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LOGISTICS IN OFFSHORE WIND

BY
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DISSERTATION SUBMITTED 2018

AALBORG UNIVERSITY
DENMARK

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PREFACE

The clean-energy transition had already commenced towards the end of the 2000s when the early foundations of this research were laid. With this transformation towards the production of clean energy, new shipping commodities had emerged with different transportation requirements. When reviewing different renewable energy forms from an angle of logistics, wind energy stood out as being particularly complex, and comparatively under-researched within academia. By comparison, solar power demonstrates relatively simple logistics, with solar panels that can be shipped in standard ocean freight containers and stored in warehouses. Although based on a bulk supply chain, it was similarly ascertained through analysis leading up to this research that biomass logistics was also executed in a very standardized supply chain for commodities such as wood pellets and wood chips.

The antecedent of this research concentrated on logistics for wind turbines erected onshore: It became clear that the firms involved in shipping, logistics, and ports had little or no influence on the design of the shipping commodity itself. The transport asset design and required capabilities were consequently largely decided by the manufacturers of the wind turbines. As wind turbines grew bigger in size, thus increasing the dimensions, volume, and weight of the individual parts, considerations were not given to potential downstream logistics implications. The shipping, logistics, and port firms serving the growing wind industry were, however, suffering greatly from their assets being rendered inadequate or even obsolete very quickly as well as from people, skills, and processes constantly in need of alterations, upgrades, and in some cases, complete reengineering. These factors put a lot of pressure on costs and made developing logistics standards difficult.

Logistics seemed particularly challenging within offshore wind. Once offshore, the influence of the harsh conditions at sea made logistics a lot more challenging, complex, and some 5-10 times more expensive than logistics ashore according to expert opinion holders interviewed before the commencement of this research. Coupled with the expected step-change in terms of wind turbine sizes and weight for offshore machines, the logistics chain from the port to the offshore wind farm site seemed complex to manage both during construction and during the ensuing operations phase for service purposes. However, many different logistics chains seemed to exist and form part of the overall logistics context. Inbound to the manufacturing sites, standard logistics chains ensured that offshore wind turbines and balance of plant components could be assembled and/or manufactured. The assembly process was made possible by complex factory logistics set-ups that included storage solutions in warehouses and yards depending on what was manufactured at a given site. And outbound from the factories to the ports, large fully assembled offshore wind components were starting to challenge the upper limits of existing land-based infrastructure leading to plans to set up manufacturing and assembly operations near waterways.

Compared to offshore oil and gas installations, offshore wind farms had many small wind turbine power units instead of one or a few offshore oil and gas platforms within a site. This made the logistics challenge different for offshore wind. Developing a better understanding of logistics in offshore wind therefore seemed to be an interesting topic with little prior research available. This view was shared by Aalborg University that already had several research groups within the area of wind energy as well as several research groups that looked at logistics or supply chain management. A hybrid of wind energy and logistics, logistics in offshore wind, was therefore an interesting proposition to Aalborg University and the research was rooted in the Department of Materials and Production (then Manufacturing and Mechanical Engineering).

External funding was obtained and as such, this research was made possible by grant 2012-097 from Den Danske Maritime Fond (the Danish Maritime Foundation). The Danish Maritime Foundation made the grant contingent upon the research output being useful to industry and decreed that a Reference Group be formed to support the research endeavors. Inaugurated in a Danish offshore wind supply chain setting, the Reference Group was put in place. This researcher recruited the member firms and defined the forum meeting structure. The Reference Group has been expanded over time and remained in place throughout the entire life-span of this project up until this time. The Reference Group has given valuable insights and guidance throughout the PhD research duration. In addition, critical case access has been obtained through Reference Group members. This PhD study balances the goal to provide sound as well as academically founded advances of science-rooted gaps in academic literature using scholarly methods with the objective to also provide results with managerial impact.

SUMMARY IN ENGLISH

The global onshore and offshore wind markets were found to be diverging with onshore turbines having reached their maximum size in terms of yield, volume, and weight. Not within immediate line of sight and without generating any significant noise or vibration challenges, no upper boundary existed for wind turbines placed offshore in the sea. As the near-shore locations were slowly getting occupied, offshore wind farms had to move farther offshore into deeper waters and this presented several logistics challenges.

