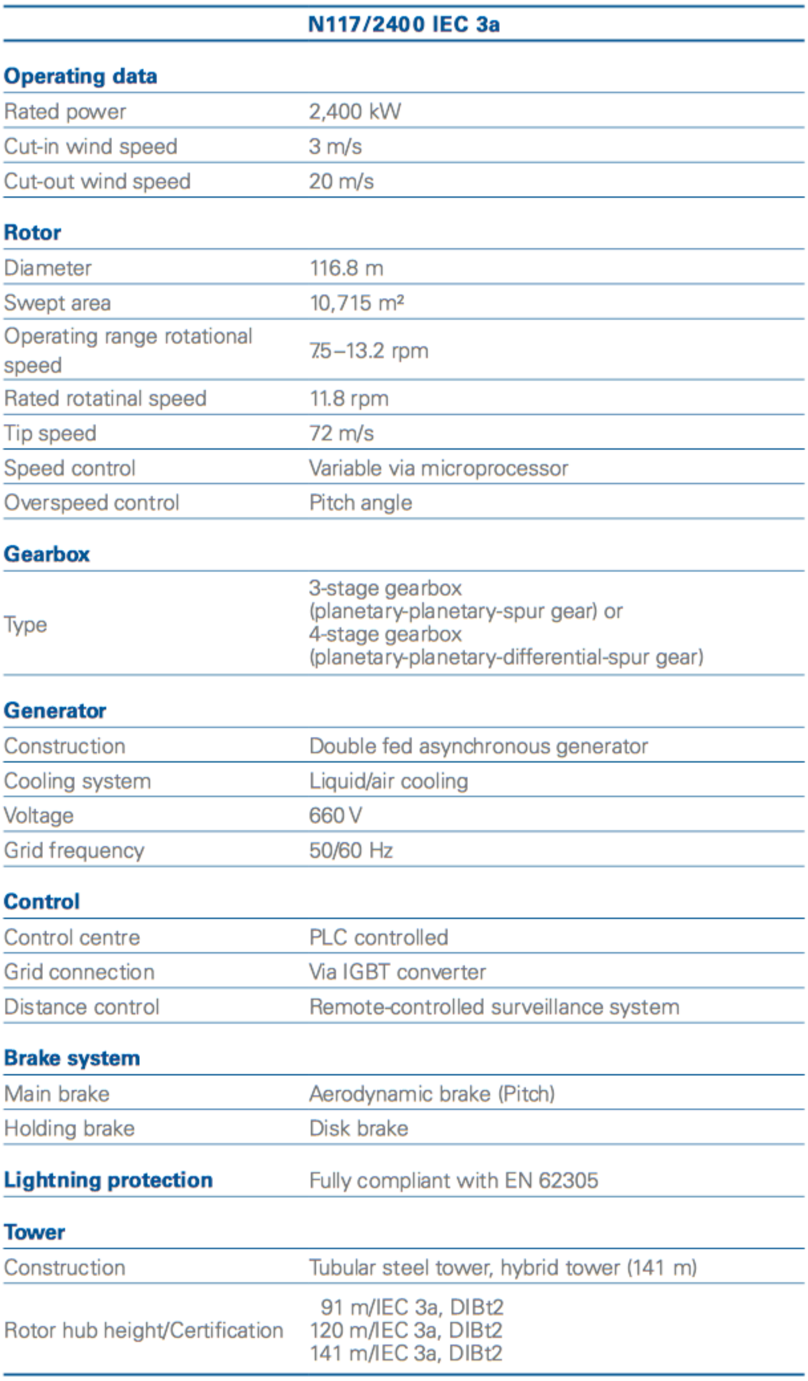
Annex I

REIPPPP - Successful Wind Energy Projects

1	**Round 1**	**Capacity**	**Region**
1.1	Hopefield	65.4	Western Cape
1.2	MetroWind van Stadens Wind Farm	27,00 MW	Eastern Cape
1.3	Dassieklip Wind Energy Facility	27,00 MW	Western Cape
1.4	Red Cap Kouga Wind Farm	77,60 MW	Eastern Cape
1.5	Jeffereys Bay Wind	138,00 MW	Eastern Cape
1.6	Noblesfontein Wind	75,00 MW	Northern Cape
1.7	Dorper Wind Farm	97.53	Eastern Cape
1.8	Cookhouse Wind Farm	138.6	Eastern Cape
	TOTAL	787,00 MW	
2	**Round 2**	**Capacity**	**Region**
2.1	Amakhala Emoyeni	133,70 MW	Eastern Cape
2.2	Tsitsikamma Community Wind Farm	94,80 MW	Eastern Cape
2.3	Wind Farm West Coast 1	90,82 MW	Western Cape
2.4	Waainek	23,28 MW	Eastern Cape
2.5	Grassridge	59,80 MW	Eastern Cape
2.6	Chaba	21,00 MW	Eastern Cape
2.7	Gouda Wind Project	135,50 MW	Western Cape
	TOTAL	558,90 MW	
3	**Round 3**	**Capacity**	**Region**
3.1	Red Cap - Gibson Bay	110,00 MW	Eastern Cape
3.2	Longyuan Mulilo De Aar 2 North Wind Energy Facility	139,00 MW	Eastern Cape
3.3	Nojoli Wind Farm	87,00 MW	Eastern Cape
3.4	Longyuan Mulilo De Aar Maanhaarberg Wind E. Facility	96,00 MW	Eastern Cape
3.5	Khobab Wind Farm	138,00 MW	Eastern Cape
3.6	Noupoort Mainstream Wind	79,00 MW	Eastern Cape
3.7	Loeriesfontein 2 Wind Farm	138,00 MW	Eastern Cape
	TOTAL	787,00 MW	
4	**Round 4**	Capacity	**Region**
4.1	Golden Valley Wind	117,00 MW	Eastern Cape
4.2	Oyster Bay Wind Farm	140,00 MW	Eastern Cape
4.3	Roggeveld Wind Farm	140,00 MW	Western Northern Cape
4.4	The Karusa Wind Farm	140,00 MW	Northern Cape
4.5	The Nxuba Wind Farm	139,00 MW	Eastern Cape
4.6	**TOTAL**	676,00 MW	
