

The effect of wind turbine transportation on wind farm development in South Africa

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Declaration

I hereby declare this dissertation is my own work. I understand what plagiarism is, and where I have used the ideas of others, I have referenced these correctly.

Signed: _____

Raymond Takuba

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Abstract

This thesis investigates the transportation of wind turbines in an emerging wind energy market with a focus on South Africa. The research goal is to understand how the transport and the wind energy sectors interact; as well as how turbine transportation can unfold as a barrier to wind farm development in South Africa. Turbine transportation was found to be a key part of the wind farm development process which has been hampered in South Africa by poor planning, the design of the renewable energy procurement program and low cooperation amongst industry participants. Barriers to wind farm development include a shortage of logistics equipment such as cranes and trailers, a shortage of skilled drivers and crane operators and several embedded bottlenecks in the abnormal load transportation process. These factors combined have resulted in a cost premium of 5 – 10% for the turbine transportation process in South Africa as compared to the cost in larger established wind energy markets. The study additionally finds that the wind energy industry could benefit from better coordination of transport projects through industry bodies such as SAWEA, as the transport system is unlikely to be altered in order to accommodate the needs of the wind energy industry.

Acronyms & Abbreviations

DoE	South African Department of Energy
DPE	South African Department of Public Enterprise
DTI	Department of Trade and Industry
EC	Eastern Cape
EPC	Engineering, Procurement & Construction
EU	European Union
FDI	Foreign Direct Investment
FPH	Factor Proportions Hypothesis
IPP	Independent Power Producer
OEM	Original Equipment Manufacturer
PCH	Production Concentration Hypothesis
PPA	Power Purchase Agreement
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
SAWEA	South African Wind Energy Association
SANRAL	South African National Roads Agency
T&L	Transport and Logistics
USA	United States of America
WC	Western Cape
WT	Wind Turbine

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1. Introduction

This thesis presents an analysis of wind turbine transportation for an emerging wind energy market, with South Africa as a case study. It explores the relationship between the transport sector and the wind energy development process.

Transportation of wind turbines is a challenge for the global wind energy sector due to the size, weight and mass of turbine components. Countries with emerging wind energy markets such as South Africa, who do not widely manufacture their own wind turbines, must import them through international trade. Once the turbines arrive the wind energy sector faces a number of transportation challenges in moving them from the ports of arrival to the wind farm locations where they will operate. These challenges include congestion of ports, crane and trailer shortages and turbine component damage during transit.

Turbine transportation is a critical part of the wind farm development process, but is not well understood in South Africa. The renewable energy procurement program has assumed the South African transport sector will be able to service the significant logistics demand that will result from wind turbine imports; James (2012) asserts this may not be true. In these assumptions the capacity of ports, roads and railways was assumed to be adequate. The equipment and logistics skills needed to support turbine transportation were also assumed to be available.

This thesis therefore takes a critical look at the process of turbine transportation in South Africa. It aims to understand the interaction between the transport and the wind sectors by identifying parts within the turbine transport process which can slow down, prevent, or cause cost escalation for wind farm development. Transportation is thus investigated as a key element and possible barrier to the development of the wind energy industry in South Africa, with recommendations made for other emerging wind energy markets. In this way, this analysis will make a positive contribution to the understanding of how turbine transportation affects wind farm development for South Africa and other emerging wind energy markets.

This thesis has used an exploratory research design to investigate the relationship between transportation of turbines and wind farm development. The objective of the research is to isolate and analyse turbine transportation with respect to the wind energy development process.

Eight wind farms with a total rated capacity of 634 MW will be developed in South Africa by 2015 (Frost & Sullivan, 2013). This scale of wind farm development is new to South Africa, which previously had a total of 10.16 MW of wind power at three wind farms. Darling wind farm, which served as a national demonstration project and which began operation in 2008 contributed 5.2 MW of this total (CEF, 2008; Esi-Africa, 2007). The Klipheuwel wind farm operating from 2002 with a capacity of 3.16 MW (DoE, 2013; Eskom, 2013) and the Coega wind farm operating from 2010 with a capacity of 1.8 MW (Electrawinds, 2012) make up the remainder of this total. The current scale of wind farm development under the first round of the REIPPPP is thus new to South Africa. Organisations from both the transport and the wind energy sectors have raised concerns about the challenges they will face in moving turbines from ports to project sites (James, 2011; Kapande, 2011; Smith, 2012; NRA, 2013).

These concerns revolve firstly around the adequacy of transport planning. Wind turbine components are transported as abnormal loads; they therefore cause traffic disruptions for other road users, in addition they require route clearance and traffic escort services. The existing research does not adequately address these problems. Secondly, the availability of equipment within the logistics industry is raised as a concern. Wind turbines require the use of specialised trailers and heavy lift crainage; as multiple project wind farm development is new to South Africa investment in new equipment may be required. Thirdly uncertainty about the capacity of South Africa's infrastructure to support an abrupt increase in abnormal load movement is expressed.

1.1 Research questions

The primary research question aims to explore and explain the relationship between the wind energy sector and the transport sector; these sectors interact in order to facilitate the transportation of wind turbines. Turbine component logistics is a

recurring part of a wind farm's life beginning during construction and continuing during the operation and maintenance (O&M) stage of turbine operation. The primary research question is thus:

a) How does the transport sector relate to the wind energy sector in South Africa?

This research question will guide the direction of this thesis. The literature review is used to understand this question from an international viewpoint which looks at the global wind industry and the effect of turbine transport in larger wind energy markets; this will then evolve to focus on the effect of turbine transport in South Africa. The literature review explains the difficulties of moving high volumes of geometrically and weight challenged machines. Once these challenges are understood, they can then be addressed in South Africa, as well as in other emerging wind markets.

The secondary research question is:

b) Does turbine transportation unfold as a barrier to wind farm development in South Africa?

In order to provide additional context to the transport discussion, a secondary research question seeks to identify the barriers turbine transportation can face. This question asks how transportation of turbines can act as a barrier to the development of wind farms. This part of the research investigates if and in what ways the turbine transportation process can hamper, prevent, or cause cost escalation of the wind farm development process in South Africa.

Both of these questions will be addressed through the research design found in the theoretical framework. For the primary research question the relationship between transport and wind energy will be established by examining the transport system through five logistics components which have been classified for this research. These are the infrastructure, equipment, operation & maintenance, costs, and planning involved with turbine transportation.

For the secondary research question the ability of each of these five components to act as barriers to turbine transportation will be discussed and presented as a conclusion of the project.

1.2 Rationale for study

An interest in wind energy and wind farm development in emerging wind energy markets was the starting point of this research. Renewable energy literature asserts that due to energy poverty, climate change, and inadequate electricity supply; renewable energy is a critical contributor to the future electricity mixes of developing economies in Africa and Asia (UNIDO, 2009; Neff, 2012). Of the renewable energy options currently available wind energy is the most mature and cost competitive technology (IEA, 2011). As such, wind energy is an important new energy source for developing countries.

However, wind energy markets in developing countries, with the exception of China and India, do not manufacture their own utility scale wind turbines; instead they rely on imports from equipment manufacturers in established markets. These turbine imports must then be transported first to the ports of the emerging markets, and then to the dispersed wind farm locations in the emerging market. This research thus aims to analyse the transportation of wind turbines in these emerging markets, with a specific focus on the South African wind energy market.

Wind turbines are large complex machines which are transported as large indivisible components. Due to their size and weight they are difficult to transport. They thus make intensive use of infrastructure when being transported from ports of import to scattered wind farm locations (Thresher & Laxson, 2006; Ozment & Tremwel, 2007; Mittal et al, 2010; AIMU, 2012).

This thesis has isolated the process of wind turbine transportation. The goal is to understand the process and the challenges faced in transportation of turbines in South Africa. Based on the findings made, recommendations on how wind turbine transportation affects the development of wind farms in other emerging markets can be made.

Wind turbine transportation has not been widely researched in literature, especially from a developing market perspective. Where a transport analysis of some level of depth has been completed it has been directed to an established market. This shortfall in research for South Africa and other developing wind energy markets has informed the design of this research project.

1.3 Structure of thesis

In order to complete the transport analysis, this thesis is divided into eight chapters. Chapter 2 reviews literature from both local and the international turbine transportation studies; it serves to build a knowledge base upon which new research focused on emerging wind energy markets can be completed. The literature review begins by exploring research which links manufacturing location decisions to turbine transportation. The relationship between turbine transportation and manufacturing location is used to confirm the importance of turbine transportation in the wind industry. Thereafter, the overall structure of the global wind energy industry and how it has developed with respect to turbine transportation is discussed. This global analysis is then narrowed down to an emerging market analysis with a focus on the local turbine transport environment in South Africa. Theory used to approach turbine transportation will be introduced in the literature review. The chapter which follows is dedicated to explaining this theory and defining it for this thesis.

The theoretical approach of this turbine transport analysis is explained and justified in Chapter 3 through the theoretical framework. The theoretical framework serves as a bridge between the theory discovered in the literature review and the methodology used to approach the research project. The concepts used and the research boundaries applicable to this study are defined in this framework, thereby giving the reader a point of reference applicable to the whole study. The theoretical framework concludes with a summary of the need for the research project.

The methodology is found in Chapter 4; it outlines the approach used to complete this thesis. In this methodology, interviews were used to gather primary data through a qualitative data analysis. In accordance with Bowen (2005), this exploratory

research was approached with minimal prior expectations so as to develop plausible project outcomes. Thirty stakeholders in total were approached with eleven declining to participate. Therefore, in total nineteen interviews were held against a response rate of 63%. Of these nineteen, twelve were from the wind energy sector and seven from the transport sector. The methodology section ends with a discussion of the research approach limitations.

Chapter 6 is an analysis of the interview data. The analysis section collates the results of the nineteen semi-structured interviews which were conducted with industry participants. The interviews focused on experiences and outlooks on the transportation of wind turbine components in South Africa. This analysis addresses each of the components of the transport system outlined in the theoretical framework. Within the analysis, the identities of all individual participants are kept anonymous. Each interviewee's organization can be identified with an interview number; the table with this information is available in Appendix B. Similarly, the questions which guided the structured component of the interviews are listed in Appendix A. Chapter 6 follows, with a summary and discussion of the key findings from Chapter 5.

Chapter 7 consists of discussions and recommendations. These are made using the information gathered in the analysis section. This section expands on the key opinions and findings which have been established through this project. The points in this section were selected either based on their relevance to the topic and the research questions, or on their recurring appearance in the analysis section where interviewees from both sectors highlighted them.

This project is concluded in Chapter 8, with a section which collates all findings and interview outcomes and summarises their meaning for the transportation of wind turbines in South Africa.

2. Literature review

2.1 Introduction

This literature review will present an overview of published research which has focused on wind turbine transportation. The purpose is to explore and understand the relationship between the transport sector and the wind energy sector in established and emerging wind energy markets.

Turbine transportation is a critical part of the wind energy development process, as turbines are large and heavy machines which need to be moved from manufacturing locations or points of import to scattered wind farm locations. Utility scale wind turbine components thus make use of project management and dedicated equipment to facilitate transportation. Despite the challenges faced in transporting turbines, dedicated research into this topic is rare, especially in new wind energy markets. The research questions thus seek to understand how the transport and wind energy sectors interact, and how transportation of turbines could act as a barrier to wind farm development for South Africa.

This chapter begins with a discussion of the relationship between manufacturing location and turbine transportation. Two theoretical approaches are presented in this literature review in an attempt to explain this relationship. The production – concentration hypothesis is the first; this hypothesis has been directly applied to the wind energy industry by Kirkegaard et al (2009). The factor proportions hypothesis is the second; Brainard (1997) has discussed this relationship with respect to international trade of capital intensive production.

The theory behind the manufacturing location of wind turbine components will be an introduction for an analysis of past work which will focus on the structure of the global wind energy industry. Thereafter, the role transportation has played in the development of the wind energy industry's manufacturing structure will be reviewed with respect to established wind energy markets. The understanding of that literature will then form a base for the analysis of turbine transportation in South Africa.

2.2 The relationship between manufacturing location and turbine transportation

This section explores the relationship between the structure of the global wind energy industry and the high transport costs involved in moving turbine components. Research into how firms decide to either export to a market, build productive capacity in a market or select to concentrate on alternative markets has been reviewed in past literature and is analysed.

Two theories on international trade are used to examine the relationship between transport costs and manufacturing location decisions. The intention is to understand the effect which transportation costs will have on developing wind energy markets. Globally, turbine transport is estimated to cost approximately 20% of turbine capital cost (Mittal et al, 2010), this makes transportation an important factor in wind farm development.

Published research works such as Platzler (2012) and Fravel & David (2012) acknowledge the proximity - concentration trade off which occurs in the wind industry. Kirkegaard et al (2009), in a more direct reference, reports directly on its applicability to the wind energy industry while presenting evidence to demonstrate why foreign direct investment (FDI) has played a major role in the development of global wind turbine manufacturing. A second theory on the structure of global trade flow and the means chosen to serve markets is encountered while researching the proximity concentration hypothesis. This second theory is the factor proportions hypothesis, which will also be discussed in the following sections.

2.2.1 The Production Concentration Hypothesis

The production concentration hypothesis (PCH) is a theory used to explain how producers of capital intensive output decide where to locate their manufacturing facilities. This theory suggests that there is a trade-off between proximity to customers and achievement of economies of scale at an existing production facility. The hypothesis suggests that proximity to a market increases the higher are

transport costs and trade barriers and the lower are investment barriers and economies of scale (Brainard, 1997).

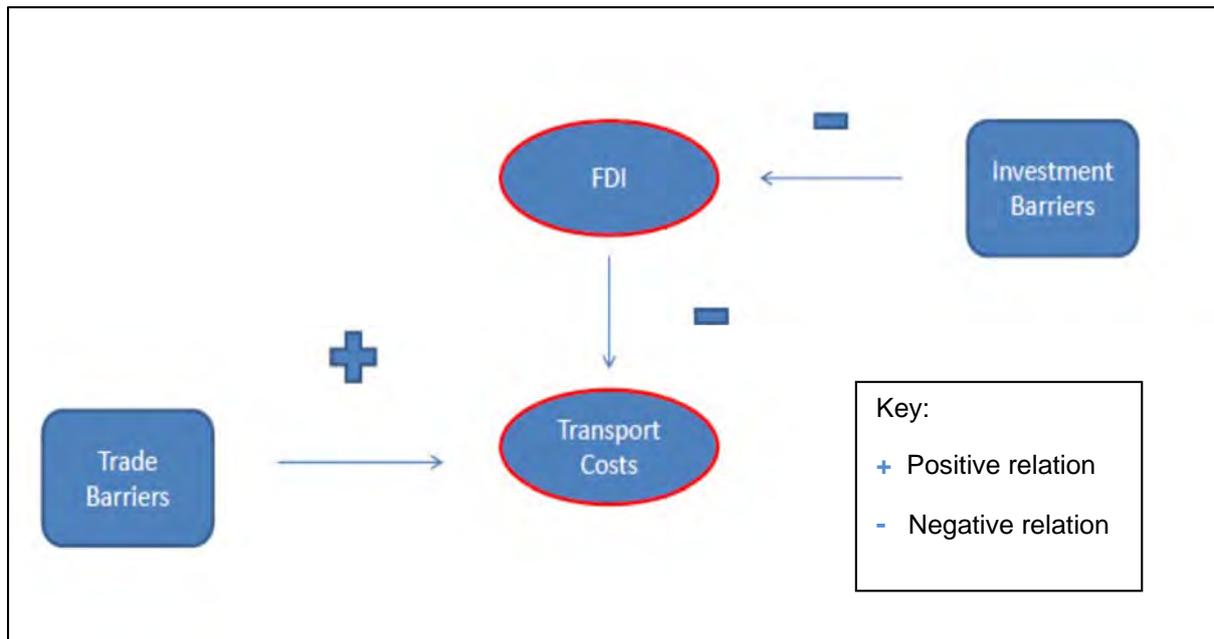
Kirkegaard et al (2009) applies the production concentration hypothesis (PCH) to the wind energy industry in an effort to explain the relationship between transport costs and foreign direct investment (FDI). FDI acts as a substitution to market proximity as investment, through factory construction as the means of achieving market proximity.

The four variables considered in the PCH are transport costs, trade barriers, investment barriers and economies of scale. Two published papers assert the importance of these variables by reporting on the performance of the American wind energy market (David & Reed, 2009; Fravel & David, 2012). The first is an industry and trade summary for the period 2003 – 2008, whilst the second is an analysis of turbine export opportunities within the Americas for 2012 and beyond.