A literature review revealed that logistics in general is hard to define and may be context dependent. In addition, logistics in offshore wind was not well researched in general. The cost of logistics had not been defined for offshore wind and comparisons of logistics costs at a line-item level across different cost studies had not been performed. The characteristics of logistics in emerging offshore wind markets were not well understood and scientific literature on the supply chains of renewable energy did not include an assessment of whether the supply chains were indeed ready for the planned government diffusion of these energy sources, including logistics in offshore wind.

Three research questions were defined. The first focused on generating a better understanding of how logistics is organized in a broad sense within offshore wind and whether logistics, as a scientific discipline, is considered to be of importance. The objective of the second research question was to establish the costs of logistics in offshore wind. And the third focused on determining the characteristics of logistics in mature versus the new and emerging markets derived from the globalization of offshore wind.

Empirical data had to be collected in different manners. The case study method was chosen as it was perceived to be flexible enough to support the research design being crafted. Several case studies were procured and from seven possible main case studies, three were prioritized as being of primary focus for this research. Empirical data was collected using a mix of semi-structured interviews, formal interviews, surveys, action research / participant observation, and desktop studies.

The data was analyzed along different dimensions with different objectives. Besides the academic objectives, some of the case studies had more purposes including exams for master's students or particular deliverables towards the case organization. In other instances, analysis results were contrasted and avenues of value were combined in order for the analyses to yield contributions which led to the publication of a total of five peer-reviewed manuscripts.

The contributions from the research were based on the gaps identified in academic literature. As such, the first research question was answered by first providing a proposed definition of logistics in offshore wind. The first research question was partly answered by providing a directional understanding of the costs of logistics in offshore wind as seen in comparison to capital expenditure, operating expenditure, and levelized

cost of energy. Although this was essentially the answer to the second research question, the relatively high percentage share of logistics costs provided the answer that logistics is probably not assigned the level of importance in academia, nor industry, that it deserves. The answer to the second research question was further amplified by a contribution pertaining to possible bias in the use of cost models on the part of the institutions, organizations, or individuals who set up the assumptions and decided on the different attributes to utilize. In addition, it was found that offshore logistics costs are not properly accounted for or defined in government sponsored and industry-wide studies. The answer to the third research question was two-fold. Firstly, it was found that significant characteristics of the Chinese emerging offshore wind market were different from those in the more mature markets of Europe. Secondly, an analysis of supply chain readiness, using the lens of logistics to evaluate, revealed that the supply chain is not ready for the projected diffusion targets of governments at this time.

This research has yielded a number of specific suggestions on how scientists may perform additional research with a focus on logistics in offshore wind.

SAMMENDRAG (SUMMARY IN DANISH)

De globale markeder for land- og havvindmøller befandt sig ved en skillevej, da landvindmøller nåede en maksimumstørrelse i forhold til ydeevne, volumen og vægt. For havvindmøller eksisterede der ingen øvre grænser, da de ikke stod i direkte synsfelt og heller ikke udsatte mennesker for vibrations- eller støjgener. Da de kystnære områder for havvindmøller langsomt begyndte at blive besat, måtte havvindmølleparker flyttes ud på dybere vand, og dette medførte adskillige logistikmæssige udfordringer.

Et litteraturstudie har vist, at begrebet logistik generelt er svært at definere og at definitionen ofte er afhængig af konteksten. Derudover har logistik indenfor havvindmølleparker ikke været grundigt forskningsmæssigt belyst. Logistikomkostningerne har ikke været defineret for havvindmølleparker, og der har ikke været foretaget sammenligninger af logistikomkostninger, på et omkostningslinjeniveau, på tværs af flere omkostningsstudier. Indenfor nye havvindmøllemarkeder under udvikling er logistik ikke godt karakteriseret, og den videnskabelige litteratur om forsyningskæder indenfor vedvarende energi har heller ikke inkluderet en logistikmæssig vurdering af, om forsyningskæderne er klar til udbredelse af disse vedvarende energikilder såsom havvindmøller, som forskellige nationer planlægger.