	Expedited Round 4	Capacity	**Region**

4.1	Soetwater Wind Farm	139,00 MW	Northern Cape
4.2	Kangnas Wind Project	137,00 MW	Northern Cape
4.3	Perdekraal East Project	108,00 MW	Western Cape
4.4	Excelsior Wind Energy Facility	32,00 MW	Western Cape
4.5	Wesley-Ciskei Project	33,00 MW	Eastern Cape
4.6	Garob Wind Farm	102,00 MW	Northern Cape
	TOTAL	551,00 MW	

Table 32: Wind Energy Preferred Bidders REIPPPP [96]



	N117/2400 IEC 3a
Operating data	
Rated power	2,400 kW
Cut-in wind speed	3 m/s
Cut-out wind speed	20 m/s
Rotor	
Diameter	116.8 m
Swept area	10,715 m²
Operating range rotational speed	7.5–13.2 rpm
Rated rotatinal speed	11.8 rpm
Tip speed	72 m/s
Speed control	Variable via microprocessor
Overspeed control	Pitch angle
Gearbox	
Type	3-stage gearbox (planetary-planetary-spur gear) or 4-stage gearbox (planetary-planetary-differential-spur gear)
Generator	
Construction	Double fed asynchronous generator
Cooling system	Liquid/air cooling
Voltage	660 V
Grid frequency	50/60 Hz
Control	
Control centre	PLC controlled
Grid connection	Via IGBT converter
Distance control	Remote-controlled surveillance system
Brake system	
Main brake	Aerodynamic brake (Pitch)
Holding brake	Disk brake
Lightning protection	Fully compliant with EN 62305
Tower	
Construction	Tubular steel tower, hybrid tower (141 m)
Rotor hub height/Certification	91 m/IEC 3a, DIBt2 120 m/IEC 3a, DIBt2 141 m/IEC 3a, DIBt2

Figure 53: Nordex N117/2400 Facts and Figures [92]

Figure 54 illustrates the actual output over the wind speed of a Nordex N117/2400 WT. The power curve indicates that the WT was de-rated for a certain amount of the measurement period, to 1,4MW as well as to 1MW.