These reports find that high transport costs have played a role in the growing manufacturing base of wind turbines in the USA market as the large global multinationals have set up production facilities in the US in order to avoid transport costs of foreign produced turbine imports (David & Reed, 2009). Additionally logistics barriers in The United States can further be reduced if turbine manufacturing facilities are located closer to wind farm sites as the permitting process for transporting turbines across multiple state boundaries is a costly and time consuming exercise (Brown, 2012). The levels of trade barriers are also examined, they are found to be relatively low as compared to the global market. Wind turbines imported into the United States are charged a tariff of 2.5%. David & Reed (2009) report that the average tariff for wind turbines in high income World Trade Organisation (WTO) members is 3% and for lower and middle income WTO members, 5%. However a list of smaller wind energy markets, have 0% tariffs on wind turbines. South Africa falls in that last category.

A simplified diagrammatic illustration of the proximity concentration hypothesis is presented in Figure 1 below. It displays the qualitative relationship between variables as positive or negative, with the arrow flowing from independent variables towards dependant variables. For example, limited FDI into South Africa for the manufacturing of wind turbine components leads to sustained high transport costs

through a negative relationship. High investment barriers, through a separate relationship have a negative effect on FDI.



Adopted using (Kirkegaard et al, 2009; David & Reed, 2009; Brainard, 1997)

Figure 1: An illustration of the production-concentration hypothesis

High transport costs are incurred in delivering wind turbines to wind farm locations (IRENA, 2012). The production – concentration theory is thus applicable to South Africa as a distant emerging market. The distance and cost incurred in importing turbines should act as an incentive for relocation of production. However, because transport cost is measured against economies of scale, the market size would first need to enable equipment manufacturers to reach economies of scale while producing for the South African market. The market size of a new or existing market refers to the demand for wind energy, which is determined by the host country’s renewable energy policy as a first catalyst.

In South Africa the push for proximity to market is driven by localisation rather than transport costs or economies of scale. Published wind energy papers describe the potential localisation policies have to distort trade and free market investment (Kuntze & Moerenhout, 2013; Rennkamp & Westin, 2013). Nevertheless the South African renewable energy procurement programme has used a threshold-target approach to localisation which will reach 40% - 65% local content for round three of

renewable energy project bidding (Department of Trade and Industry, 2012). Localisation is a key competitive area in winning power supply bids with the Department of Energy. The largest localisation investment in South Africa to date will be an investment by a large steel processing company which has publicised its commitment to build locally made wind turbine towers with production starting in early 2014. This investment will be located in the Coega industrial development zone where towers will be manufactured in close proximity to the wind farms in the Eastern Cape Province (Esi-Africa, 2013). The increased localisation thresholds in round two and round three of project bidding has made the local manufacture of towers necessary even though prices of local towers will be higher than imported towers; the small size of the South African market will also mean reaching economies of scale will be a challenge.

2.2.2 The Factor Proportions Hypothesis

The Factor Proportions Hypothesis (FPH) is an alternative theory in international trade and investment flows. This theory is much older than the PCH and is considerably more dominant appearing in literature in the early 20th century. Brainard (1997) explains it in the context of international good production; firms integrate production vertically across borders to take advantage of factor price differentials. For wind turbine manufacturing this refers to the main material, technical and financial inputs which component manufacturers require to develop a market ready turbine in a relocated factory; that factory would then serve its new market and possibly export from that market in future.

The factor proportions hypothesis aims to explain how a firm decides to locate a production facility. The location of this facility then has a material impact on the transport cost of the factory output. As the distance from the target market increases so does the cost and the difficulty of turbine transportation. Wind turbines have a total transport cost which is a high proportion of the turbine capital cost (IRENA, 2012), this makes manufacturing location uniquely important in the wind energy industry (David & Reed, 2009). In this factor proportions theory the price and availability of factor inputs such as labour and steel, determine where production will develop. Where the factor is affordable and available, increasing use of it is made.

Therefore production patterns will reflect the cost of available inputs. Steel and labour have been used below as examples of factor inputs.

Factor prices naturally vary in wind turbine manufacturing countries and these prices, according to the factor proportions hypothesis are important in deciding where production will occur. As Lema et al (2011) point out, the Chinese wind industry like other industries in China has access to low labour costs, companies manufacturing in the Chinese market thus have an incentive to migrate to labour intensive production methods.

As China has developed its wind energy manufacturing base, cost and availability of labour has helped to sustain turbine producers in the Chinese market. Initially relocation to China was driven by a local content requirement which started at 20% and peaked at 70% before being removed in 2009 (Kuntze & Moerenhout, 2013). China did not have a technology advantage in wind turbine manufacturing; instead much of the technology was imported into Chinese firms via joint ventures with small to medium sized European companies. China does however have a labour cost advantage, and as wind energy is a labour intensive form of energy production (Poncin et al, 2011), labour cost would have been a key factor in the growth of the Chinese wind turbine manufacturing industry. The factor-proportions hypothesis suggests a low factor price leads to development of industries that make increasing use of that factor against other more expensive factor inputs. Chinese turbines are cost competitive because of the labour cost advantage turbine manufacturing enjoys in China; this is despite the concerns about quality which often arise. However, Poncin et al (2011) goes on to explain that this labour cost advantage will only be relevant if markets in close geography are supplied as labour costs advantages can be off-set by rising transportation costs which come with producing for distant internal or export markets.

It is useful at this stage to compare labour cost in China to labour cost in South Africa. China's economy has been growing rapidly over the past 30 years. Most of this growth has resulted from a combination of high labour productivity and supply driven low labour cost (Haltmaier, 2013). However, as the Chinese economy has grown, the cost of labour in China has risen (Rochan, 2014; Ceglowski & Golub,

2012). Research has suggested the cost of labour is now the biggest contributor to the rising cost of manufacturing in China (The Economist, 2012). This leads on the the question of whether or not low South African wages would be sufficient, according to the factor proportions hypothesis to encourage manufacturing relocation of turbine components to South Africa. Firstly, despite the strong growth in the cost of Chinese labour, this growth occurs off a low base resulting in average Chinese labour cost being approximately a third of South Africa's average labour cost based on 2008 data (Ceglowski & Golub, 2012). Secondly, even if the South African labour costs were lower, the size and structure of the Chinese economy lends itself to highly developed supply chains for production inputs, a large and diversely skilled labour force which exhibits higher productivity, and a proximity to larger Chinese markets (The Economist, 2012). The FPH suggests that firms integrate production vertically across borders to take advantage of factor price differentials; this hypothesis therefore possibly explains the role of labour cost in supporting the historical and current growth of wind turbine manufacturing in China.

A second example of a factor input cost in wind turbine manufacturing is the price of steel. Steel is a major factor input for a wind turbine as the tower, which is the heaviest part of a wind turbine, is made from steel. The largest firms in South Africa's steel supply industry have been taken to the competition commission on several occasions due to alleged monopoly pricing.

Figure 2 below shows the structure of the steel supply market.

	Flat steel products	Long steel products
AMSA	80%	52%
Highveld	20% (incl. imports)	15%
Scaw		15%
Cape Gate		12%
Cisco		6%

Source: (Competition Commission, 2010)

Figure 2: Market shares of firms in South Africa's steel market

It is argued that the cost of steel in South Africa is affected by monopoly pricing and this is a generator of excessive profit for the industry's dominant firms. Pricing of steel by the market leader is done according to Import Parity Pricing, which is the price local consumers would pay if they were to import their steel consumption from international markets. A second price referred to as the Export Parity Price is quoted for export customers with the export price being approximately 40% lower than the import parity price (Competition Commission, 2010). This arrangement is sustained by two factors; firstly, export customers usually enter agreements preventing resale of products back to local customers and secondly transport costs and trade restrictions of steel imports prevent local customers from importing their demand. Steel is thus an expensive input cost in steel processing in South Africa. Input costs are passed onto consumers in the form of higher prices which would in this scenario translate to more expensive wind turbine towers.

The renewable energy bidding process has become more competitive; this has caused electricity supply prices to fall in each round of contract bidding. These declining prices have encouraged project developers to minimise costs. As wind turbine towers make up a significant portion of the total turbine value (IRENA, 2012), locally manufactured towers on the face of it would be priced too highly for the South African market. However, market forces are accompanied by legislation and bid restrictions. The demand for the steel towers which will be manufactured in the Coega industrial development zone is thus driven by localisation legislation rather than market forces or price competition. Without localisation requirements, which have crossed the 40% threshold of weight and value and which basically makes locally made towers mandatory, the manufacturing of towers for wind turbines would not take place in South Africa. This therefore explains the apparent diversion from the factor proportions hypothesis. The steel price is an example of how factor costs affect manufacturing location especially in cases where import restrictions, transport costs or factor immobility prevent the easy transfer of factor inputs.

The cost of labour in China and the steel price in South Africa have been used to describe how the factor proportions hypothesis explains the manufacturing locations of wind turbine components. In both markets localisation legislation had and continues to have a greater influence on the development of manufacturing capacity than factor costs. However these examples were used only to illustrate the

importance of turbine transportation. Turbine transportation acutely affects the wind energy industry through the cost and difficulty of transporting turbine components. In theory transportation plays a significant role in determining where turbine components are manufactured.

2.2.3 Conclusion

The relationship between manufacturing location and transport cost of wind turbines is not a simple one which can be allocated a precise definition. A number of additional factors affect the location of productive capacity and thus the cost of transportation. These include trade barriers, investment barriers, market size, factor availability and the potential for economies of scale. What is clear however, is that transport costs are considered when production location decisions are taken. This is partly because transport costs can eat away at location advantages. Reaching economies of scale in a factory far from market demand will result in disproportionately high transport costs for the components. This can affect final price to consumers and benefit competitors who are located closer to the target market. In addition, because of the size and weight of wind turbine blades, nacelles and towers, combined transport costs are already a significant portion of total turbine value therefore they need to be explicitly controlled.

2.3 The effect of transport and logistics on the wind energy industry's structure

Economies of scale in turbine component manufacturing are strongly applicable to the wind energy industry (IRENA, 2012). However, the transportation of wind turbine components subsequently faces technical and financial challenges due of the weight and size of the modern multi-megawatt wind turbine components (Van Rensselar, 2010; AIMU, 2012). This has affected the current structure of the global wind sector where emerging markets rely on turbine imports, whilst established markets have built supply capacity which enables their demand to be serviced locally.

This thesis investigates the development of emerging wind energy markets with respect to turbine transportation. Literature explored below will examine the effect transport costs had on the structure of turbine manufacturing industries in China and America. An analysis will then attempt to understand how turbine transportation will affect the development of the South African wind energy sector.

Kirkegaard et al (2009) report on the structure and value chains in the global wind turbine industry. They find that the export-import approach to wind turbine trade is limited globally. The majority of wind turbine demand is satisfied within the national boundaries of a market. The dominant means of serving external turbine demand is foreign investment in manufacturing capacity, corporate mergers, and manufacturing licencing agreements. Turbine logistics are explored in more detail by Mittal et al (2010), who finds transportation costs of turbine components account for 20% of total equipment costs. Other research has suggested a higher proportion of transport cost to capital cost for wind turbines; in these studies the proportion of transport to capital cost is estimated to fall between 20 – 25% (Ozment & Tremwel, 2007; Patel, 2010).

Cross border trade in wind turbines has been driven by relocation of manufacturing capacity as opposed to physical trade. Lema et al (2011) provides some clarity on this structural development by observing historical industry concentration. A decade ago global wind industry manufacturing, sales and installation was dominated by European companies. As demand patterns changed, fewer of the top market share holders were European based companies, with only four remaining in the top ten by 2010 as displayed in Table 1 below. An increase in demand for wind turbines in the Asian energy markets has driven this change. European producers have subsequently relocated production to where there is market demand.

This relocation has happened mostly through licencing agreements, where Chinese manufacturers import technological know-how from the European technology leaders in exchange for revenue participation. Chinese localisation legislation initially drove the relocation of productive capacity; however this legislation was removed in 2009. Avoiding transport and import costs are key benefits of manufacturing relocation. Table 1 displays the above using a comparison of market shares of the largest equipment makers. The increase in Asian demand has seen manufacturing capacity

develop in the Asian markets, in most cases in corporate partnership with medium or large European technology leaders.

Table 1: Top ten global turbine manufacturers 2003 & 2010 (world market shares)

2003			2010		
Origin	Firm	Share	Origin	Firm	Share
EU	Vestas (DK)	21.80%	EU	Vestas (DK)	14.80%
US	GE Wind	18.00%	CN	Sinovel	11.10%
EU	Enercon (DE)	14.60%	US	GE Wind Energy	9.60%
EU	Gamesa (ES)	11.50%	CN	Goldwind	9.50%
EU	NEG Micon (DK)	10.30%	EU	Enercon (DE)	7.20%
EU	Bonus (DK)	6.60%	IN	Suzlon	6.90%
EU	REpower (DE)	3.50%	CN	Dongfang Electric	6.70%
EU	Nordex (DE)	2.90%	EU	Gamesa (ES)	6.60%
EU	Made (ES)	2.90%	EU	Siemens Wind Power (DK)	5.90%
JP	Mitsubishi	2.60%	CN	United Power	4.20%
	Others	5.30%		Others	17.5%

Source: (Lema et al, 2011)

Verification for the relationship between transport costs and manufacturing location is observed by Poncin et al (2011). The majority of wind turbine original equipment manufacturers (OEMs) are driven by home market sales where cross continental transport expenses are avoided. The Chinese manufacturers Goldwind and Sinovel for example make almost all sales in the Chinese market. In the same way, Vestas, which is the largest OEM in the world, uses a global manufacturing network. In this network Asia is supplied from Asia, Europe from Europe and North America from North America (Poncin et al, 2011).

2.4 Transporting wind turbines in established markets

2.4.1 Introduction

There is a separation between where wind turbine components are manufactured and the final site where wind energy is generated and turned into electricity (Thresher & Laxson, 2006; Lema et al, 2011). This is especially true for wind energy markets where imports are a large portion of total supply. The USA, which is the largest importer of wind turbine equipment, imports 28% of its wind turbine components (US Department of Energy, 2013). In contrast, emerging wind energy markets such as South Africa are reliant on imports for all turbine components (SIB Energy, 2011).

2.4.2 Turbine transportation in established vs. emerging markets

Each time a wind turbine is transported, a complex logistics project is required. Neff (2012) asserts the importance of turbine transportation by examining multi modal transport options with a focus on the American state of Kansas. Similarly, Ozment & Tremwel (2007) examine the evolving supply chain for turbine components in the American wind energy industry.

Turbine transport studies which have focused on established markets will be useful in understanding new markets but will not be perfectly applicable. For example, while Neff (2012) discusses the movement of turbine components in Kansas, no interviews with industry participants were used. The study was based only on an American literature review. This methodology has limited the study's potential to create transferable insight into turbine transportation, thus limiting the study's applicability to South Africa.

Likewise, Ozment & Tremwel (2012) demonstrate the importance of post construction logistics management. This is in contrast to the majority of transport studies which have focused on transportation during construction. This is an important transferable insight. However, the capacity in the logistics industry to mode switching between road, rail and barge is a distinct feature of the American transportation environment. South Africa has a less advanced rail system with

transportation by sea also limited. These differences confirm the need for a study which is focused on transporting wind turbines in South Africa.

Modern utility scale wind turbines have a life span of approximately 20 years and transportation of components plays a continuous role in turbine operation. At the end of a wind project's operating life cycle, site restoration as required in the environmental approval would then imply further logistics. The capacity of infrastructure to support the needs of wind turbine transportation is nevertheless a secondary consideration in wind energy planning (Shihundu & Morrall, 2011; AIMU, 2012). Planning for the transportation of wind turbines instead occurs in a reactive manner. The Shihundu & Morrall (2011) and the AIMU (2012) studies have again focused on turbine transportation in the North American wind energy markets, the former on Canada and the latter on the USA. The level of infrastructure in these countries is not necessarily comparable to the level of infrastructure in a less developed market (GIZ, 2013). Therefore an analysis of South Africa's turbine transport system would be needed to confirm the validity of these papers findings.

2.4.3 Reasons for the growth in turbine size

Wind turbines have increased in size as the wind energy sector has grown. This has made turbine component transportation an increasingly important issue. The difficulty of moving larger machines has encouraged the decentralization of the modern wind energy industry as explained in Table 1. The growth in turbine size has been driven by economies of scale in production and increased efficiency in operation. However, increased performance must be achieved against variable and potentially low wind speeds meaning larger turbines are needed for sustained power production (Grogg, 2005; Ozment & Tremwel, 2007).