Tre forskningsspørgsmål blev defineret. Det første fokuserede på at opbygge en bedre forståelse af, hvordan logistik er organiseret i en bred forstand indenfor havvindmølleindustrien, samt at forstå, hvorvidt logistik er betragtet som værende betydningsfuld som en videnskabelig disciplin. Det andet fokuserede på at estimere, hvad omkostningerne er for logistik indenfor havvindmøller. Det tredje fokuserede på at karakterisere logistik i veletablerede markeder i forhold til de nyetablerede markeder, der er opstået som resultat af den igangværende globalisering af havvindmølleindustrien.

Den empiriske dataindsamling foregik ved hjælp af forskellige arbejdsgange. Case studie-metoden blev valgt ud fra den opfattelse, at denne metode var fleksibel nok til at understøtte det udviklede studiedesign. Flere case studier blev kultiveret, og ud af syv mulige case studier blev tre prioriteret som værende af primær interesse for denne forskning. Empirisk data blev indsamlet ved hjælp af semi-strukturerede interviews, formelle interviews, spørgeskemaundersøgelser, aktionsforskning / deltager observation samt desktop studier.

De indsamlede data blev analyseret udad flere dimensioner og med flere formål. Nogle af case studierne skulle udover at inkludere dele af ovennævnte forskningsspørgsmål også bruges til forskellige eksaminer for kandidatstuderende eller imødekomme specifikke leverancekrav aftalt med case-organisationen. I andre tilfælde blev analyseresultaterne sat i forhold til hinanden, og grupperinger af forskningsmæssig værdi blev kombineret, for at analyserne kunne skabe bidrag, som ledte til udgivelse af i alt fem peer-reviewed publikationer.

Bidragene fra forskningen var baseret på den manglende viden identificeret i den akademiske litteratur. I den forbindelse blev det første forskningsspørgsmål besvaret med en foreslået definition af logistik indenfor havvindmøller. Det første forskningsspørgsmål blev også delvist besvaret med en retningsgivende forståelse af logistikomkostninger set i relation til anlægsudgifter, driftsudgifter og levelerede levetidsomkostninger (levelized cost of energy). Selvom dette reelt set var svaret på det andet forskningsspørgsmål, gav den forholdsmæssigt høje procentuelle andel af logistikomkostninger det svar, at logistik sandsynligvis - hverken indenfor det akademiske miljø eller industrien - er blevet håndteret med den grad af vigtighed, som logistikken rent faktisk fortjener. Svaret til det andet forskningsspørgsmål blev yderligere forstærket af et bidrag omhandlende mulig partiskhed hos de institutioner, organisationer eller personer, der afgør forudsætningerne for- og bestemmer indstillingerne af omkostningsmodellerne brugt indenfor havvindmølleindustrien. Et yderligere bidrag var, at omkostninger for havvindmøllelogistik ikke er godt repræsenteret eller defineret i statssponsorerede- og tværindustrielle omkostningsstudier. Svaret på det tredje forskningsspørgsmål var todelt. For det første blev det konkluderet, at betydelige karakteristika på det nyopståede kinesiske havvindmøllemarked adskilte sig fra de tilsvarende karakteristika på de mere etablerede europæiske markeder. For det andet konkluderede en analyse af forsyningskædens parathed, set ud fra en logistikmæssig vinkel, at forsyningskæden ikke er klar til de forskellige statsligt projekterede udbredningsmål for nærværende.

Denne forskning har genereret et antal specifikke forslag til, hvordan forskere kan foretage yderligere studier fokuseret på havvindmøllelogistik.