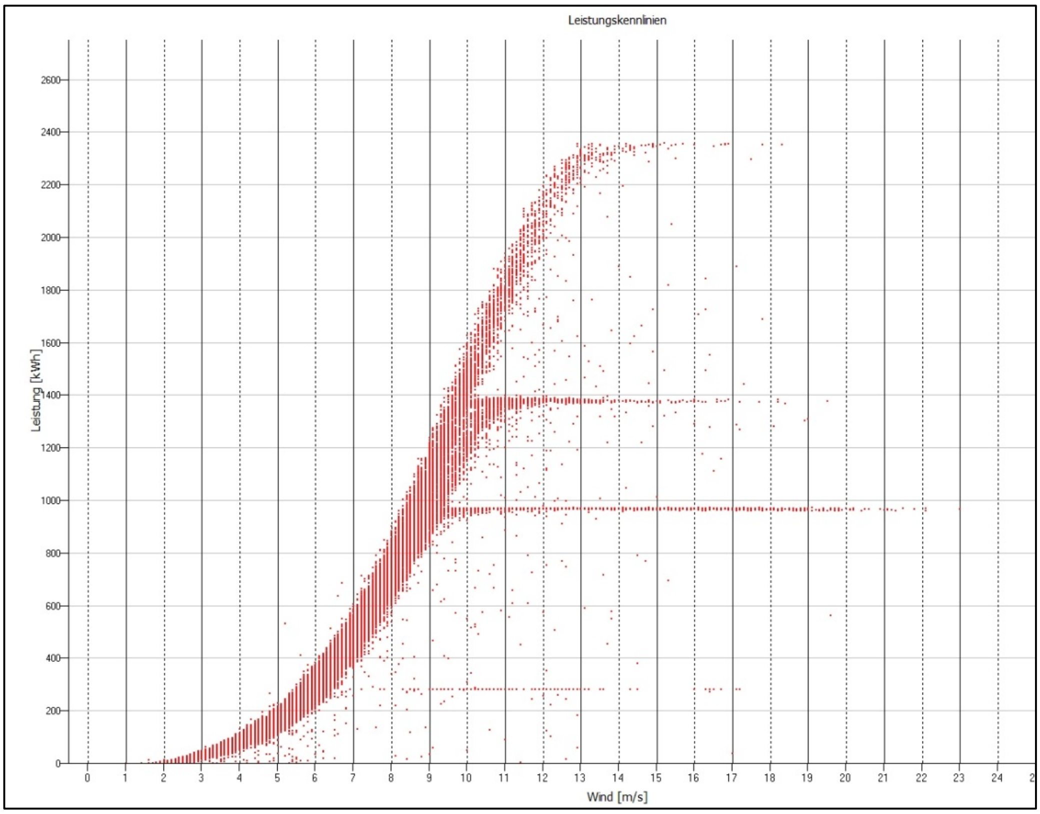


Figure 54: De-rated Wind Turbine 2.4MW[58]

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[58] *Made available by Energy Consult GmbH, June 2013*

Managing Director - Competence Profile

Report to the project company's board. Act as a liaison between management and the board; ensure that the directors are properly informed and that sufficient information is provided to the board to enable the directors to form appropriate judgements; request that special meetings of the board be called when appropriate;

- Will be responsible for commercial and administrative construction, operations, and consultancy contracts.
- Be in regular contact with the project company team as well as construction contractors, stakeholders and other third parties including the Local Planning Authorities and transmission and distribution network operators. Lead, in conjunction with the board, the development of the company's strategy;
- Lead and oversee the implementation of the company's long and short term plans in accordance with its strategy;
- Ensure that the SPV complies with all EDO requirements, including reporting to the DOE
- Ensure the company is appropriately organised and staffed and to have the authority to hire and terminate staff as necessary to enable it to achieve the approved strategy;
- Ensure that expenditures of the company are within the authorised annual budget of the company;
- Assess the principal risks of the company and to ensure that these risks are being monitored and managed;
- Ensure effective internal controls and management information systems are in place;
- Ensure that the company has appropriate systems to enable it to conduct its activities both lawfully and ethically;
- Ensure that the company maintains high standards of corporate citizenship and social responsibility wherever it does business;
- Communicate effectively with shareholders, employees, government authorities, other stakeholders and the public;
- Keep abreast of all material undertakings and activities of the company and all material external factors affecting the company and to ensure that the processes and systems are in place to ensure that the General Manager and management of the company are adequately informed;
- Ensure the integrity of all public disclosure by the company;
- Determine the date, time and location of the annual meeting of shareholders and to develop the agenda for the meeting;
- Sit on committees of the board where appropriate as determined by the board.