The growing length of the blades is attributed to the greater than proportional increase in rated power which results per unit of length increase (UK Department of Environment, 2009). Meanwhile, the growing height of towers is driven by the increased power output possible the higher is the turbine axis. The "cube effect" of wind energy refers to the cubing of power output as a result of a doubling in the speed of wind flow. Wind speed increases with height; therefore, the higher the

turbine axis sits the more energy can be extracted from the wind (Mittal et al, 2010; Nawair et al, 2013; IRENA, 2012).

2.5 Transporting wind turbines in South Africa

2.5.1 The infrastructure needed to support wind turbine transportation

This section will focus on the logistical and infrastructure challenges faced in the South African wind energy market which is in its infancy stage with expansion plans as outlined in the Department of Energy's IRP (Department of Energy, 2011). Construction of wind farms for successfully bid projects began in 2013. Eight round one projects are either preparing for, or are in the construction phase as of mid-2013. Fifteen wind farm projects have been approved in the first two rounds of the Department's renewable energy program with seven more following in the third round.

Although all wind energy markets face transport and logistics challenges as shown by the logistics focus in organisations such as the American Wind Energy Association's (AWEA) and the South African Wind Energy Association (SAWEA), the lower level of infrastructure development in developing countries results in infrastructure bottlenecks which are more acute and expensive (GIZ, 2013).

An African Infrastructure review carried out by the World Bank found infrastructure to be the largest constraint to business and investment in African countries. The state of present infrastructure was also confirmed to be lagging behind that of not only developed countries, but other similarly less developed regions as well (Foster, 2008). The capacities of the roads, railways, bridges, ports, the trucking industry and the crane industry are important in understanding how far the wind energy industry can be carried by the existing transport systems in developing wind markets.

Three main groups of physical infrastructure are used in moving turbines. These are the roads, the railways and the ports. In South Africa each of these groups presents the transportation of turbines with certain capabilities and limitations.

A study by the Department of Transport into the state of road maintenance in South Africa helps readers understand key road management issues (Department of Transport, 2012). In South Africa a road falls under one of three jurisdictions. Either it is a national road, a provincial road or a municipal road. The jurisdiction then determines which public body is responsible for maintaining the road. Of the country's 746 978 km of road network, approximately 140 000 km or 19% are defined as un-proclaimed roads. These un-proclaimed roads are not maintained by any sphere of government as none are legally able to allocate funds to them (National Treasury, 2011). In the case of planning and coordination of road maintenance there is a lack of data from some of the provinces and municipalities as to the exact state of their road networks and this leads to uncertainty as to the condition of the network (Department of Transport, 2012). A road network with no maintenance data is unlikely to be well maintained. This is the same road network which will be tasked with supporting the sustained heavy haulage arising from the wind sector's development. If either poor quality roads or un-proclaimed roads are needed to provide access to any wind farm sites, immediate as well as long term operability of that wind farm will be hampered. Project developers could build their own roads, but this would need to be factored into the feasibility study and the cost evaluated.

The damage that can accrue to a road network as a result of sustained heavy haulage is exemplified by the current state of the road network in Mpumalanga and Limpopo. The road networks in these provinces have been heavily damaged by the trucking of coal loads to power stations (Department of Transport, 2012; Eberhard, 2011). These two provinces are the heart of the South African electricity supply industry which is reliant on coal for 92% of electricity generated (Newbery & Eberhard, 2008). Wind farms in South Africa are currently found in Northern Cape, Eastern Cape and Western Cape, with wind farm development in other provinces possible in latter rounds of the REIPPPP. The former two are amongst the poorest provinces in the country where the road network is at its lowest quality (Department of Transport, 2012).

Wind turbine equipment is large and heavy. For remote rural locations where some wind farms will be located, the roads will be newly exposed to sustained loads of heavy equipment. Saarenketo et al (2011) describe a series of experiments carried

out in order to evaluate the impact of heavy haulage trucks on road structures. Although this study was carried out on roads in Finland where different methods and materials are used to make the roads, the theoretical basis on which the study is based is applicable even to a developing country. Heavy haulage systems have an effect on the condition of the roads they use. Network operators should ideally test and understand these effects before the damage can occur.

Inevitably, heavy haulage trucks will damage roads and this may disadvantage surrounding communities. However there are also consequences for trucking and trailer equipment as Wittmann (2010) explains in a study of the cost of logistics in South Africa. Roads damaged by neglect of maintenance and unplanned excessive heavy haulage will in-turn damage freight trucks which continue to use the distressed routes. Operation costs of haulage trucks will increase thereby driving up the overall cost of logistics. The equipment which will be needed to service the wind energy sector will in this way also suffer increasing maintenance costs due to the deteriorated road surfaces which it will operate on.

When heavy freight is transported over longer distances, moving tonnage by rail is generally cheaper than moving tonnage by road (NPC, 2010; David & Reed, 2009), in this way transportation of wind turbine equipment by rail is an alternative to transportation by road, however the individual locations of wind farms would be the determining factor of the mode of transportation used since not all wind farms will have capable railroads in close proximity. In cases where rail transport is used it would also have to be complemented by road transport for the final part of the journey, and in some cases for the initial part of the journey if ports or manufacturing facilities lack rail road access (AWEA, 2007; Neff, 2012).

Figure 3 below shows an extract of the national rail network. It is worth noting that the wind energy industry will be concentrated in the south and south-west of the country.



Source: (DBSA, 2012)

Figure 3: South Africa's National Railway Network

Transnet is South Africa's state-run railway monopoly. It has state approved investment plans to refurbish infrastructure and expand capacity. Unfortunately for the wind energy industry, according to these investment and expansion plans, the historical focus on the mining industry will continue (DBSA, 2012). The expansion of the rail industry capacity in the wind energy provinces will thus be limited. Below is a DBSA (2012) sourced table of Transnet's investment priorities.

Table 2: Transnet Rail Business – Investment priorities 2011 – 2015

Rail freight business sector	Investment focus	Comments
Export coal	<ul style="list-style-type: none"> Expansion of the Richards Bay coal export line from current 61mt capacity to 81mt by 2015 Upgrade of existing rolling stock Rail yard expansions/electrical power upgrades Purchase 110 new locomotives 	Operational challenge of optimising bulk volumes in context of working with multiple coal suppliers
Major feasibility studies	<ul style="list-style-type: none"> Expansion of Richards Bay line beyond 81mt Capacity to Mpumalanga power stations Capacity to export from Waterberg coalfields 	Additional exports could involve links through other countries
Iron ore and manganese exports	<ul style="list-style-type: none"> Expansion of ore exporting capacity to 80mt Relocate manganese export facility from Port Elizabeth to Ngqura or Saldanha Expand rail carrying capacity accordingly 	Market desire is to grow manganese exports from current 5.5mt to 14mt
General freight business	<ul style="list-style-type: none"> Investments in wagons and locomotives for growth in rail transport of containers Investment in wagons, and new rail line for domestic coal transport routes 	Aim is to increase total GFB volumes from current 72mt to 110mt, focusing on bringing containers from road to rail and expanding domestic coal deliveries

Source: (DBSA, 2012)

Table 2 shows the firm’s investment priorities for the period 2011 – 2015. As shown above the coal and iron ore sectors will receive the bulk of Transnet freight rail's investment. Growth in coal export capacity is prioritised for the jobs and foreign currency benefits which will accrue to the country.

The South African freight railway system could be used to transport wind turbines for some projects but capacity will be limited by low railway penetration. The historical development of the freight railway system was based on servicing several bulk cargo industries, especially mining and coal transportation (DBSA, 2012). As such the freight rail network is more developed in the north-eastern part of the country where the mining industry is concentrated.

Before wind turbine components can use the road or rail systems, they must arrive and be processed through the trade ports. In emerging wind energy markets, where component manufacturing is undeveloped, the ports are the starting point of wind turbine deployment. South Africa currently does not manufacture utility scale wind turbine components. Ports are thus important in facilitating the arrival of turbines in the country and a port capacity limitation would translate to an industry size limitation (Wiesegart et al, 2011).

South Africa has eight main commercial sea ports. Five of these are deep water ports with two able to receive ships carrying turbine equipment (DBSA, 2012; Smith, 2013). Each port's capacity to handle multi-tonne wind components will have to be supplemented by new cranes as the present crane capacity is designed for smaller sustained loads.

2.5.2 The Support and equipment used in turbine transportation

Wind turbine development is moving toward larger turbines; as such the equipment used in wind energy transportation will have to contend with ever increasing turbine dimensions (Morthorst, 2001; Thresher & Laxson, 2006; World Steel Association, 2012). In South Africa it will also have to contend with limited availability of equipment.

The economics around trailers and the cranes will be relevant to understanding where potential barriers can affect the movement of wind turbines. To move wind turbines enough cranes and trailers need to be present in South Africa. As demand for these pieces of equipment increases, additional supply will be needed. There is currently a shortage of this equipment in the country as wind farm development has been limited before the Department of Energy's renewable energy procurement programme. A surge in equipment demand has followed the commencement of turbine import and construction for round one projects (Smith, 2012).

Specialised multi-axle trailers are needed to transport turbines and distribute the components loads onto the road surface (David & Reed, 2009; UK Department of Transport, 2001). As weight increases, the number of axles must also increase. Similarly, specialised cranes are needed to lift turbine components to the tower heights of up to 100 meters. These cranes have been acquired for use by the wind industry, where they will be used to hoist blades and nacelles (Brisben, 2011). The dedicated use of turbine logistics equipment has important economic considerations because for a small market such as South Africa, economies of scale in operating this equipment will be challenging to reach. At the same time for the wind industry to commence construction, these trailers and cranes will need to be sourced from overseas markets. Currently only a small number of these pieces of equipment are

available in South Africa (Frost & Sullivan, 2013). Published details on the number of heavy lift cranes and trailers available in the South African market were not available. Logistics firms consider their fleet capacities to be competitive information.

The Department of Energy's updated IRP 2010 has remodelled the allocation for wind energy. This may lead to a change in the 8400 MW allocated in the older IRP 2010 which was allocated up to 2030 (Department of Energy, 2011; 2013). The current updated version is a living document in that it is subject to change and stakeholder input. However, uncertainty with regards to the long term prospects of wind energy in South Africa will have a negative effect on the outlook for equipment investment and skills development in the turbine transport sector. Furthermore, the manufacture of localised turbine components becomes increasingly unattractive when the market is small (Kuntze & Moerenhout, 2013).

2.5.3 Transportation during operation and maintenance

The purpose of a modern utility scale wind turbine is to convert wind energy into useful electric power for local or distributed use. Operation and Maintenance (O&M) of a wind turbine and the wind farm as a whole is a means to maximize the turbine performance and availability. This research found extensive examples of research into operation and maintenance where cost minimisation and availability maximisation are covered (Hahn et al, 2006; Graves et al, 2008; Tjernberg & Wennerhag, 2012; Grey, 2012).

Maximisation of turbine availability is a priority in every wind market as availability is directly related to operational revenue. Some markets perform better than others in this area and this research aims to understand what of these differences can be attributed to logistical challenges. Graves et al (2008), suggest the wind turbine availability in the (at the time of study, 2008) American wind energy market is slightly lower than the average availability in the European wind energy market. According to their research key reasons for this include the remoteness of wind farm locations, and the limited availability of spare parts and cranes to assist in operation and management (Graves et al, 2008). These findings come with caveats; the data used to reach them was not fully representative as wind farms and modern sized turbines have not operated for periods long enough to guarantee the validity of such findings

(Stevens & Harman, 2008). However, the importance of logistics to the life time of wind turbines is again emphasized.

In another study, Lindqvist & Lundin (2010) investigate the effects spare parts logistics and storage can have on the availability and performance of wind turbines. After differentiating between corrective and preventative operation and maintenance, the authors report on the effects of spare part logistics, where repairs or replacement parts need to be ordered, transported and installed. They also discuss economies of scale in spare part management suggesting there is a threshold of turbine numbers below which spare part supply and storage is increasingly cost inefficient. Using a model based on operational research, they proceed to provide strong conclusions to support their hypothesis that availability and cost are highly sensitive to component transportation and the efficiency of logistics execution. A closer look into the operational management of what in round one has been a fragmented South African wind industry would make a valuable addition to knowledge for wind farm management in South Africa. At the moment, several small to mid-sized wind farms will operate independently from each other using different turbine makes and independent operation planning.

2.6 Conclusion

This literature review has discussed the factors which create a relationship between the transport sector and the development of the wind energy industry. This has been done using literature from the global wind industry where the largest markets, specifically the American, Chinese and European markets are examined. Themes that arise are firstly that the location of manufacturing output has a relationship with the transport cost and transportability of the manufactured wind turbines. The challenges faced in moving turbines are financial, physical, and legislative and have encouraged the collation of demand and production throughout the global sector. However other factors such as factor prices, market size and trade barriers also affect the manufacturing location decision making process. If a market incurs high transport costs of supply but is still relatively small the economies of scale achieved in an external market will outweigh the increasing local transport costs.

The literature review has revealed an underlying theory applicable to wind turbine transportation. This theory is explicitly expressed in a number of the documents which were reviewed for this project (Ozment & Tremwel, 2007; Kirkegaard et al, 2009; Lindqvist & Lundin, 2010). Understanding the theory behind how turbine transportation affects the wind energy sector is critical to an emerging wind energy market, given the significant costs of wind turbine transportation.

The literature review has revealed that there are multiple areas that need to be considered in promoting the feasibility of turbine transportation, these include the infrastructure to support turbine imports, and the supporting equipment that will be needed such as cranes and trailers. Adequate provision and planning for the transport needs of the operation and maintenance stage will also need to be made. The economics of movable cranes and trailer fleets is an area which needs more research if these are to be prevented from becoming barriers.

Infrastructure planning and energy planning need to be carried out in unison as energy investments make intensive use of a country's infrastructure. In a scenario where continued investment in wind energy is made, additional investment in roads, railways and port capacities will be needed. Importing turbines and transporting them to wind farm sites via road is currently the dominant method of wind farm development in small wind markets and will remain so until local manufacturing capacity has grown to an extent where local demand can be serviced. This research project now proceeds to explore the process of turbine transportation specifically for South Africa.

3. Theoretical framework

3.1 Project framework

The primary research question seeks to investigate and understand the relationship between the transport sector and the development of wind farms in South Africa. The different stages of the turbine transport process are analysed using a framework built on international literature as transportation of wind turbines is new to South Africa. This study will establish if transportation is an integral part of the development of wind farms. This thesis aims to build a basis for understanding the planning for and process of moving turbines in the South African context.

A secondary research question will then analyse how the transport sector could act as a barrier to wind farm development in South Africa.

The research questions are repeated below:

- a.) How does the transport sector relate to the wind energy sector in South Africa?
- b.) Does turbine transportation unfold as a barrier to wind farm development in South Africa?

South Africa is currently one of the world's leading emerging wind energy markets (UNEP, 2013), which will serve as a trial for other new wind energy markets, especially those in Africa. However the use of wind energy on a multi wind farm utility scale is new to South Africa. This novelty results in limited experience along the wind energy value chain. This research aims to make an addition to knowledge regarding the local process of transporting turbines. Turbine transportation has been chosen as a particular research focus for this project because it is one of the least researched components of the wind energy development process. In South Africa it has been frequently mentioned as a challenge which the wind industry will need to overcome (James, 2011; Kapande, 2011; Smith, 2012; NRA, 2013). It has however not yet been singled out for dedicated research. This leaves a gap in academic knowledge within the local wind energy industry with respect to turbine transportation and the unique challenges to be met in South Africa.

This research project proposes that the global and local turbine transport environments are fundamentally different. South Africa is geographically distant from the manufacturing locations of wind turbines in Europe, China and India. Additionally, the infrastructure, logistics equipment availability and level of planning preparedness of the different transport systems are not comparable.

The transport sector as defined by this research project refers specifically to the transport costs, infrastructures, planning and labour involved in the movement of wind turbines from their point of manufacture to the wind farms locations where they will operate. Wind energy development as defined for this research refers to the process and cost of developing wind farms in locations around South Africa.

Turbine transport and turbine logistics are terms which can be used interchangeably in this project. Transport is a subset of logistics but both are closely related and refer to the same process, as they are generally used interchangeably. According to Waters (2009), logistics is the function responsible for all aspects of the movement and storage of materials on their journey from original suppliers through to final consumers. With respect to the wind energy industry, logistics is the entire process of moving, planning, and paying for turbine transportation. At the same time transportation is the process of moving turbines and will be used when referring to one of the individual components such as infrastructure, equipment or planning which make up the turbine logistics process.

There is limited experience in moving turbines in South Africa, therefore this research has adopted an exploratory approach where the experience of industry subjects is gathered and analysed in the absence of preconceived conclusions. Qualitative interviews will be held with responsive industry participants who have worked on the movement of turbines in the first round of wind farm developments awarded in the renewable energy procurement programme. The focus of this thesis is on the eight successful wind farm projects from this first round.