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ABBREVIATIONS

BOP	Balance of plant such as turbine foundations, cables, and substations
CapEx	Capital Expenditure
CSCMP	Council of Supply Chain Management Professionals
EU	European Union
EUR	Euro, currency
GW	giga-Watt
LCoE	Levelized Cost of Energy
M&A	Mergers and acquisitions
MW	mega-Watt
O&M	Operations and maintenance
OpEx	Operating Expenditure
OWF	Offshore wind farm
UK	United Kingdom
US	United States of America
USA	United States of America
SCM	Supply chain management
WACC	Weighted average cost of capital
WTG	Wind turbine generator, wind turbine
WTIV	Wind turbine installation vessel

GLOSSARY

DONG Energy Wind Power	Developer, now Ørsted
Logistics	Academic research stream and management discipline, antecedent of SCM. Broad definition here includes shipping, ports, and transportation activities
Longyuan	Developer, formerly part of Guodian now part of China Energy Investment Corp.
Offshore wind	Wind turbines installed in the sea to generate power
Offshore wind farm	Cluster of several wind turbines located in the sea
Offshore wind industry	The offshore wind industry at large including supporting functions such as logistics
Offshore wind logistics	The process of logistics management across all life-cycle phases
Offshore wind farm project	One offshore wind farm project from planning through decommissioning
Onshore wind	Wind turbines on land
Portfolio of offshore wind farms	A view across several active offshore wind farm projects of the same developer
Shipping	Shipping activities, broadly defined
Siemens Gamesa Renewable Energy	Wind turbine manufacturer, formerly Siemens Wind Power
Siemens Wind Power	Wind turbine manufacturer, now Siemens Gamesa Renewable Energy
Subsea	Activities performed under water
Supply chain management	Academic research stream and management discipline, successor of ‘logistics’
Topside	Activities performed above water
Wind turbine generator	The machine which converts wind to energy
Ørsted	Developer, formerly DONG Energy Wind Power

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CHAPTER 1: MOTIVATION

At the time of commencing this PhD study early 2014, it was clear that the wind turbine generators (WTGs) being installed on land and offshore would begin to diverge in terms of size: The 111 offshore WTGs installed, for example, as part of the Danish Anholt offshore wind farm (OWF) were of 3.6 mega-Watt (MW) capacity each and this level of WTG yield was considered the upper boundary of what could be installed onshore. However, for offshore WTGs, the Upwind project (WindEurope, 2011) had concluded that WTGs with a rated capacity of 20 MW would be technically feasible to design, build, erect, maintain, and decommission. Conversely, WTGs to be erected onshore would not be altered considerably in terms of size, volume, and weight.

For OWFs, the logistics process was already more complex and costly than onshore due to the sea element. And it seemed that offshore wind logistics was bound to become costlier and more complex as WTGs would grow bigger in size, become more voluminous, get bigger in terms of dimensions, and become exponentially heavier. These factors made the offshore wind logistics conundrum a more interesting one and many WTG manufacturers had reportedly announced plans and/or already constructed much larger prototype WTGs able to yield 5, 6, 8, 10, and possibly 15 MW (see Table 1 for a summation of the key attributes determining logistics complexity).

Logistical attributes early 2013	**Onshore**	**Offshore**
Rated WTG output	At 2.5 – 3.5 MW, the upper limit would be reached from a noise / vibration / size / view perspective	Infinite size opportunities. 20 MW WTGs tested and theoretically feasible with different WTG manufacturers working on 5-10-15 MW prototypes
Infrastructure	Land-based infrastructure maxing out in terms of roads, bridges, and weights	Supply chain hub points located at facilities with sea access and sufficient water depth would yield opportunity for growth
Individual components	Tower sections, nacelle, hub, and blades reaching ‘critical size’ in terms of weight,volume, and dimensions for handling	Much larger WTG components in need of handling along with balance of plant (BOP) components such as cables, WTG foundations, and offshore substations

Table 1. Logistics complexity attributes for wind energy.

The point of departure of this PhD study was therefore a strong motivation to better understand logistics in offshore wind. In what follows, section 1.1 describes the work which had already gone into the area of understanding wind energy logistics when this PhD project commenced. Section 1.2 outlines several changes faced by the offshore wind industry with an impact on logistics at the time this research was initiated. This is followed by section 1.3 which outlines how additional research efforts were directed towards offshore wind during the life-span of this PhD project. Section 1.4 briefly covers the case access via the PhD project Reference Group and section 1.5 presents the overall structure of this PhD thesis document.