Business Manager - Competence Profile

Manage the contractual interfaces associated with the WEF (inter alia, PPA, IA, SA, O&M) and loan and equity documents.

- Development of contract management framework to ensure all SPV obligations under relevant contracts are being monitored and complied with
- Report to the CEO on progress under relevant contracts
- Monitoring of construction budget and contract progress under the EPC contract
- Prepare information for board packs; investor updates, investment committees; project updates and other ad hoc financial reporting information.
- Prepare budgets and forecasts, and financial reports for management, shareholders and lenders.
- Accounting and contract management associated with sub-- contractors and Buyer
- Report to the CEO on progress under relevant contracts
- Prepare budgets and forecasts, and financial reports for management, shareholders and lenders.
- Management of relationship with lender bank
- Preparation of monthly updates to the financial model
- Monitoring and reporting on progress under key project sub-contracts (Service Agreement, wind forecasting contract
- Prepare information for board packs; investor updates, investment committee project updates and other ad hoc financial reporting information.
- Treasury and cash management including foreign exchange exposure monitoring.
- Advise and review finance-related matters (distributions, cash flows, finance issues, technical issues).
- Working with the Technical Manager to ensure that information required from contractors and advisors under the senior loan agreements is obtained in a timely manner and meets the necessary requirements
- Oversight and control of monthly payments to all suppliers and service providers.
- Establish appropriate policies and procedures to ensure that the reporting systems are fit for purpose and are being utilised effectively
- Audit liaison and preparation of annual financial statements.
- Support CEO in preparing Annual Operating Plans and Annual General Meetings
- Ensure compliance with all shareholders, lender and government agreements.
- Prepare and submit tax returns (general income tax, VAT and STC queries).

- Economic Development / Community Management:
- Understand the economic development commitments made and obligations on the companies under the government agreements.
- Work closely with contractors and suppliers of the companies to ensure that the information required in order to prepare the economic development reports is obtained in a timely manner and meets the necessary requirements.
- Prepare economic development reports for management, shareholders and lenders.
- Preparation of economic development forecasts and budgets

Technical Manager - Competence Profile

Manage the technical sub-contractors of the SPV as well as operators to monitor operation and maintenance of wind turbine generators, as well as balance the plant to optimise the project performance.

- Full technical operations responsibility
- Recruitment and management of key technician staff
- Management of all technical subcontractors
- Appointment and management of service providers to assist the SPV
- Development of detailed operation and maintenance planning tools and reports
- Monitor compliance with all environmental and other permit requirements