Within this thesis reference is made to several small wind farms developed in round one of the REIPPPP. This reference is made to wind farms that are on the lower scale of the DoE's maximum wind farm size limit of 140 MW. When discussing large wind farms this thesis is similarly referring to those close to 140 MW. It is important to note these distinctions are not globally applicable as wind farms considered small

in South Africa's wind industry are considered large elsewhere. For example, In Ireland, Germany, Spain and other European markets, average wind farm sizes are smaller with an industry inclination to develop smaller distributed wind farms (IEA Wind, 2013).

Figure 4 is a diagrammatic illustration of the theoretical framework which will be used to approach this research project. The main research question is illustrated by the top two boxes where the question of how the transport sector affects the development of the wind energy industry is asked. The components of the transport sector which affect the wind energy industry are then explained below the figure.

The role out of the wind energy procurement programme has made steep assumptions of the local transport sectors capacity. Sustained turbine movement will test this capacity and expose any inherent limitations. This thesis will reveal and discuss these limitations, and suggest measures for their improvement.

3.2 Components and attributes of research approach

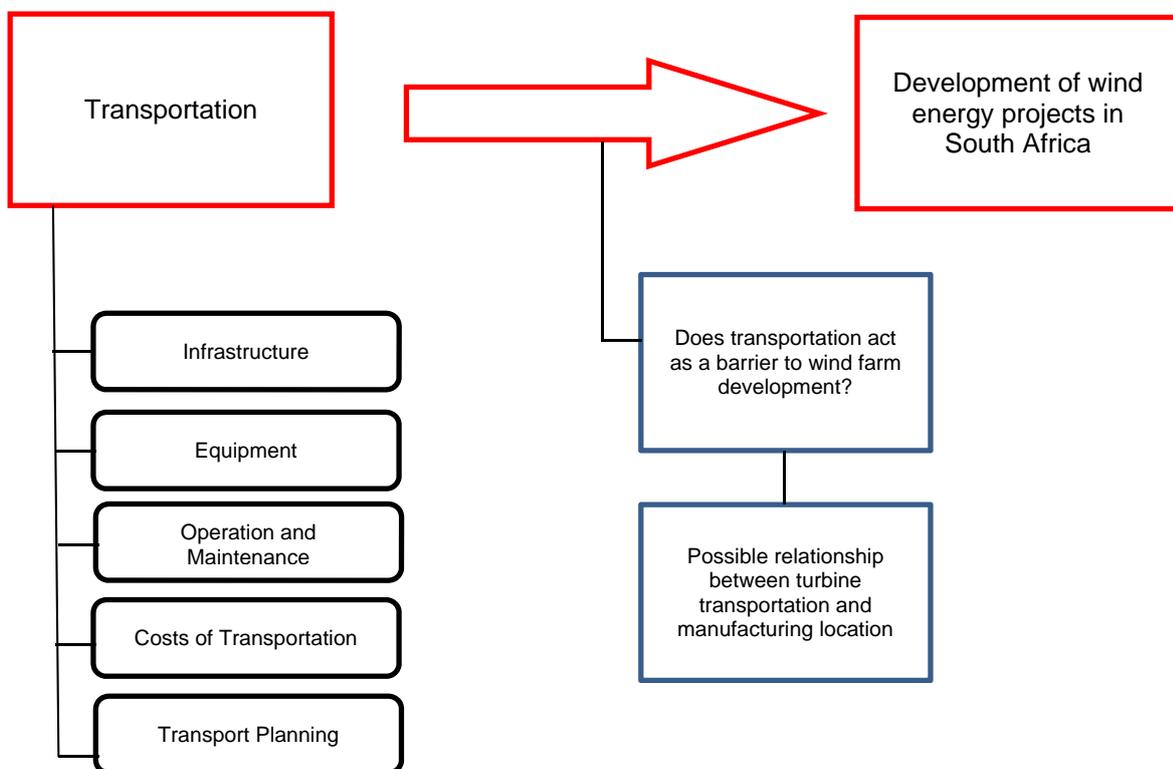


Figure 4: An illustration of the research design

The arrow between transportation and wind energy projects depicts the direction of analysis. The five components of transportation have been developed using the literature review's experience with international turbine movement. Each component is expanded below to detail its attributes which are in each case analysed specifically for turbine transport.

- a) Infrastructure - refers to the physical country assets which make up the transport system used to move turbines. As turbines are imported, ports are the first point of arrival. Roads and railways make up the remainder of the infrastructure component.
- b) Equipment – refers to the machinery needed to support wind turbine logistics. This includes the cranes use to hoist and erect, the trucks used to transport, and the trailers which are needed to secure components during transportation.
- c) Operation and Maintenance (O&M) – this section refers to the execution of post construction O&M with respect to the sourcing, storage and transportation of spare parts and technical knowledge. The contracting of service agreements and their prior warranties are also included as part of O&M.
- d) Cost of Transportation – this is the price of the transportation service needed to move a turbine or an individual component from the point of production or import to the wind farm. The literature suggests cost is an important stand-alone aspect for the wind energy sector. The size, weight and fragility of turbine components results in a price of transport which is a large portion of capital value. Similarly the insurance costs incurred in moving wind turbines will be examined as part of the cost of transportation. Insurance is a vital part of moving capital equipment in any country. Turbine movement into South Africa is prone to risk as a new sector, insurance costs are thus an important focus area.

- e) Transport Planning – this component includes the planning and administrative capacity which accompanies the turbine transport process. Super route clearance, road and bridge design or redesign, police escorts, abnormal load permitting, and procurement programme design are all planning attributes included under the planning component.

Explicit consideration for each of these sections would have needed to be part of wind energy procurement planning as transport is a key part of wind farm development. Conclusions from each of these focus areas are discussed in this project's final sections.

Wind turbines are completely dependent on the existing and future transport systems for arrival to site and for post construction spare parts management. The perceived absence of these considerations is the gap in knowledge this research project will confront. The secondary research question will then seek to add depth to the relationship established for the South African wind energy sector. This question will ask how transport can unfold as a barrier to wind farm development. The term barrier in the context of this project refers to the capacity to slow down, prevent or cause cost escalation in turbine logistics projects. The resulting insight can then be used to make suggestions and recommendations for other emerging wind energy markets, especially in sub-Saharan Africa.

Following the discussion on transportation of turbines as a potential barrier to wind farm development, the possible relationship between turbine transportation and manufacturing location is discussed. This discussion aims to add depth to the transport as a barrier analysis through the discussion of a group of theories on the effect turbine transportation has had on the manufacturing structure of the global wind energy industry.

3.3 Conclusion

This research project will contribute toward the long term development of the wind energy sector in South Africa and other developing wind energy markets. Firstly, it will clarify the importance of transportation in the wind energy development chain. Secondly, it will provide an understanding of the transport challenges currently being faced in the South African wind energy procurement program. Once the present issues are understood, those which are found to impede timeous wind farm construction and future spare parts management can be rectified.

The next section is the methodology. It will provide details of the process followed to gather the data used to reach the project results and conclusions. It will also explain how the different groups of industry experts who contributed to this research came to be interviewed. The theoretical framework was written partly to form a base for the methodology such that any process presented in the methodology can be tied back to the research design in the theoretical framework.

4. Methodology

4.1 Methods of data collection

This thesis has adopted an exploratory research methodology where minimal prior expectations of the subject topic are held in approaching and conducting data gathering in an attempt to develop plausible explanations and conclusions for the research (Bowen, 2005). In line with the research questions which are qualitative in nature, the thesis methodology chosen is that of a qualitative analysis. An exploratory research method has therefore been adopted through a qualitative analysis to provide answers to the research questions which guide this thesis. In this way the gap in current understanding of how the transport and the wind sectors interact can be understood.

The aim of this thesis was to identify the effect which transportation of wind turbines has on the wind energy industry's development. The envisioned outcome was to strengthen the knowledge base and understanding of the transport sector. The potential of turbine movement to hamper industry development was also investigated and extended into an exploratory impact analysis for the different components of the wind turbine transportation sector.

The renewable energy sector in South Africa grew out of a government commitment to diversify the electricity generation sector and add wind energy and other renewables to the South African electricity generation grid. The wind energy industry has thus been awarded fifteen projects in the REIPPPP's first and second rounds, with an additional seven projects awarded in the third round. Prior to the awarding of these projects South Africa had a negligible amount of wind energy capacity of approximately 10.16 MW. Large scale wind energy development is thus new to South Africa.

Transport and Logistics is a major part of project delivery and makes up an estimated 20-25% proportion of turbine capital cost (Ozment & Tremwel, 2007). Knowledge and understanding of the role logistics will play in the wind energy industry is thus important to the wind sector as a whole. Round one of wind farm construction will generate learning curves which will improve the process of planning

for and transporting wind turbines in subsequent rounds. Interviews and comparable international literature review was therefore considered a suitable approach to gathering data as interviewees reflect on the first round of turbine transportation.

Interviews were held with professionals or representatives from organisations which have a defined interest in turbine transportation or are active in the sector. Four key groups were identified: Wind project developers and their engineering, procurement and construction (EPC) firms, original equipment manufacturers (OEMs), transport planners, and logistics service providers. Interviews were carried out in a semi – structured format to allow interviewees to not only divulge their own views, experiences and grievances but to also allow a common set of parameters and deductions to be discussed.

4.2 Participant selection and interview process

The research questions guided the interviewee selection process. Organisations active in the transportation of wind turbines were approached. These organisations for the purposes of this research project can be split into four groups. Two groups operate in the wind energy sector, whilst the other two operate in the transport sector.

As the first round of renewable energy projects are at an advanced stage of planning or construction, project developers from round one were the first set of interviewees to be approached.

Project developers typically receive technical, advisory and project management support from a contracted Engineering, Procurement and Construction (EPC) firm. Therefore these two groups were considered as one. In total, fourteen first round project developers and EPC firms were invited to participate in this research project. Six interviews from this group were ultimately conducted for this project.

Six Original Equipment Manufacturers (OEMs) were approached next. These six firms cover the entire South African market whereby all project developers are sourcing turbines from one of these six turbine makers. OEMs are responsible for

turbine transportation as the contract purchase price includes turbine logistics. Four of these companies responded to interview requests and each gave a detailed analysis of turbine movement for their South African projects. The other two OEMs did not agree to be interviewed.

Five transport planners were invited to participate in this turbine transport project. These included two from the private sector and three from the public sector. This covered the scope of those involved in transport planning. The public sector planners are active in the greater transport sector while the two private sector organisations have been involved in every turbine transport project in South Africa.

Logistics companies are the fourth group that was approached. Five firms were requested to participate and four responded positively. Two out of these four have a combined market share of just over 90%¹ of the turbine transportation sector in South Africa. They are able to hold this market share due to the specialised equipment they have acquired for their wind energy divisions.

Initial contact with the interviewees was made either via email or telephone. Of the thirty individuals approached, nineteen ultimately agreed to participate in this project resulting in a 63% response rate. After an introduction to the research and an explanation of the research objectives, the issue of ethics was discussed. The ethics discussion focused on confidentiality and ensured risk minimization for the interview participants. Interviews were conducted either at the Windaba 2013 conference or in privately scheduled meetings at the respective company offices. Where neither option was possible interviews were conducted over the phone, especially for those companies which did not have access to a Cape Town office.

Turbine transportation is a large cost factor in wind farm development. It is also a critical phase of the wind farm development process which can severely hamper or delay a project if not managed effectively. In this regard it is a competitive area for wind developers and more so for logistics firms who are selected using a competitive bid process. Interviewees were assured of confidentiality as cost management questions were included in the interview questions. Unattached nomenclature is used to achieve this confidentiality in the body of the thesis and in the endnotes

where a report on interview data is compiled. In total nineteen interviews and countless literature documents were consulted for this research.

The wind turbine transport sector is highly concentrated. As such, the scope of firms approached for interviews gave comprehensive industry coverage. The 63% response rate is considered strong enough to support the results. Interviews were between 30 minutes and 1^{1/2} hours long. The longer interviews had a larger unstructured component. A list of participating companies is provided in Appendix B.

4.3 Limitations to research approach

Three particular limitations to the approach adopted for this research project are acknowledged in this section. Firstly, South Africa has limited experience in the transport and logistics of wind turbine components. The first utility scale multi-turbine wind farms are currently under construction, therefore the thesis will have a limited scope to build on. It will also take a critical look forward into the operation of the projects once construction is complete. This future forecast is based on interviews with industry participants.

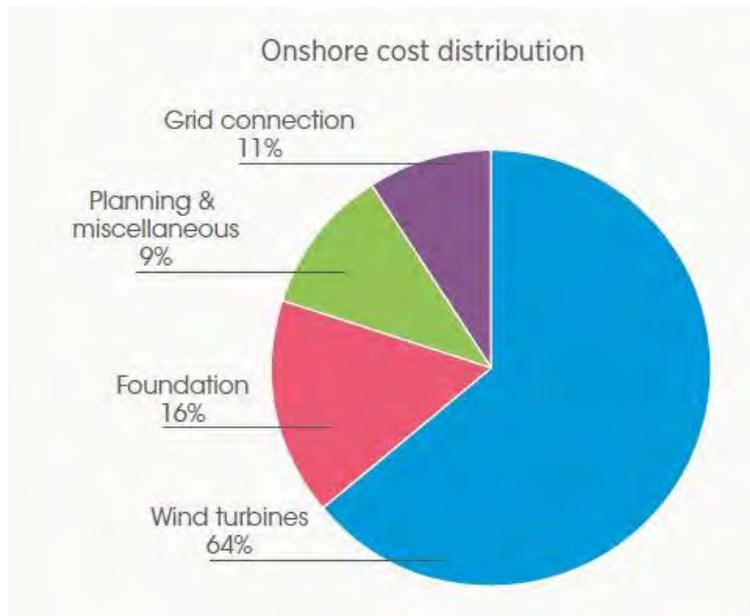
Secondly, the logistics industry in South Africa is fairly well developed. From a transport and logistics stand point this means capacity might exist for the needs of the wind energy industry to be absorbed and provided for by other already existing logistics sectors such as heavy engineering equipment and electricity generation and transmission. However, this would only be possible to a limited extent as the equipment used in wind turbine movement is wind specific. The geographical spread of wind farms and the sustained demand for heavy haulage mitigate this concern. Turbine movement projects are still unique transport projects which require specialisation of skills and equipment.

Thirdly, there is a risk that this logistics research is happening too soon in the life of turbine transport sector as not much has been learnt so far through lack of experience in a new industry. It was nevertheless concluded that what has been learnt so far can be used to build on for future research.

5. Analysis: Transporting wind turbines in South Africa

5.1 Introduction

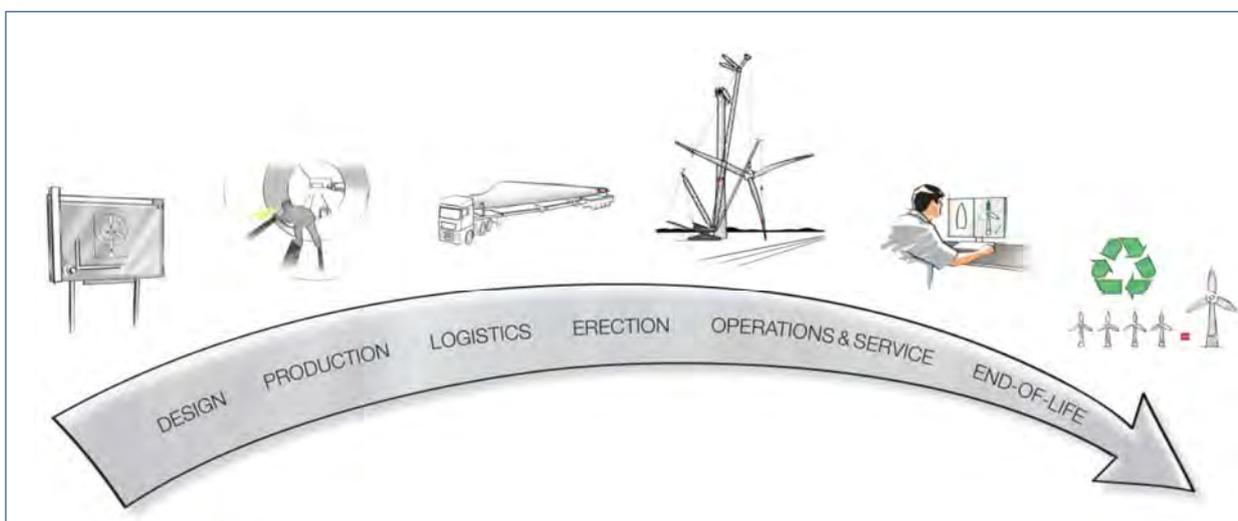
Transportation of wind turbines is an integral part of the wind energy development process. While it is no more important than any of the other stages of wind farm development, it is a critical part which can affect the on-time development of the project thus potentially invoking financial penalties for the developers and the contracted logistics firms². Logistics was cited by local developers and engineering, procurement and construction (EPC) firms as an area which can cause significant project delays if planning and equipment availability and capacity are not available on time³. Project delays in the context of the REIPPPP have grave consequences for IPPs, with penalties set out for those that fail to deliver projects in the stipulated time. Execution challenges in logistical deliveries were also cited as a key risk area, these are explained in more detail in the body of this project. Transportation and Logistics is an important capital cost component. International literature has listed this cost as approximately 20% of capital cost of a wind turbine (Ozment & Tremwel, 2007; Platzer, 2012); this should however not be confused with project cost as turbines make up slightly less than two-thirds of that total. IRENA has estimated that turbine capital costs amount to 64% of project costs as illustrated in Figure 5 below (IRENA, 2012). The IRENA figures are calculated as international averages, the exact South African figures would however be dependent on exchange rates as wind turbines are imported and paid for in dollars or euros.