1.1 TAIL WIND TO GET THE RESEARCH PROJECT STARTED

The empirical data collected on wind energy logistics prior to the commencement of this research revealed that firm managers faced significant logistics challenges along several dimensions such as macro economy/policy level, supply chain economics, supply chain facilities/transport equipment, and supply chain operations (see Table 2).

Dimension	Challenge examples
Macro economy/ policy	Stable investment environment required to invest in expensive transport assets such as vessels and ports
Supply chain economics	Government supported logistics competition and financial returns on logistics investments made
Supply chain facilities / transport equipment	Changes in logistics demand patterns, asset bottlenecks, and alterations of the supply chain composition
Supply chain operations	Standardization of processes and rules as well as basic understanding of the logistics chains

Table 2. Managerial challenges faced with offshore wind logistics by category (Poulsen, et al., 2013a).

These findings implied that the offshore wind industry was immature compared to other industries, also from a logistics perspective.

The empirical data collected and the ensuing contextual analysis during the beginning of this research revealed three important factors to also be considered:

- Logistics made up an integral part of an OWF. However, logistics appeared to be an ill-defined yet important part of the different stages of development an OWF would go through. Different ‘parcels’ of logistics content existed with the individual logistics processes being viewed as isolated ‘slivers’, and attributes like costs were treated as stand-alone ‘silos’.

- As offshore wind was gaining popularity within more governments across Europe, academia and industry became cost-focused (as offshore wind was largely funded by government subsidies). However, logistics remained understudied, despite substantial logistics costs and other industries showing potential for cost reductions through a logistics focus.

- Offshore wind was primarily a European phenomenon as the first OWF had been erected in Denmark back in 1991. Outside Europe, China was the only other market with a firm and legally binding framework at national level to create an offshore wind market locally. Several other countries such as South Korea, Japan, Taiwan, India, and the United States (US) also had plans for offshore wind diffusion. However, these diffusion plans were far from realization compared to China. It was unclear whether logistics processes, knowledge, skills, people, and logistics assets would be replicated from the more mature European markets to these emerging offshore wind markets outside of Europe. Or if the emerging markets would proceed down a path of gaining their own experience to learn without benefiting from the prior mistakes made, as well as knowledge amassed, in Europe.

The offshore wind industry could develop in several directions in terms of logistics and a comparison to the development of other industries along several dimensions would be useful. Key questions arising from the implementation of different standards, the balancing of asset supply/demand, and the relative strength of buyers/suppliers would be useful to understand for offshore wind with knowledge of other industries as a backdrop.

1.2 AN INDUSTRY FACING WINDS OF CHANGE

In Europe, construction efforts during the early years of offshore wind diffusion focused on erecting WTGs in shallow waters near the coast lines of different countries. The proximity to land made it possible for the offshore wind logistics industry to gain experience under protected circumstances when it came to wind speeds, wave heights, and vessel steaming time from port to OWF site. This was advantageous during the construction phase as well as the subsequent operations and maintenance (O&M) life-cycle phase of an OWF project. However, the near-shore, offshore wind era was about to be replaced by a new reality where available OWF sites would move farther offshore which presented a new set of logistical challenges (see Table 3).

To a larger extent than before, the construction and operations phases would need to be sea-based with assets and personnel remaining offshore for extended periods of time instead of e.g. the traditional daily personnel transfer modus operandum introduced for near-shore OWFs. This meant that the logistics industry had to rethink how to service offshore wind and changes to assets, training, as well as processes were needed.