ANNEX VI

Financial Model Alpha Energy Wind Farm Management

	Set up Cos 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Human Resource											
Operations Centre											
Managing Director	R 104.167	R 1.250.000	R 1.300.000	R 1.352.000	R 1.406.080	R 1.462.323	R 1.520.816	R 1.581.649	R 1.644.915	R 1.710.711	R 1.779.140
Technical Manager	R 70.833	R 850.000	R 884.000	R 919.360	R 956.134	R 994.380	R 1.034.155	R 1.075.521	R 1.118.542	R 1.163.284	R 1.209.815
Technical Operator	R 41.667	R 500.000	R 520.000	R 540.800	R 562.432	R 584.929	R 608.326	R 632.660	R 657.966	R 684.285	R 711.656
Business Manager	R 70.833	R 850.000	R 884.000	R 919.360	R 956.134	R 994.380	R 1.034.155	R 1.075.521	R 1.118.542	R 1.163.284	R 1.209.815
Accountant	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -
Subsubtotal	**R 287.500**	**R 3.450.000**	**R 3.588.000**	**R 3.731.520**	**R 3.880.781**	**R 4.036.012**	**R 4.197.453**	**R 4.365.351**	**R 4.539.965**	**R 4.721.563**	**R 4.910.426**
Site Office Alpha Energy											
Site Manager	R 62.500	R 750.000	R 780.000	R 811.200	R 843.648	R 877.394	R 912.490	R 948.989	R 986.949	R 1.026.427	R 1.067.484
Site Maintenance	0	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -
Security Guard	0	R 400.000	R 416.000	R 432.640	R 449.946	R 467.943	R 486.661	R 506.128	R 526.373	R 547.428	R 569.325
Subsubtotal	**R 62.500**	**R 1.150.000**	**R 1.196.000**	**R 1.243.840**	**R 1.293.594**	**R 1.345.337**	**R 1.399.151**	**R 1.455.117**	**R 1.513.322**	**R 1.573.854**	**R 1.636.809**
Subtotal A	**R 350.000**	**R 4.600.000**	**R 4.784.000**	**R 4.975.360**	**R 5.174.374**	**R 5.381.349**	**R 5.596.603**	**R 5.820.467**	**R 6.053.286**	**R 6.295.418**	**R 6.547.234**
Expert Services	-369000										
TO Management System	€ 3.000	€ 24.600	€ 24.698	€ 24.797	€ 24.896	€ 24.996	€ 25.096	€ 25.196	€ 25.297	€ 25.398	€ 25.500
Condition Monitoring	€ 369.000	€ 53.300	€ 53.513	€ 53.727	€ 53.942	€ 54.158	€ 54.375	€ 54.592	€ 54.810	€ 55.030	€ 55.250
Technical Inspections	€ -	€ 194.750	€ -	€ -	€ 155.602	€ -	€ -	€ 157.477	€ -	€ -	€ 201.874
Subsubtotal Euro based	**€3.000**	**€272.650**	**€78.212**	**€78.524**	**€234.441**	**€79.154**	**€79.471**	**€237.265**	**€80.108**	**€80.428**	**€282.624**
Exchange rate	€ -	€ -	€ -	€ -	-€ 2.178.433	€ -	€ -	-€ 2.204.679	€ -	€ -	-€ 2.826.239
Subtotal B	**R 42.000**	**R 3.817.100**	**R 1.094.962**	**R 1.099.342**	**R 1.103.740**	**R 1.108.155**	**R 1.112.587**	**R 1.117.038**	**R 1.121.506**	**R 1.125.992**	**R 1.130.496**
Operational Cost											
Technical Operation Manager	R 200.000	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -
Financial Advisor	R 250.000	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -
Legal Advisor		R 100.000	R 104.000	R 108.160	R 112.486	R 116.986	R 121.665	R 126.532	R 131.593	R 136.857	R 142.331
Auditing		R 100.000	R 104.000	R 108.160	R 112.486	R 116.986	R 121.665	R 126.532	R 131.593	R 136.857	R 142.331
Insurance		R 150.000	R 156.000	R 162.240	R 168.730	R 175.479	R 182.498	R 189.798	R 197.390	R 205.285	R 213.497
Cost Operational Centre		R 300.000	R 312.000	R 324.480	R 337.459	R 350.958	R 364.996	R 379.596	R 394.780	R 410.571	R 426.994
Cost Site Office		R 200.000	R 208.000	R 216.320	R 224.973	R 233.972	R 243.331	R 253.064	R 263.186	R 273.714	R 284.662
Susubbtotal	**R 450.000**	**R 850.000**	**R 884.000**	**R 919.360**	**R 956.134**	**R 994.380**	**R 1.034.155**	**R 1.075.521**	**R 1.118.542**	**R 1.163.284**	**R 1.209.815**
Subtotal C	**R 450.000**	**R 850.000**	**R 884.000**	**R 919.360**	**R 956.134**	**R 994.380**	**R 1.034.155**	**R 1.075.521**	**R 1.118.542**	**R 1.163.284**	**R 1.209.815**
TOTAL COST	R 842.000	R 9.267.100	R 6.762.962	R 6.994.062	R 7.234.248	R 7.483.884	R 7.743.346	R 8.013.026	R 8.293.334	R 8.584.693	R 8.887.545