Source: (IRENA, 2012)

Figure 5: Onshore cost distribution of wind farm development

Figure 6 goes on to illustrate the wind energy development process. The areas of transportation, erection and operation & maintenance (O&M) as shown below are the areas this thesis will focus on and analyse with respect to the research questions. It is important to note that logistics is a life time function. It will not end with the successful construction of the wind farm.



Source: (Beinke & Bodenstab, 2012)

Figure 6: The wind farm development process

Each scheduled and unscheduled maintenance incident could potentially require a logistics project which would require the recalling of much of the support equipment used in the construction phase. In the case of South Africa which is a small wind energy market as compared to the larger traditional Chinese, American and European markets, this equipment would have lower utilization rates and would often be rented and not owned thus leading to increased costs for short term use⁴.

Turbine logistics for the South African wind market begin when the components arrive at the country's ports. Currently turbines destined for erection in the Eastern Cape will arrive at Ngquru port and those destined for Western Cape wind farms will arrive at the Saldana Bay port. These are the best suited deep water ports currently capable of receiving the deep water cargo delivered by ships carrying wind turbines⁵. With two ports capable of receiving turbines, the transportation distance to wind farm sites which are located inland and far from these ports is a cost factor. If more of the countries' ports were to undergo capacity expansion the transport costs for inland wind farms could come down slightly. However transport cost variability with respect to distance is far less important than the quality of the wind resource at the wind farm site⁶. Wind farms with better wind resources would be able to easily shoulder the cost of longer transport distances since a wind farm's revenue is earned over 20 years whilst the largest transport costs occur initially during construction. The energy conversion output over a life time of turbine operation would cover the increased initial cost if availability is maximised. As a general rule, developers and EPC contractors agreed that the greater is the wind speed and capacity factor of a wind farm site, the greater cost and inconvenience they are prepared to shoulder to develop that site and transport turbines to the site⁷. Project feasibility becomes a factor for the wind sites where land slopes and ground conditions create practical feasibility challenges. One developer gave an example of a particular local wind farm development site where the slope of the access road was not taken into consideration at the planning stage, the tower and nacelle loads were then too heavy to haul up the access road using the contracted transport plan and equipment. A solution was found where more than one truck was used to haul the loads up the slope. The increased cost of this adjustment was not revealed⁸.

The literature review of this thesis described the history of turbine development and explained why turbine components have been increasing in size. Wind turbines are expected to operate with increased efficiency and produce more energy at sites with lower wind speeds due to the declining availability of prime sites⁹. As a general rule the larger are turbine components in dimension and weight, the more challenges will occur in transporting them to site. In South Africa all turbine transport occurs by road, as the rail road infrastructure is not yet widely developed in the provinces where wind farm development will be taking place, in addition unlike many of the traditional wind energy markets, South Africa does not have an extensive network of inland water ways thereby removing the potential of transport mode switching. The current future investment plans of the freight rail industry will maintain these patterns as port expansion and rail road expansion continues to be directed toward the growth of the current South African electricity generation industry which is dominated by coal.

5.2 The costs of turbine transportation

5.2.1 Introduction

Turbine transportation and logistics for a South African wind project typically begins at the Ngquru or Saldana ports of entry. From there, deck cranes mounted on cargo ships load awaiting trucks with blades, nacelles and tower sections before moving the components to storage bays or directly to wind farm locations on routes which have been adequately studied and prepared by a registered engineer in a route clearance process. At the moment South Africa does not charge an import tariff for wind turbine equipment, and will not in the future as localisation of turbine components is becoming mandatory in the bidding stages of the REIPPPP. Where locally produced components are available, it is almost certain that developers will select them for their projects as localisation is an increasingly important competitive area for the winning of supply bids from the department of energy¹⁰. Import tariffs will therefore be left out of this South African logistics discussion.

Insurance costs are incurred by all turbine logistics projects. This will be the first direct cost area to be explored in this project. Reference is made to information published by a major renewable energy project insurer. Total project transport cost taken as a proportion of turbine capital cost is also discussed in the body of this research project. As cost of transport is a key part of the transportation analysis it is discussed not just in this section, but throughout the project with application to other areas of analysis.

5.2.2 Insurance for the transportation process

The potential loss that can occur in moving large wind turbines through long transit has necessitated the growth of an insurance industry which supports the transit and operation of wind turbine components. Wind turbines are particularly high risk because of the size and weight of the different parts.

South Africa is a developing wind energy market, which has only recently awarded wind energy contracts which should take it past the 1 GW of capacity mark by the end of 2015. As such the industries which support the development of the wind sector are themselves in early development. Wind turbine logistics services are one example of such a developing sector. Here, a lack of local experience has been identified by participants as a current concern. The firms which have excelled in this area have used their links to their overseas parent companies that have had greater experience with turbine movement. Two firms have come to dominate the component transport market. Smaller firms with no turbine transportation experience have also been active in the local turbine logistics industry by winning small contracts.

While details of the number and scope of transit incidents uncovered in the interview process was limited by corporate nondisclosure policies, a summary released by the largest global wind and renewable energy insurer has noted that the number of incidents in the transit of turbines in South Africa has steadily increased in the short time that the sector has been active. The top reasons given for this are inadequate packaging of equipment¹¹, rough handling of components¹² which are often fragile especially in the case of the blades, and a skilled driver shortage¹³ (Pavey, 2012).

Original Equipment Manufacturers (OEMs) are ultimately responsible for the transport and logistics of wind turbines as turbine transportation is part of a standard purchase contract¹⁴. The execution of the logistics function is thereafter contracted out to service providers with the equipment to haul the loads to the wind farm site. At each level of implementation insurance is required to protect against loss from damage and potentially against delayed liquidity damages. For an incident causing a loss in the process of delivering a component e.g. if the component is damaged beyond use or needs repair, the developer will expect the EPC firm to look to the OEM which would seek recourse from the logistics contractors. If they are found liable they will need to compensate for incurred losses.

Turbine transportation contracts include delivery to site, crane rental and operation, and turbine installation. In South Africa few companies are able to offer the complete services needed to transport and install turbines. Thus the responsibilities can be contracted out to one or more firms.

5.2.3 Turbine transport cost in South Africa

Turbine transport is a competitive area for the different firms involved. Transport contracts are won on a competitive tender basis¹⁵ therefore access to detailed cost data for individual wind energy projects in South Africa was not readily accessible from the project developers. The logistics service companies also consider details of their service prices to be competitive data. However the lack of that data does not weaken the output of this thesis because each wind farm is different in location, distance and geography meaning their transport needs are not comparable at an individual level. This transport analysis is still applicable because it focuses on the logistics components of wind farm development which are shared by different wind farms. Infrastructure, transport planning regimes, industry equipment and labour are all shared components of the turbine movement process.

Data collected through the semi-structured interviews suggests the logistics and transport cost of moving wind turbines to wind farm development sites in South Africa is greater than the average cost of moving turbines in larger traditional markets¹⁶. Where the literature average was suggested to be 20% of turbine capital

costs, South African industry participants suggested a 5 – 10% premium above this. The first factor is the distance involved in importing by sea, where the distances to South Africa’s ports are greater than traditional wind energy markets which are mostly located in the Northern hemisphere. Other factors include administration and quality of infrastructure in South Africa, small volumes of turbine demand which accompany a small market, low transport mode switching capacity, and high insurance costs. Table 3 below summarises these factors using data gathered during interviews.

Table 3: Factors affecting transport costs in South Africa

Factor Driving Increased Transport Cost	Specific Challenges in South Africa	Transportation advantages for South Africa	Comments
Administration and quality of infrastructure in South Africa	Abnormal route clearance necessary, Crane and Truck driver skills limited, Transport department planning and administration inadequate.	Quality of infrastructure and roads in South Africa is significantly better than in other potential developing wind energy markets (Africa especially).	Better planning and accommodation of the wind energy sector is needed. Private sector innovation in dealing with administrative bottlenecks will also help the industry.
Small volumes of turbine demand	Small fragmented demand for turbines and spare parts.	If the local wind sector continues to grow, and if regional demand comes online, localisation and spare parts warehousing may begin to benefit from economies of scale.	Economies of scale in transporting and managing spare parts will not be reached for the smaller wind farms, especially since different OEMs are used. Often single or limited numbers of spare parts will be needed and individual transportation will be costly.
Low transport mode switching capacity	No inland water-ways. No distributed railroad capacity	Both turbine receiving ports are fairly well developed.	Some mode switching would be possible for internal tower transportation where port to port barge looks attractive
High insurance costs	New industry with limited skills capacity currently at the lower end of the learning curve.	Currently skills have been imported internally by firms in an effort to encourage skills transfer.	As learning curves take effect, insurance claims and incident frequency will fall in South Africa

Source (All Interviews)

5.2.4 Conclusion

Turbine transportation cost in South Africa is approximately 25 – 30% of turbine capital costs. It is slightly higher than in developed wind energy markets, where proximity to market and more developed heavy haulage transport systems limit this to approximately 20% of turbine capital cost. Similarly the cost of insurance for South African wind turbine movement is an area of concern for the industry as lack of skilled drivers and planners drive up project insurance costs. The risks which afflict the turbine transportation process would need to be mitigated to reduce insurance costs.

5.3 The role of planning

5.3.1 Introduction

The role of planning from both a project developer level and a government department level affects the efficiency and cost with which wind turbines can be transported on South African roads. Turbine component movement is resource intensive requiring road clearance and escort services. Delays inflicted upon other road and port users are also inevitable due to the dimensions on the components. Wind turbine movement is particularly high impact because of the frequency of component transportation. With other abnormal loads, the frequency of movement is limited, but for wind turbines each turbine requires eight or nine loads depending on the tower length. This must then be multiplied by the number of turbines. The average wind farm between round one and two of the REIPPPP has approximately 33 wind turbines, which would be 297 abnormal load trips¹⁷ for a single wind farm. Additionally because average wind farms size is growing the skilled worker and road planning bottlenecks explained here would only worsen with time unless the transport system is more accommodating to wind turbine transportation.

5.3.2 The provincial and municipal transport approval process

In order to transport turbines to the wind farm construction sites, an abnormal load approval permit as well as an abnormal load escort is required by law for weights and dimensions which exceed those stipulated in the National Road Traffic Regulations (CSIR, 2000). In the Eastern Cape the process is jointly administered by both the provincial and municipal departments of transport while in the Western Cape the provincial government is the sole transport authority. An abnormal load is a transport load that cannot be dismantled into more manageable parts without substantial expense and risk, if movement of such a load is in the nation's economic interest an abnormal load permit and escort can be granted by the provincial government (Department of Transport, 2009). Wind turbines components due to their weight and dimensions fall within the definition of abnormal loads, where a weight exceeding 56 tonnes, a length exceeding 22 meters or a height exceeding 4.3

meters are all classified as abnormal loads on South African roads. The logistics function is usually included as part of the purchase package made between the project developer (IPP) and the OEM, the EPC may take responsibility for logistics depending on the details of individual contracts which will differ from project to project. Route clearance firms then assist the contracted logistics company to deliver the components by preparing the route to be travelled. Structural and safety investigations and possibly interventions are made along the route.

EPC firms and IPPs thus have a direct interest in the logistics function through their OEMs and their chosen subcontractors. The logistics companies whom were interviewed for this project were found to have the capacity to haul wind turbine equipment from the ports of entry to a variety of inland destinations. This capacity has been developed from past experience with other transport projects as all logistics firms were found to have experience with components of much greater size and weight than wind turbines. Some of these companies are international concerns who would have direct experience in wind turbine transportation through their divisions in other regions of the world, especially Europe and the USA. This experience is then claimed as local experience through internal company skills transfer. As such, a small number of logistics firms have dominated the sector.

5.3.3 The routes used to transport abnormal wind equipment

A super route is a defined critical transport route used by the logistics industry to transport recurring super loads and abnormal loads over long road distances. Such a route would have recently verified geometrics and bridge capacity measurements in order to support weights, lengths, and heights of abnormal loads (Nordengen et al, 2002).

The wind farm projects in South Africa are located in the Eastern Cape and the Western Cape provinces. The logistics working group at SAWEA have identified the N2 in the Eastern Cape and the N7 in the Western Cape as routes which will be used extensively in the delivery of turbines in each respective province¹⁸.

Super route planning is identified by transport planners and logistics industry participants as a way to reduce the risks involved with turbine transportation. The ability of the chosen routes to support freight mass and provide sufficient space for components to manoeuvre turns and obstacles would contribute to the on-time and incident-free delivery of components during construction and during operation and maintenance.

Interview participants raised two critical barriers to the transportation of wind turbines on South African roads during discussion of the primary routes to be used for abnormal load transportation. These are disruptions to traffic flow¹⁹ and the staffing capacity²⁰ within provincial transport departments.

With respect to the first, traffic disruptions are a key concern for the development of wind farms in South Africa. The wind energy industry needs to share the roads with a multitude of other users and civilians are disposed to complain if undue delays are experienced for any reason let alone due to wind turbines. Recent unrelated policy decisions have put significant strain on SANRAL's public image so further strain through traffic disruptions or potential accidents is unwelcome. Additionally if specific users are inconvenienced to the point where business losses are incurred a legitimate legal claim can be lodged against SANRAL. Fruit farmers for example whom have a limited time to deliver their produce would be severely inconvenienced by the delays and road closures which occur during turbine transportation²¹.

Secondly the capacity of traffic departments to staff the abnormal load application process and the escort process with appropriate numbers of skilled staff will be a challenge which the wind energy industry can attempt to counter with long term planning and constant dialogue with traffic departments, however the road agency and the traffic departments are unlikely to give preference to assisting one particular road using industry over all others who make use of the road infrastructure²². If a logistics load qualifies as an abnormal load, according to the National Road Traffic Regulations, an escort is required to ensure its safe travel on public roads. Training of escort traffic staff by the transport department takes approximately a year and budget approval for the costs of escort projects takes an additional year. Thus two years in total are required to allow the traffic departments to prepare themselves to assist the logistics process. Each wind turbine requires multiple abnormal loads to

reach its destination, with additional abnormal loads required for the foundation building of a turbine and the support equipment needed to erect and later maintain each wind turbine.

The provincial traffic department is an important partner to the process of transporting wind turbines. Unfortunately they are also a bottleneck to the transportation of high numbers of turbines through budgetary and staff limitations. The traffic officers themselves are required to operate within a distance budget. Once that budget (i.e. 3000 km per month) is reached, additional input costs and depreciation borne by the department is then deducted from the employee wages, in this case, from the abnormal load escort traffic officer. This is the case in both the EC and the WC. This scenario creates a logistics barrier which is particularly difficult to fix because of diverging interests. It is important to note that other types of abnormal loads still require access to South Africa's roads and wind turbines are not prioritised in any special way since other loads can also argue their broad economic development mandate. This means the normal demands on the services of the transport department are multiplied without a corresponding increase in capacity. No planning or budgetary allocation was made at provincial transport planning level for the high demand of support services that the wind farm development process would bring²³.

5.3.4 Turbine transport plans and industry confidentiality

One of the major challenges encountered in writing this thesis was the secretive nature of the wind energy industry. Gathering information on the cost and difficulties involved with turbine transportation proved to be a guarded area as logistics price and fleet capacity is a key competitive segment of the wind farm development process. The time taken to convince industry participants to share information and the limited information that sometimes resulted from that long process are testament to the challenges that any attempt to address the logistics challenge through planning and co-operation will face. Consequences of poor planning inconvenience each wind farm in different ways. Several wind farms have already experienced challenges in the movement of their components and this is likely to worsen over

time. Towards the end of wind farm construction, project delays which then encroach into delay penalties will inevitably result.