ANNEX VI

Financial Model Alpha Energy Wind Farm Management

	Set up Costs 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
TOTAL INCOME		R 8.548.945	R 8.890.903	R 9.246.539	R 9.616.400	R 10.001.056	R 10.401.098	R 10.817.142	R 11.249.828	R 11.699.821	R 12.167.814
NET INCOME (excluding reserve)	R (842.000)	R (718.155)	R 2.127.940	R 2.252.476	R 2.382.152	R 2.517.172	R 2.657.753	R 2.804.116	R 2.956.494	R 3.115.128	R 3.280.269
Reserve annual deposit			R 801.039	R 801.039	R 801.039	R 801.039	R 801.039	R 801.039	R 801.039	R 801.039	R 801.039
Reserve Accumulated	R -	R -	R 801.039	R 1.602.078	R 224.684	R 1.025.723	R 1.826.762	R 423.122	R 1.224.161	R 2.025.200	R -
EBIT	R (842.000)	R (718.155)	R 1.326.901	R 1.451.437	R 1.581.113	R 1.716.133	R 1.856.714	R 2.003.077	R 2.155.455	R 2.314.089	R 2.479.230
Interest on Loan		R (264.000)	R (248.956)	R (232.107)	R (213.236)	R (192.101)	R (168.429)	R (141.917)	R (112.223)	R (78.966)	R (41.718)
Accumulated Interests		R (264.000)	R (512.956)	R (745.063)	R (958.299)	R (1.150.400)	R (1.318.829)	R (1.460.746)	R (1.572.968)	R (1.651.934)	R (1.693.652)
EBT		R (982.155)	R 1.077.945	R 1.219.330	R 1.367.877	R 1.524.033	R 1.688.285	R 1.861.161	R 2.043.232	R 2.235.123	R 2.437.512
Accumulated Earnings		R (982.155)	R 95.790	R 1.315.120	R 2.682.996	R 4.207.029	R 5.895.314	R 7.756.475	R 9.799.707	R 12.034.830	R 14.472.343
Tax		R -	R 26.821	R 341.412	R 383.005	R 426.729	R 472.720	R 521.125	R 572.105	R 625.835	R 682.503
EAT		R (982.155)	R 1.051.124	R 877.918	R 984.871	R 1.097.304	R 1.215.565	R 1.340.036	R 1.471.127	R 1.609.289	R 1.755.009
Cash flow available for repayment of loan		R 1.358.000	R 639.845	R 1.300.080	R 1.110.025	R 1.198.107	R 1.289.404	R 1.383.994	R 1.481.952	R 1.583.350	R 1.688.255
Required payment on loan		R (389.365)	R (389.365)	R (389.365)	R (389.365)	R (389.365)	R (389.365)	R (389.365)	R (389.365)	R (389.365)	R (389.365)
Free Cash	R 1.358.000	R 250.480	R 910.715	R 720.660	R 808.742	R 900.039	R 994.629	R 1.092.587	R 1.193.985	R 1.298.889	R 1.407.361
DSCR		1,64	3,34	2,85	3,08	3,31	3,55	3,81	4,07	4,34	4,61
Debt / Income	R (2.200.000)	R (1.824.155)	R (773.031)	R 104.886	R 1.089.757	R 2.187.061	R 3.402.626	R 4.742.662	R 6.213.789	R 7.823.078	R 9.578.087
Debt	R (2.200.000)	R (2.074.635)	R (1.934.226)	R (1.776.968)	R (1.600.839)	R (1.403.574)	R (1.182.638)	R (935.189)	R (658.047)	R (347.647)	R 0
Dividends	R (2.200.000)	R 250.480	R 910.715	R 720.660	R 808.742	R 900.039	R 994.629	R 1.092.587	R 1.193.985	R 1.298.889	R 1.407.361
DFC		R 224.605	R 816.638	R 646.216	R 725.199	R 807.065	R 891.884	R 979.723	R 1.070.646	R 1.164.714	R 1.261.981
Net Present Value		R (1.975.395)	R (1.243.115)	R (723.512)	R (200.636)	R 321.156	R 838.221	R 1.347.536	R 1.846.624	R 2.333.476	R 2.806.494

ANNEX VI

Timetable Job Shadow Period

	MONDAY	**TUESDAY**	**WEDNESDAY**	**THURSDAY**	**FRIDAY**	**d**
24 – 30 JUNE	WKN - SA	WKN - SA	Energy Consult	Energy Consult	Energy Consult	
.	+ Meet the SA Team + Weekly team meeting + Greenfield	+ Meet with Wind & Sites regarding greenfield	+ General overview of Energy Consult + Meeting with Kai Nohme	+ Test financial model (Kai Nohme) + See into EC financial planning	+ Shadow different divisions of EC (Control Centre / Site Team / Electrical Team)	
01 – 05 JULY	BGZ	Energy Consult	Energy Consult	Energy Consult	WKN - SA	
	+ Business Management + Scope of work of BGZ +Discuss feasibility of SPV management in SA	+ Shadow different divisions of EC (Control Centre / Site Team / Electrical Team)	+ Shadow different divisions of EC (Control Centre / Site Team / Electrical Team)	+ Shadow different divisions of EC (Control Centre / Site Team / Electrical Team)	+ Concluding meeting WKN-SA	