When it comes to transport planning for wind energy, co-operation is critical. Country infrastructure such as ports, roads and customs services is shared. If the transport planning is not co-ordinated, unnecessary pressure on infrastructure and services will result. This will lead to project delays for the wind developers if unplanned transport projects clash. Infrastructure and public comfort and safety would additionally be placed under increased pressure.

The negative effects of the uncoordinated transport activities of the wind energy industry in South Africa are a challenge for the present and the future. For the moment eight wind farms with a total capacity of 634 MW are set for construction in 2013 and 2014, the wind industry as a body continues to lobby for additional MW to be allocated to it by the Department of Energy in future energy rounds, this increase in capacity allocation is pursued against a status quo of secrecy regardless of the consolidation that the industry has seen with each bidding round. The logistics pressure points such as ports, critical routes and escort staffing are as yet not critical barriers because the industry is relatively small. If it grows, which it will as turbines come online for operation and maintenance while the goal of increased capacity allocation is pursued towards 2030, logistics bottle necks will play an increasingly important role in retarding construction and performance of wind farms²⁴.

The interviews conducted with firms active in transport planning and implementation suggested the projects currently under construction will suffer from transport and logistics induced delays because of lack of capacity in the provincial departments and more so a lack of coordinated planning for the transport and logistics needs of the industry²⁵. Supporting equipment, namely cranes, trucks and trailers will also have an effect on the delivery of turbines to wind farms. These particular issues will be explored further in subsequent sections of the analysis.

5.3.5 Conclusion

Transport planning and coordination in the wind energy industry has taken place only to a limited extent. This shows that transport planning has been a gap in the overall planning for the wind energy development process in South Africa. The resulting delays to road users and project developers are undesirable and could be planned out of the system if sufficient willingness and cooperation is achieved in the subsequent phases of wind farm construction.

5.4 The equipment used in turbine logistics

5.4.1 Introduction

In order to facilitate the movement of wind turbines, support equipment is required to safely transport and erect turbine components. Deck cranes are cranes which are attached to cargo ships and are used by ships delivering turbines to South Africa; these ships are required to bring their own on-board cranes. Land based cranes are not readily available and are much more expensive than on-ship crainage²⁶.

Other equipment needed for turbine logistics includes trucks, specialised trailers and heavy lift cranes. Haulage trucks are used extensively in the logistics industry, with the logistics industry having gained operational experience involving haulage of weights greater than those of turbine components²⁷.

5.4.2 Trailer availability and registration

Multi axle extendable trailers are used to transport abnormal loads of turbine blades and tower sections. These trailers are dedicated pieces of equipment which are specifically used to transport wind turbine components. These trailers were imported into the country for the development of the first round of wind energy projects. Two specific problems are faced with the use of trailers. Firstly, a risk of low utilisation creates a disincentive for investment in extendable trailers²⁸. The local wind industry is still relatively small and the use of this dedicated equipment is limited to the

demand coming out of the sector. Therefore, uncertain long term prospects such as the potential downward revision of the wind energy allocation in the Updated IRP (Department of Energy, 2013) create uncertainty as to the potential payoff of long-term investment in dedicated capital equipment. Similarly, the major demand for the trailers is concentrated in the pre-construction transportation period which lasts up to five months with reduced use required thereafter in spare part transportation. This disincentive leads to a shortage which places a limit on the speed with which multiple blade and tower consignments can be delivered across the wind energy sector. Tight scheduling and delays for turbine transportation have been the result. The low number of trailers in South Africa will be one of the factors which lead to project delays in completing first round projects. Project delays can then lead to the imposition of delay penalties on logistics firms who must make firm commitments of delivery dates to win service contracts.

The second specific problem can broadly be described as the regulation of use and registration of extendable trailers. Extendable trailers are currently forbidden from operating at night, on weekends and on public holidays. This imposes an utilisation limit on the trailers, and an increase in the time needed for the delivery of a consignment of components. This follows the difficulty faced by logistics firms in registering their trailers with the Department of Transport. The lead times required to complete this registration process have frustrated several participants in the industry and continue to do so, while unintentionally discouraging permanent investment in trailers²⁹. Small to medium sized logistics companies have opted not to invest in extendible axle trailers because larger logistics multinationals are able to import this equipment from their parent logistics firms which operate in larger currently depressed markets, and bring them into the country temporarily through three month operating permits thereby crowding smaller operators out of the industry. All this can be done without needing to make long term investment decisions. The transport industry is thus missing an opportunity to build a local trailer fleet. If the process to register and operate an extendable trailer is made more accessible, the South African logistics industry may be able to build up a larger total fleet which would be permanently located in South Africa³⁰.

On the other hand however, the regulation of trailer use should also be considered in the context of the regulating body which would be one of either the Western or

Eastern Cape provincial Departments of Transport. If trailer use and abnormal load transportation is tailored to accommodate the needs of the wind energy industry, a disproportionate amount of manpower and traffic resources will also need to be allocated to this one specific sector. If abnormal loads are to be transported after hours and on weekends, traffic officers will also need to escort the loads, and labour law would require that they are paid overtime and possibly qualified for additional employment benefits. Their monthly distance allocations would also be consumed assisting one specific industry instead of the broader abnormal load transportation sector which also demands the same services. These adjustments would put pressure on already squeezed provincial traffic budgets.

5.4.3 Crane availability

On the wind farm site sufficient crainage capacity is needed to unload the delivery trucks and place the components on a storage area. There after the hub, blades and nacelle all need to be raised using a heavy lift crane to the height of the tower and attached during erection and installation.

Currently there is a shortage of crane capacity in South Africa; the demand for heavy lift cranes far exceeds the supply. This shortage is seen at the point of turbine erection when nacelles and blade sets need to be lifted. Cranes capable of steadily and safely lifting blade sets (which weigh 36 tonnes when adjoined to the hub) and nacelles (which weigh 70 – 85 tonnes) are a severe bottle neck for the wind energy sector. The dates on which wind farms are contracted to begin operation will likely be delayed due to the demand for crainage outstripping supply³¹. This will have contractual consequences and penalties for project development companies.

The shortage of heavy lift cranes is a complex one to solve. The demand for heavy lift services by the wind energy industry is highest during the construction and installation phase of wind farm development. There after utilization rates drastically decline to levels needed during operation and maintenance. As such, investing in crane capacity is constantly threatened by the risk of under-utilisation. At the same time South Africa does have a fleet of cranes and much of the heavy lift equipment is fully utilised in Eskom's Medupi and Kusile power station projects. Medupi is a

particular problem because a full fleet of cranes is utilised there³². The completion of Medupi has been delayed numerous times and a deadline of July 2012 has now been adjusted to 2014.

Crane and trailer equipment is often committed against an uncertain availability in the course of competition for logistics contracts. Equipment currently in use in other contracts, committed to other projects with very tight time schedules, or not yet acquired, is used to bid for transport contracts in the uncertain assumption that it will eventually be available by the time wind farm work is due³³. Temporarily available equipment creates availability uncertainty in a similar fashion.

An analysis of the equipment used in turbine transportation and logistics thus suggests that delays are set to affect the wind farm development stage of the REIPPPP, and solving the equipment bottlenecks and administrative problems is not an easily accomplished task. Much of the same equipment will also be needed in the operation and maintenance stage albeit with much lower utilization levels.

5.5 Logistics of turbine components during Operation and Maintenance

5.5.1 Introduction

Wind turbine transportation and logistics is an on-going process for a wind farm development even after the construction stage is complete as spare parts and maintenance activities will require the use of support equipment, and spare parts themselves will require abnormal load permits to travel to the wind farm if they are not stored on site. The wind energy industry in South Africa has focused on the winning of contracts at every stage, with limited long term operational planning³⁴. Exploratory discussion with industry players revealed that planning and preparation for the operation and maintenance (O&M) stage has been minimal with most having taken a future learning curve approach to the O&M stage, especially the post warranty period where the most risk will arise. This area is seen by several interviewees as a medium to long term challenge that could severely undermine the

operation of the South African wind energy industry, especially with the current level of planning.

5.5.2 Logistics during Operation and Maintenance in South Africa

The relationship between transport and wind energy development extends beyond the construction phase of the wind farm. During the operation and maintenance (O&M) stage logistics management of spare parts ensures that availability and operational revenue is maximised. A wind farm earns revenue by supplying electric power to the electricity off-taker as outlined in the power purchase agreement. The off-taker, who in the South African context is currently Eskom, would be required to buy all of the electricity supplied.

There is a strong incentive to maximize the availability of the individual power producing units in the wind farm. Logistics can affect O&M of turbines and thus revenue of the wind project in several ways. Firstly, the availability and capacity of support equipment such as cranes and transport trailers can cause delay in the maintenance or replacement of spare parts that need crane support such as gearboxes and generators or trailer support such as replacement blades. Crane availability is a significant concern here, more so for small wind farms located in remote areas. Replacement of any major wind turbine component will require the use of a crane. If cranes are unavailable, that translates to a direct unavailability of the wind turbine, which will be time lost for revenue generation.

Delays in repair and maintenance of wind turbines will affect the current South African wind energy sector more acutely than other larger wind industries through the balance sheet and the individual projects financial performance. Project finance charges are generally higher and direct financial incentives absent in South Africa as compared to other emerging or established wind energy markets. Project development in South Africa is financed using private funding from commercial banks and local development finance institutions. The interest rate charges are close to the prevalent market rates of 11 – 14%. This is unlike other emerging wind energy markets such as Brazil where preferential financing is available at lower interest rates and additional tax and depreciation incentives are available for renewable

energy projects. Interest rates as low as 0.9% for wind farm development are available in Brazil (Rennkamp & Westin, 2013). In the American wind energy markets, incentives are available which cheapen the long term cost of wind energy development. The production tax credit is available from the federal government and additional benefits in the form of subsidies and allowances are available from state governments such as those in Texas and Iowa (Governors' Wind Energy Coalition, 2013). Therefore because of high initial finance charges, delays in the return to service of a wind turbine in South Africa would have an enhanced effect on future investment performance.

5.5.3 Transporting spare parts for small wind farms

The size of wind farms in South Africa with respect to logistics and O&M can be understood via the application of economic principles. Larger wind farms are cheaper to operate firstly because fixed expenses can be spread over a greater number of turbines (Houston, 2013); and secondly because utilisation of equipment and planning of maintenance can be carried out more effectively with economies of scale. Probability assumptions for failure and incidental costs can similarly be applied to a larger number of turbines. Logistics is not the only factor driving cost efficiency, all operational management factors would have the same effect, however this thesis argues that the effect of logistics would be significant in the local market given the current relationship between turbine transportation and wind farm development which will not be as smooth as was assumed in the planning stage of project development³⁵.

In the medium to long term period of wind turbine operation, profitability and turbine availability vary due to the quality of O&M management. There has however been limited research into the operation of multi MW machines. Most turbines with capacities of greater than 1 MW were introduced from 2005 onwards so do not yet have a lifetime track record. Lindqvist & Lundin (2010) suggests that 60-80 wind turbines of the same type are needed for spare part supply and storage to be cost efficient. This would partly explain the trend to larger wind farms in South Africa, although only three projects from round one and two approach that number.

Cookhouse wind farm has 66 turbines, Jeffrey's bay wind farm has 60 turbines and Amakhala Emoyeni has 58 turbines.

For an emerging wind energy market like South Africa there is no long term data as to how wind turbines perform over their operation lifetime. Indeed even in developed wind energy markets, because the turbines installed today are newly designed multi megawatt models the experience in operating them is limited³⁶. Developed markets do however have the advantage that they have a large labor force with extensive levels of wind turbine operation experience as well as high levels of technological advancement.

The first and second round of the REIPPPP has approved 15 small to medium size wind farms which negotiated their own supplier and maintenance contracts.

Economies of scale in the operation of the majority of these wind farms, especially the smaller round one projects, will be absent³⁷. The maximum size of wind farms allowed in the REIPPPP is 140 MW.

Many of the initial developers thought they would implement phased development with initially small bid wins combining with bid success in latter rounds, and thereby creating larger and more efficient wind operations, however price competition from local competitors and large international renewable energy investors prevented this strategy from working.

5.5.4 Warranties and contracting of Operation and Maintenance

During the initial years of operation, the original equipment manufacturer (OEM) is normally contracted to carry out operation and maintenance (O&M). The exact number of years this arrangement continues is dependent on the individual contract details negotiated for each specific project. This warranty period can range between 5 to 10 years during which the OEM maintains turbines and carries out spare parts management. Typically a purchase of a set of wind turbines is accompanied by a consignment of spare parts.

The after-warranty period uncovered a number of concerns during the data gathering process. During the after-warranty period development companies must either renew O&M contracts or seek alternative models of O&M such as contracting with specialist service providers or managing assets in-house. Warranty renewal is prohibitively expensive so is not often a favoured choice³⁸.

In South Africa the after-warranty period will expose the wind industry to a number of risks which were not considered in the planning and development stage.

Transporting equipment and spare parts will still be necessary and demand for O&M will likely follow a “bathtub” curve and begin to rise at about the same time turbine warranties come to an end. A bathtub curve illustrates the probability of failure against the age of electrical equipment (Lindqvist & Lundin, 2010), starting off at a high probability, falling as new turbines operate in their first few warranty covered years of operation, and then rising as equipment ages and goes off warranty while key components begin to demand maintenance.

The South African wind energy industry uses the same technology as the rest of the global industry and as such competes globally for skills and investment. One of the reasons the South African industry has seen such keen interest from global companies is the recession currently affecting the traditional wind energy markets³⁹. The EU has been going through some economic turmoil and the renewable energy sector in that region, which is a receiver of substantial state support, has suffered from declining demand, overcapacity and declining state support. Should the economies of the EU recover the skills and some of the equipment that seems to be available at the moment for developing wind energy markets will mostly return to the more profitable, subsidy paying traditional markets of the EU⁴⁰. This will not happen immediately, meaning the operation and maintenance stages of the local wind energy industry would face that challenge. The solution would be to develop a local operation and maintenance industry, but the current small size of the local industry would lead to either declining turbine performance or rapidly rising O&M costs⁴¹.

Turbines, turbine components, and maintenance services are paid for in foreign currency, either US dollars or Euros as the wind energy industry is globalised with all productive capacity currently located outside South Africa. Once South African wind

farms are off warranty, spare part purchase and transportation will also need to be paid for in foreign currency. In this way, the future strength of the Rand is another key concern that was highlighted during the data gathering process⁴². A weak local currency boosts exports and makes imports more expensive. The wind energy industry is import driven with all components currently produced in developed wind energy markets, thereby making essential services and investment decisions calculated today as affordable potentially more expensive by the time warranties end, even if attempts are made to factor in exchange rate fluctuations, predicting these correctly is challenging.

A detailed explanation of the mechanisms which will drive the rand's fluctuation and long term outlook would be outside of the scope of this transport and logistics thesis. However factors such as South Africa's reliance on foreign investment flows and a growing current account deficit place downward pressure on the value of the rand. Long term exchange rates forecasts make use of inflation differentials to understand the direction in which a currencies relative value will move (de Bruyn et al, 2013). Between two currencies, the nation with the higher inflation rate would see its currency lose value by the differential as compared to the country with a lower inflation rate. South Africa has a higher inflation rate than its major trading partners which includes the EU where wind energy equipment and services are generally supplied from.

5.5.5 Conclusion

Operation and maintenance planning and capacity building has been limited in the local wind energy sector. This should not be the case as 20 - 30% of a wind project's total life time value lies in the O&M stage (Lema et al, 2011). The period after warranties end will expose wind energy projects to a spectrum of O&M challenges including new contracting, exchange rates risks and spare part sourcing. Relative market attractiveness will also reduce multinational interest in the local market if the traditional larger markets recover.

Wind farms can benefit from economies of scale in spare parts management. The optimum size of wind farms is approximately 60 – 80 multi MW turbines. Small wind

farms in the REIPPPP whose parent companies have not managed to win subsequent supply bids will thus suffer from higher spare part management costs in the O&M stage.

5.6. Turbine transportation as a barrier to wind farm development in South Africa

5.6.1 Introduction

The secondary research question investigates how turbine transportation unfolds as a barrier to the development of wind farms in South Africa.

This section aims to answer the guiding research question with respect to the barrier that transportation of turbines could inflict on the development of wind farms in South Africa. The guiding research question seeks to establish the relationship between turbine movement and wind farm development by looking at the five main derived components of turbine transportation. These are represented in Figure 4 in the theoretical framework.

The data from the interview responses gave answers of a varying level of severity for this question. This variance is explained by the differing levels of involvement in the turbine movement process. Four groups of professionals were interviewed for this research project as detailed in the methodology: Planners and policy makers, wind project developers and their project contract firms (EPC firms), Logistics providers and original equipment manufacturers (OEMs).

5.6.2 Barriers to wind turbine transportation in South Africa

Interviewed participants responded to questions around this topic by discussing their own experiences with respect to those challenges faced in moving turbines which could qualify as barriers. As the analysis in this project aims to provide conclusions from an industry perspective, individual experiences were collated, and then focused on shared outlooks.

The table below highlights the areas viewed as barriers by interview participants. The industry wide effect is then summarised and analysed as low, medium or high depending on interview responses. This information is collated in the table below in order to directly analyse transportation as a barrier.

Table 4: Barriers to turbine component logistics in South Africa

Barrier	Effect on wind farm development	Relative analysis of barrier strength
Quality of physical infrastructure	The quality of roads, bridges and ports is fairly good for a developing country. However where there are weaknesses such as neglected bridges along transport super-routes. The risk of damage to cargo and the increased cost of route clearance across the industry contributes to overall industry logistics cost. ⁴³	Medium: South Africa's two wind turbine receiving ports are in good condition. Similarly the greater portions of roads are maintained in a workable condition. Rail transportation is currently not viable.
Congestion in ports, roads	Congestion leads to component delays and possibly accidents through rushed load and unload timelines. The issue of delays might have contractual consequences for the project developers. ⁴⁴	High: the design of the renewable energy procurement program leads to multiple turbine imports arriving at the same time. This creates undue pressure on infrastructure.
Abnormal load escort process	The legislative framework surrounding the movement of abnormal loads is a major barrier to timeous delivery of turbines. The restrictions on transport times as well as the absence of enough escort vehicles and staff makes this a bottleneck for the wind farm development process. ⁴⁵	High: demurrage is the largest cost which can accrue to a logistics provider. Furthermore as project fail to stay on schedule, as some already have, penalties for delayed construction will accrue.
Equipment shortages	Crainage which is unavailable to lift or unable to safety lift the nacelles, blades and hubs to tower tops is a barrier to wind farm development. Similarly trailer shortages translate to direct delays because turbine components utilise specialised equipment. ⁴⁶	High: There is a shortage of both trailers and cranes in South Africa's wind development process. This is due to the programme procurement design, equipment regulation, poor planning and competition for equipment.
Shortage of skilled drivers and crane operators	There is a shortage of skills needed to deliver the different stages of the logistics process. Incidents of damage, accidents and rising insurance premiums within the turbine component logistics process in South Africa is evidence of this.	High: rising insurance premiums raise the cost of turbine transportation. Where incidents do occur, project timelines would suffer. In the event of a major accident, the cooperation from the authorities and the public needed to improve the transport process would be harder to achieve.
Post construction planning	The operation & maintenance stage of wind farm development contains the greater portion of project life time value. Planning for the logistics needs of spare parts after warranties end has been limited. ⁴⁷	High: post construction planning has taken a back foot as compared to securing project contracts this has led to an uncertain future once operation is underway.
Post warranty component finance	Wind turbines, wind turbine components and wind farm service contracts are procured on the international market in either US dollars or Euros. The logistics cost of spare parts and service contracts are thus vulnerable to exchange rate fluctuation if the local currency deteriorates in the medium to long term. ⁴⁸	High: South Africa needs to develop internal capacity to service wind farms and manufacture turbines and their components. So far localisation has tried to encourage the latter. Other fundamentals such as technology transfer and increased market size would also be needed.

Source: (All interviews)

The table above gives a summation of transport challenges faced in South Africa. Other new wind energy markets, especially those with less developed transport infrastructure are susceptible to face challenges greater than those faced in South Africa. For example, Ashegoda wind energy farm in Ethiopia suffered delayed commercial operation date (COD) by a full two years due to logistics challenges. The 84 turbine wind park at Ashegoda in Ethiopia's northern region of Tigray was initiated in 2009 and was initially scheduled to be completed in 2011 but this was delayed to 2013 due to logistics challenges (Electric Light & Power, 2013). The delays experienced by Ashegoda show that the duration of logistics delays vary widely depending on the constraints in a particular market and the wind farm's particular project site.

5.6.4 Conclusion

Three main themes on how transportation can act as a barrier to wind farm development came out of the data analysis process.

Firstly, inefficient transport planning and capacity limitations in terms of skills, equipment and regulation lead to delays in the delivery of turbines. Wind farm projects are struggling to achieve delivery deadlines. This not only adds costs from possible project delays, but also adds storage costs to the logistics process as components need to be kept at port storage areas while they await movement. Delays additionally lead to under-utilisation of support equipment.

Secondly, transportation acts as a barrier to wind farm development when accident damage occurs while transporting turbine components. A shortage of skilled drivers and crane operators is mainly responsible for this. Pressure on infrastructure through congestion also leads to increased incidents of component damage.

Thirdly, the increasing cost which turbine transportation inflicts on the wind farm development process is a barrier to wind energy development, especially since turbine component transportation is already a large portion of turbine capital value. Wind energy development is still a relatively new process to the South African. Therefore inadequate skills of equipment operators and inadequate transport planning and cooperation from the transport authorities and project developers will have to be addressed in order to accommodate the future demand for turbine movement as the wind energy industry grows.

6. Key findings from turbine transportation analysis

6.1 Introduction

Chapter 6 will present a discussion of the key findings which arose from the data gathering process. The five components of the transport sector which interact with the process of turbine transportation are appraised based on the key interview and research outcomes. These components originate from the theoretical framework and the results analysis.

6.1.1 Key findings: Transport costs

The cost of turbine transportation has been determined to be approximately 20% of the turbine capital cost (Ozment & Tremwel, 2007; Mittal, 2010; Patel, 2010). This is a finding based on research which has focused on the global wind energy industry. Interview respondents accepted this global estimate, but strongly suggested a 5 – 10% premium above this for turbine transportation in South Africa. This research project considered the reasoning for this premium and found it valid. Unlike larger wind energy markets in the developed countries, South Africa does not have an extensive network of inland water ways. In addition the railroad system is not well developed in the provinces where wind farms will be located. The space for transport mode switching in South Africa is thus generally absent. Likewise, a route clearance certificate is needed in South Africa which is not the case for developed transport systems. In this route clearance process, the route to be travelled by the turbine component must be checked and signed off by a registered engineer. Route planning is typically a transport department function. Lastly, insurance for the transportation of wind turbine components adds to the overall costs of logistics projects in South Africa. While all capital projects require transit insurance, in South Africa due to the high number of wind turbine transit incidents, the lack of skilled drivers and machine operators and the poor packaging of turbine components the cost of insurance for the transit of wind turbines has risen.

6.1.2 Key findings: Transport planning

Transport planning for wind turbine transportation was a second focus area in this thesis. The key finding here was the lack of comprehensive industry planning where the private sector and the public sector did not cooperate as closely as they could have. This has led to delays in turbine transportation and congestion at key points of shared infrastructure. The transportation of wind turbines has a particularly high impact on the transport system because of the frequency of transportation. Due to this frequency the disruption of normal traffic flow, which is unwanted by the road management agencies, is an inevitably part of the turbine transportation process. Similarly the frequency of transportation has revealed a shortage of staff and resources in provincial and municipal transport departments. Transport authorities are required to train and supply traffic escort officers when abnormal loads are in transit, however, their capacity to supply traffic escorts is limited by a lack of staff and a lack of resources. This was found to be a severe challenge for the transporting of wind turbine components.

In order to solve the problems of inadequate planning and allocation of resources to the process of wind turbine transportation, lobbying for relaxation of transport restrictions and allocation of extra resources was suggested. However, transport regulations and municipal budget allocations for staff training are unlikely to be changed to accommodate one industry. Innovation which works around the existing transport framework will be needed. The wind energy industry through the industry body SAWEA or through another private planning agency will need to be given the opportunity to provide better coordination and cooperation for the transportation of wind turbines.

6.1.3 Key findings: Supporting equipment

Heavy lift cranes and extendable blade trailers are needed to construct and erect wind turbines. The supply and use of this equipment was found to be a bottle neck for the wind farm development process in South Africa.

Low utilization rates of extendable blade trailers after transportation of components from ports is complete creates a disincentive for investing in these trailers.

Furthermore, logistics companies have struggled to register their trailers with the Department of Transport. Unregistered trailers are not supposed to operate on the country's roads. Bureaucracy and unpreparedness on the part of the Department of Transport was given as the reason of this difficulty. Overall industry participants suggested there was a national shortage of extendible axle trailers. This shortage will affect the delivery time lines of turbine components to project sites.

Key findings for crane capacity point to a national shortage in adequate numbers of cranes. The majority of the countries heavy lift crainage is currently utilised in the construction of Eskom's two large coal fired power plants. Competition from such large capital projects which offer longer term contracts is a challenge for the wind energy industry.

It also emerged, that both cranes and trailers are often committed against an uncertain availability. Equipment which is unavailable or tightly committed is used to bid for transport contracts. An analysis of the equipment used in turbine transportation and logistics therefore suggests that project delays are set to affect the development of wind farms in South Africa.

6.1.4 Key findings: Operation and maintenance

Transportation and logistics of wind turbine components is an on-going part of a wind farm's life. It is needed during construction but also during the operation and maintenance (O&M) stage, albeit at much reduced frequency. Interviews revealed that the focus of wind sector participants has been on the winning of supply and service contracts, this has resulted in limited long term planning for the operation and maintenance stage of the wind farms' operation.

The lack of long term investment in vital equipment as outlined in section 6.3 lead to an important finding for the O&M stage. The long term availability of cranes and trailers is not guaranteed for the South African wind industry. When post construction O&M is needed this will have the potential to delay the maintenance and return to service of generating units. Small distant wind farms are especially vulnerable to the unavailability of cranes. Each major incident of maintenance or component

replacement will require the use of supporting equipment. If this equipment is not available the wind turbine will sit idle until equipment can be sourced.

Interviewees also revealed that the O&M stage may be exposed to competition from established wind energy markets. At the moment, macro-economic challenges in the EU have held up demand for wind energy; when these markets recover much of the skill and equipment available in South Africa may return to larger more profitable markets. By that stage the warranty period during which the OEM is responsible for maintenance may be over. If the local currency has depreciated, the cost of importing services and spare parts would have risen. The future strength of the Rand is thus another key concern that was highlighted during the data gathering process.

6.1.5 Key findings: Infrastructure

Wind turbine transportation in South Africa relies on the road network. Interviewees were complementary of the quality of the road network and its ability to carry turbine components. The road network's functionality is closely related to the availability of extendable axle trailers. The correct use of trailers is able to limit the damage done to the road surface, as weight can be distributed depending on axle configurations.

The route clearance process however, occasionally uncovered the need for structural support on bridge or particular sections of roads. When this is needed the cost of the logistics project increases significantly. Besides poor maintenance and out-dated infrastructure, the leading cause of route damage is cost cutting within the logistics industry itself. In such instances abnormal loads are transported without the correct safety and preparation, leading to damaged roads and bridges⁴⁹.

6.2 Primary research question

How does the transport sector relate to the wind energy sector in South Africa?

The wind energy sector relies on the transport sector to deliver turbines to wind farm locations. Turbine component delivery is critical not only during construction but also during the operation and maintenance stage of a wind farm's life.

Without a well-developed transport sector which has adequate skills and equipment, the development of wind farms would not be possible. This is especially true where the wind farm locations are located in areas which are far from ports and manufacturing facilities. When planning for wind energy adoption, it is important to confirm that the wind turbine components are indeed transportable. In South Africa the logistics industry was already well developed by the time wind energy adoption gained momentum. Other emerging wind energy markets which do not have extensive logistics sectors must ensure that their infrastructure can support wind turbine transportation prior to planning for wind energy adoption.

Turbine transportation is a significant portion of initial capital cost of wind energy equipment, over the life time of a wind farm the importance of this initial cost declines. Therefore as a cost factor, logistics of wind turbine components is secondary to the quality of the wind energy resource at the wind farm site.

Even though the importance of turbine logistics will decline as a cost factor once the wind turbine is operational, the role it plays in the operation and maintenance stage can affect availability of turbines and thus wind farm revenue. Logistics during spare parts management and operational maintenance has the capacity to keep a wind turbine out of service when awaiting the arrival or availability of replacement parts and the cranes needed to hoist replacement parts.

6.3 Secondary research question

Does turbine transportation unfold as a barrier to wind farm development in South Africa?

As the primary research question is extended, it goes on to ask if turbine transportation is a barrier to wind farm development in South Africa. Turbine transportation unfolds as a barrier to project development in three ways. Firstly, turbine transportation can expose wind energy developments to delayed damages and lost revenue. This would occur through project delays and extended time frames for construction and grid connection readiness. Secondly when components are damaged through accidents or poor handling, turbine transportation exposes projects to transit risk. When components are damaged in transit additional delays for replacement or repair will follow. Thirdly turbine transportation is a high cost area for the South African market. The distance from manufacturing locations, the cost of administration and route clearance and the low transport mode switching capacity that other wind markets enjoy is absent in South Africa. In this way the transportation of turbines may develop into a stronger barrier to wind farm development in the future as wind turbines increase in size and the wind market possibly grows.

7. Discussion and recommendations

This chapter will discuss the key issues that came out of the interview process and the remainder of the research project. It discusses the transport and logistics in the local wind energy industry. Emerging wind energy markets in African can then learn from the recommendations, based on the experiences seen in South Africa.

7.1 Transport planning, industry co-operation and secrecy

Companies active in the delivery of wind turbines in South Africa have so far managed to deliver turbines to the respective wind farm development sites despite numerous challenges presented by the infrastructure, administration and planning of the transport sector. The deliveries have been slow and delayed in many instances but overall the fact that they have delivered in this new industry is commendable. The process of turbine delivery has so far managed to avoid major public safety incidents although a few incidents have occurred within the industry and with contractors. That there have been a handful of minor incidents is not to discredit the logistics service providers, the larger established firms take safety and protocol very seriously much more so than the smaller firms who are accused of regularly flouting safety regulations. Round one of the REIPPPP has awarded projects which will erect 294 wind turbines. Each turbine has three blades, three to four tower sections, a hub and a nacelle, meaning nine abnormal loads for each turbine and approximately 2646 abnormal loads for round one alone. Transportation of these loads is on-going and is a carefully implemented process. Skills development in the turbine transport sector will thus develop on a learning curve.

The Department of Transport and SANRAL have not contributed as much as expected to addressing the transportation constraints faced by the wind energy industry. Initially they did participate with transportation stakeholders, where minimal contributions to planning were made to prepare for the turbine influx, however little action followed and the problems of congestion, limited provincial and municipal staff numbers and interfering road works have still plagued the turbine logistics process. Most of these problems could have been solved or partly mitigated if action had been

taken in time. However the lack of commitment and dysfunction of bureaucratic systems plagued government action.

Government entities and the Departments of Transport are however not solely to blame in failing to deal with retarding systems which have affected the local movement of turbines. Project developers could have worked together to prevent congestion and infrastructure pressure at certain key points of the transport system. When asked to submit transport plans to a SAWEA working committee on logistics most did not comply despite assurance that the plans would be kept confidential. So both sides have lessons to learn in order to make subsequent bidding rounds more effective when it comes to moving turbines from ports to wind farm development sites.

7.2 Construction timelines in the REIPPPP

The analysis section has documented the barriers to incident-free and timeous turbine transportation. These barriers include scarce driver skills, provincial traffic escort force capacities, port and road congestion and poor planning by the roads agency and the transport departments. Many of these difficulties originate from the design of the REIPPPP bidding system. Instead of a gradual introduction of capacity on a recurring periodic basis, all the successful bidders are announced at once, sign their PPAs at once and construct their wind farms within roughly the same time frames. This approach is likely to lead to delays through pressure on infrastructure, especially for wind turbines which make high and recurring demands on ports, roads and support equipment such as cranes and trailers.

The actual date of connection to the national electricity grid is subject to Eskom's capacity to connect the wind farm either to an existing substation or to a newly constructed one, so from the signing of the PPA the wind farm is given either 24 or 36 months to connection to the grid depending on Eskom's need to build new substations⁵⁰.

Interview responses as to why wind farm development is carried out simultaneously pointed to convenience for the Department of Energy which is responsible for the

administration of the REIPPPP. A second explanation was the engrained approach of large scale planning which dominates the South African electricity sector's development. This amalgamated approach also makes it easier for Department of Energy officials to report back to government on renewable energy targets and renewable energy progress⁵¹.

In implementing turbine transportation and construction schedules, risks are not shared evenly, if a project developer fails to deliver its project on time it will be subjected to penalties which will affect its revenue flow and possibly its ability to repay borrowed capital. However when the DoE or Eskom through administrative bottlenecks delay PPA signing or grid access, no penalty is levied on them. In this way it should be clear to participants in the wind energy industry that the DoE would require significant lobbying to alter the way it operates the REIPPPP for the sake of improved logistics performances. The benefits that reform would bring to the future of the industry can be made clear through research, cooperation and demonstration. However, at the moment, there is no penalty to bear and no incentive to encourage the Department of Energy to reform the procurement process with respect to development timelines. Making sure the transportation and logistics of wind turbines for each round of construction runs smoothly is thus the industry's own responsibility. The secrecy and non-cooperation seen in the early stages of round one of construction will hopefully be a learning curve for wind sector project developers. If the envisioned delays do result, the industry must take initiatives such as the transport plan submission to SAWEA more seriously in future rounds. Coordination and co-operation will be able to mitigate at least some of the logistics challenges especially those of congestion at ports and roads. The disruptions faced from road-works can also be worked out of the system by working closely with SANRAL.

At the same time the wind energy sector through its industry body should lobby government around the rules which currently constrain logistics of turbines. The abnormal load transport process which allows abnormal loads to move only between sunrise and sunset on working week days which exclude public holidays can be a subject of such a lobby. Additionally, innovation that can combine provincial and municipal administrative capacity with private sector resources to deliver turbines safely and on time is a potential solution; opportunities for this type of cooperation need to be studied further.

It is important for this thesis to contextualise the significance of potential project delays to wind farms in South Africa's REIPPPP. The power purchase agreement (PPA) signed with a wind farm is for a fixed period of 20 years. When a project delivers before its scheduled date the power produced from operation to contract commercial operation date (COD) is sold at a discount to the grid operator until the contract date is reached at which point the full price is then earned. When the project is late within a period of 12 months, the difference between the scheduled operation date and the delay time is subtracted from the 20 year PPA thus reducing the wind farms financial operation period. The resulting reduction in operation period is thus twice the length of the initial deferment. Delay to operation greater than 12 months allow for cancellation of the PPA depending on the cause and the contractual liability, which would be assessed on a case by case basis (DLA Cliffe Dekker Hofmeyr, 2012). As such, any delay to the contracted operation date would have a negative effect on the future of the affected wind farm, this is unlike the case for state financed energy projects such as Medupi and Kusile. Logistics as a high risk area with respect to project delays thus warrants explicit monitoring and control.

7.3 The relationship between manufacturing location and turbine transportation

The association between the manufacturing location of wind turbine components and their subsequent transportation has been discussed in several published documents. Thresher & Laxson (2006), affirm the benefits of producing turbine blades on or near the project site as a way to reduce transport costs and lower blade prices. Similarly Avis & Maegaard (2008) encourage the production of towers and blades in the market they are demanded in order to reduce transport costs of turbine imports from distant markets. Kirkegaard et al (2009), Lema et al (2011), and Lewis (2011) all take similar positions in recognising the manufacturing location of wind turbine components as a driver of transport costs. It should therefore follow that the production concentration hypothesis introduced in the literature review is highly applicable to the wind energy industry. Firms will relocate production to markets where high transport costs of supply are incurred.

However, as this thesis has discussed, the relationship between manufacturing location and turbine transportation is more complicated. In practice, a number of additional factors come into play in urging component manufactures to locate or relocate their production facilities. The main factor was found to be the market size of the target market. As market proximity (i.e reduced transport cost) is compared to economies of scale in production, in a case where economies of scale cannot be reached, equipment manufacturers prefer to export their output at a high transport cost. Indeed when asked their preference, interviewees chose high transport costs over market proximity for South Africa⁵².

Conversely, a preference for high transport cost is not the case in larger markets. To illustrate, this discussion compares the current South African wind energy industry to the USA market when it was still driven by turbine imports. As the wind energy industry in the USA has grown so has local manufacturing of turbine components. Ozment & Tremwel anticipate in their 2007 paper that transport cost reduction of turbine equipment will drive a shift of manufacturing location towards the USA market. This anticipation gradually followed. The shift corresponds to a period where larger turbines, which are more difficult and expensive to transport have seen greater use in the global wind energy industry. The proportion of wind turbine components manufactured in the USA has risen from 25% in 2007 to 72% in 2012 (US Department of Energy, 2013). It should be noted that other attractions to the American market such as stable renewable energy policy and production tax credits have also supported the growth of the wind energy market.

Local manufacturing in South Africa, where the wind energy market is newer and much smaller is yet to develop. So far only one investment in local tower manufacturing will serve the South African market. This investment is driven by localisation policy and renewable energy bid restrictions. It will however result in the supply of towers which are priced higher than imported towers would be.

8. Conclusions

Two main sources of information were consulted in the compilation of this research project which has aimed to understand the process and the challenges faced in the transportation of wind turbines in South Africa. The first source was a literature review, whilst the second source of data was a set of interviews with professionals who are currently involved in transporting turbines in South Africa's wind energy sector.

Transportation was found to be a critical phase of wind farm development as there will always be a separation between where wind turbines are produced and where they are erected to collect and convert wind energy into electricity. This separation has created a sector in-between turbine production and wind farm location where skilled professionals and specialised equipment are contracted to transport turbines within strict time frames.

All wind turbine components are abnormal loads, either through length, weight or height. Transporting them thus requires planning and project management as well as support and approval from local transport authorities. The wind farm development process hence has a recurring dependency on the transport sector to move and lift components during construction and during operation. Challenges faced in this critical part of the supply chain can obstruct the wind farm development process and should thus be taken seriously and considered at the start rather than at the end of industry development and planning.

The role component transportation plays in wind farm development is now clear. It can affect the success of wind farm development through safe delivery of components during construction and during operation. The capacity barriers and constraining systems embedded in the local turbine transport process can also cause delays in completion and escalation of costs for wind farm developments.

In new wind energy markets where the transport sector is extremely undeveloped, turbine movement may become an independent disincentive to wind farm development. This is however not the case in South Africa where the capacity of the logistics sector and the shared transport infrastructure are previously developed to serve larger industries. The current challenges in South Africa's turbine logistics

environment are more inclined to poor planning, non-cooperation and inexperience due to the novelty of wind farm development in South Africa. Wind energy planning in South Africa has assumed the transport sector would easily support the development of multiple wind farms; other developing countries should not make similar assumptions of their transport sectors as planning will need to commence sooner and associated investment made earlier for those markets where transportation is an even greater concern.

Turbine transportation is an important factor of the capital cost of wind farm development. This is important to manufacturers because final price of turbines is affected by transport cost.

The wind energy industry has become more competitive as it has grown, at the same time; the cost of generated wind power has fallen and continues to fall. Every stage of the wind farm development process, including turbine transportation will consequently need to find ways to reduce costs. As such, turbine transportation will be an increasingly important part of developing wind farms and supporting the wind energy industry.

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Appendix A

The lists of questions used to conduct the interview stage amongst the four groups of interviewees are documented below. The interviews were semi-structured, with both a guided and an open discussion.

- Questioner to Project Developers/ EPC contractors

1. What have you learnt from the logistics needs of wind farm projects?
2. Do you think logistics can affect wind farm performance during O&M?
3. Can spare part management have any negative implications for smaller wind farms?
4. How do you find the transportation approval/ regulation process?
5. What has been your experience with roads into and around your projects?
6. What does it cost to transport a turbine or its components?
7. Would localization affect the final cost of logistics?
8. Will exchange rate fluctuations have an effect on the future cost of logistics or O&M activities?
9. What is the contracting process for Logistics services

- Questioner to Original Equipment Manufacturers (OEM)

1. How has turbine logistics affected business development in South Africa?
2. Has logistics been a barrier at any level?
3. What is the relationship between manufacturing location and turbine transportation?
4. What proportion of a turbine capital cost is transport cost?
5. What steps are taken to minimize transport costs?
6. Do low trade tariffs and import duties delay relocation to South Africa?
7. What is more important to an OEM? Economies of Scale or proximity to markets.
8. What is the process to appointing a transport contractor?
9. Will spare parts be warehoused locally or imported when needed?
10. Are turbine purchases protected from exchange rate fluctuations?
11. How long does your warranty period last, what options are available after?

- Questioner for Logistics firms

1. What has been your experience with wind turbine transportation?
2. Are there enough heavy lift cranes and extendable trailers to cope with demand?
3. How do you find the transportation regulation process?
4. How is the cost of turbine transport decided?
5. Is the transport infrastructure in South Africa capable of supporting high wind energy penetration?
6. Is there any level of co-operation between different wind developers?
7. Can you give me an industry range of the cost of the turbine transport service?
8. How often is turbine damage a problem and for whose account is any damage?
9. What equipment does turbine transportation require?
10. How has the development of super routes for component delivery gone so far?

- Questioner for Transport Planners

1. What has been your experience with the transportation of wind turbines?
2. Are route clearance services essential to wind turbine movement?
3. Is the transport infrastructure in South Africa capable of supporting high wind energy penetration?
4. What steps are taken to minimize transport costs?
5. How far along are the developments of super routes in South Africa?
6. Are transport authorities ready to support the arrival of turbines in South Africa?
7. Is there any level of co-operation between different wind developers?
8. How often would turbine damage be a problem and for whose account is any incidence of damage?
9. Is it reasonable to ask IPPs or their dedicated contractors to pay for the escort service directly to the municipality/ traffic department?
10. What effects may higher levels of turbine transportation have on other road users?

Appendix B

The table below shows the interviewed firms which participated in this research project. The firms are arranged alphabetically by company name.

Interview	Interviewee	Company
1	Representative	Barloworld Logistics
2	Representative	Deugro South Africa
3	Representative	ALE South Africa
4	Representative	SAWEA
5	Director	African Route Clearance Consultants
6	Representative	African Route Clearance Consultants
7	Director	Department of Trade and Industry
8	Director	Department of Trade and Industry
9	Director	DCD
10	Representative	DCD
11	Representative	Wind Prospect South Africa
12	Representative	Suzlon
13	Director	LM Wind Power
14	Representative	Nordex
15	Director	Cape Africa - RES
16	Director	3ENERGY
17	Representative	3ENERGY
18	Representative	Wind Prospect South Africa
19	Representative	Eskom Renewables

In total 30 companies were contacted with requests for interviews. 19 responded positively whilst 11 declined or did not respond to contact.

Appendix C

The aim of this thesis was not to detail the size and weight of individual turbine models – this information is available if researched for individual turbine makes hence its inclusion only in the appendix section. The point on the thesis was to understand the transportation challenges faced in moving wind turbine components for South Africa and similar developing markets. However the specific measurements of three Vestus onshore turbines are detailed in the table below.

Table 1: Weight and length comparison of wind turbines installed or proposed for the region.

Turbine Model and Output	Vestas V-90 1.8 MW Onshore		Vestas V-80 2 MW Onshore		V-90 3 MW On/offshore		GE 4 MW Offshore*
Blade Length	144.4 ft (44 m)		128.0 ft (39 m)		144.4 ft (44 m)		131.2-164.0 ft (40-50 m)
Blade Weight	14,771 lb (6,700 kg)		14,330.1 lb (6,500 kg)		14,771 lb (6, 700 kg)		> 15,432.4 lb (> 7,000 kg)
Nacelle Height: For Transport Installed	13.1 ft (4 m) 17.7 ft (5.4 m)		13.1 ft (4 m) 17.7 ft (5.4 m)		13.1 ft (4 m)		> 16.4 ft (> 5 m) > 18.0 ft (> 5.5 m)
Nacelle Length and Width	34.1 x 11.2 ft (10.4 x 3.4 m)		34.1 x 11.2 ft (10.4 x 3.4 m)		31.7 x 12.0 ft (9.7 m x 3.7 m)		> 36.1 x 13.1 ft (> 11 x > 4 m)
Nacelle Weight	70 MT		69 MT		70 MT		>80 MT
Hub Dimensions (diameter x width x length)	10.8 x 13.1 x 14.1 ft (3.3 x 4 x 4.3 m)		10.8 x 13.1 x 13.8 ft (3.3 x 4 x 4.2 m)		11.8 x 13.8 x 14.4 ft (3.6 x 4.2 x 4.4 m)		
Hub Weight	18 MT		18 MT		22 MT		
Tower Length	262.5 ft (80 m)	311.7 ft (95 m)	219.8 ft (67 m)	262.5 ft (80 m)	262.5 ft (80 m)/ 50 hz	344.5 ft (105 m)	Offshore (site specific)
Tower Weight	155 MT	205 MT	117 MT	155 MT	145 MT	255 MT	

* As the specifications of the GE 4. MW offshore turbine is confidential, LEEDCo has provided us with a range in which the specifications will fall.

Sources: Vestas, 2007, Turbine Overview, accessed at <http://www.vestas.com/en/wind-power-plants/procurement/turbine-overview.aspx#/vestas-univers> (7/2010); Dr. Lorry Wagner, President, Lake Erie Energy Development Corporation (LEEDCo), personal communication (7/2010).

Source: (Great Lakes Wind Collaborative, 2010)

Endnotes

¹ Interview 3 – Through a breakdown of the market shares of the logistics firms participating in turbine transportation as well as details of who is working on which projects.

² Interview 1, Interview 19

³ Interview 14, Interview 17, Interview 18

⁴ Interview 1, Interview 2, Interview 5, Interview 12, Interview 18, Interview 19 – the support equipment used in wind turbine logistics is often acquired for temporary use, because of the market size, permanent equipment will not be fully utilised

⁵ Interview 4

⁶ Interview 19

⁷ Interview 4, Interview 15, Interview 19

⁸ Interview 19

⁹ Interview 11

¹⁰ Interview 10, Interview 12, Interview 13, Interview 17 – localisation is a very important part of a project bid, complying with these requirements is essential to winning supply bids.

¹¹ Interview 5

¹² Interview 5

¹³ Interview 1, Interview 2, Interview 5, Interview 11, Interview 19 – A lack of skilled drivers to drive the unique abnormal loads that are turbine components has caused an increasing number of incidents in transit. Insurance claims have risen as a result.

¹⁴ Interview 11, Interview 12

¹⁵ Interview 1, Interview 15

¹⁶ Interview 1, Interview 12, Interview 13 – Transporting turbines to and in South Africa is more costly than in other larger wind energy markets.

¹⁷ Interview 4

¹⁸ Interview 4

¹⁹ Interview 4, Interview 5, Interview 14, Interview 19

²⁰ Interview 2, Interview 5, Interview 14

²¹ Interview 5, Interview 6

²² Interview 2, Interview 5, Interview 6, Interview 14

²³ Interview 2, Interview 5, Interview 6

²⁴ Interview 4, Interview 6

²⁵ Interview 2, Interview 14

²⁶ Interview 3

²⁷ Interview 1, Interview 2, Interview 3

²⁸ Interview 1, Interview 2, Interview 6, Interview 12, Interview 17 – An extendable blade trailer is a piece of bespoke abnormal load transport equipment. Low utilisation of these trailers creates a disincentive for investment in them.

²⁹ Interview 2, Interview 5

³⁰ Interview 2, Interview 4, Interview 5, Interview 6

³¹ Interview 1, Interview 2, Interview 14, Interview 15 – Simultaneous construction time frames result in immense pressure on crane capacity, leading to project delays and probably delay penalties.

³² Interview 5

³³ Interview 14, Interview 17

³⁴ Interview 16, Interview 17, Interview 18, Interview 19 – Long term operational planning has taken a secondary role as compared to immediate bid competition for supply contracts

³⁵ Interview 6

³⁶ Interview 13

³⁷ Interview 12, Interview 16, Interview 17, Interview 19

³⁸ Interview 15, Interview 16

³⁹ Interview 12, Interview 15

⁴⁰ Interview 14, Interview 18

⁴¹ Interview 14, Interview 18

⁴² Interview 12, Interview 16

⁴³ Interview 2, Interview 5, Interview 6, Interview 12

⁴⁴ Interview 2, Interview 5, Interview 6, Interview 12, Interview 15

⁴⁵ Interview 4, Interview 5, Interview 6, Interview 12

⁴⁶ Interview 2, Interview 12, Interview 15

⁴⁷ Interview 11, Interview 18, Interview 15

⁴⁸ Interview 2, Interview 16, Interview 18

⁴⁹ Interview 5 – The logistics industry is highly competitive. This competition often leads smaller logistics firms to deviate from best practice in order to cut costs. Incidents of unauthorised load transportation and weight tampering have been reported.

⁵⁰ Interview 18

⁵¹ Interview 6, Interview 16

⁵² Interview 12, Interview 13, Interview 14