With large OWF projects like London Array coming online in connection with the London Olympics in 2012, the OWF sizes were increasing in terms of number of

WTG positions as well as the power output generated. This development entailed that the logistics would need to be better organized in terms of efficiency and effectiveness through the installation phase as well as during the subsequent operations phase of the OWF. This again led to increased demands on the part of the shipping and port assets as well as the supporting logistics chains. The implication was also that the logistics contracts were becoming more extensive and the WTG manufacturers, as well as OWF developers / operators, looked to be able to acquire more elaborate solutions spanning not only installation services but also engineering, procurement, and construction as well as O&M. This expanded procurement scope meant that the traditional offshore wind logistics constituencies now faced new competition from financially strong entrant firms that had traditionally been involved only in other industries with larger contractual scopes. Often small, entrepreneurial offshore wind logistics niche firms now started to face competition from much larger and differently organized constituencies with more extensive financial, organizational, and geographical firm resources.

Factors	**Near-shore**	**Far offshore**
1. Proximity port to site	Shore personnel can go and return to the site daily	Shore personnel must remain offshore for extended periods of time
2. Vessel steaming time	Up to 90 minutes	Hours, alternatively helicopter
3. Weather	Wind speeds and wave heights could be rough	Generally rougher weather than for near-shore
4. Operations base	Land-based for construction and operations	Sea-based for construction and operations
5. Number of positions	Smaller OWFs, fewer WTG positions	Larger available sites, more WTG positions
6. WTG yield	Earlier WTGs had less yield; closer to the people living ashore (the view)	No size restrictions on WTGs and theoretically unlimited yield
7. Procurement	Individual OWF projects, case-by-case	Industrialization of procurement function including more customer demands
8. Logistics servic scope	More narrow logistics ser-vice scope	Wider logistics solutions with greater risk
9. Logistics firms	Often smaller and niche	Larger, strong balance sheet, and industry consolidation

Table 3. Difference in logistics complexity as offshore wind farms move farther away from shore.

1.3 OFFSHORE WIND AS A MORE MAINSTREAM AND POPULAR RESEARCH TOPIC

Throughout the duration of this PhD study, the offshore wind market has expanded considerably and so has the body of literature available on the topic in general as well as literature on the specific discipline of logistics within offshore wind.

More OWFs have come on stream and more data has been made available for academics to utilize in research efforts. This also includes the logistics, especially during the operations phase.

OWFs have been constructed in emerging markets and China especially has achieved an install base which has fostered a flourishing offshore wind research environment there. As offshore wind has been encouraged by governments in other emerging markets, academia has been involved in studies pertaining to e.g. seabed conditions, animal life, and weather, well in advance of the first OWF projects being realized.

1.4 THE DATA COLLECTED IN THIS RESEARCH

Empirical data collection efforts of this research have mainly been made possible through case studies. The case access secured has, to a large degree, been through work of this researcher with members of the Reference Group of offshore wind logistics constituencies supporting this research. The Reference Group was recruited by this researcher and it was inaugurated during 2013 at the direct request of the main funding provider of this research, the Danish Maritime Foundation (Den Danske Maritime Fond).

1.5 THE STRUCTURE OF THIS RESEARCH

The peer reviewed and published papers forming part of this PhD thesis each present, in detail, the motivation, literature, method, data collection efforts, analysis, results, discussion, and conclusion, including relevant recommended additional research efforts. This is done for each of the five published papers in line with their respective titles as follows:

- Paper A: Changing Strategies in Global Wind Energy Shipping, Logistics, and Supply Chain Management (Poulsen, 2015)

- Paper B: How Expensive Is Expensive Enough? Opportunities for Cost Reductions in Offshore Wind Energy Logistics (Poulsen & Hasager, 2016)

- Paper C: The Role of Logistics in Practical Levelized Cost of Energy Reduction Implementation and Government Sponsored Cost Reduction Studies: Day and Night in Offshore Wind Operations and Maintenance Logistics (Poulsen, et al., 2017)

- Paper D: The (R)evolution of China: Offshore Wind Diffusion (Poulsen & Hasager, 2017)

- Paper E: Is the supply chain ready for the green transformation? The case of offshore wind logistics (Poulsen & Lema, 2017)

Figure 1 represents a graphic visualization of the five papers forming part of this research. Paper A is the contextual paper that frames this research. Papers B, C, and D are the individual publications on the three primary case studies of this research. Paper E is the cross-case paper based on the three underlying primary case studies.

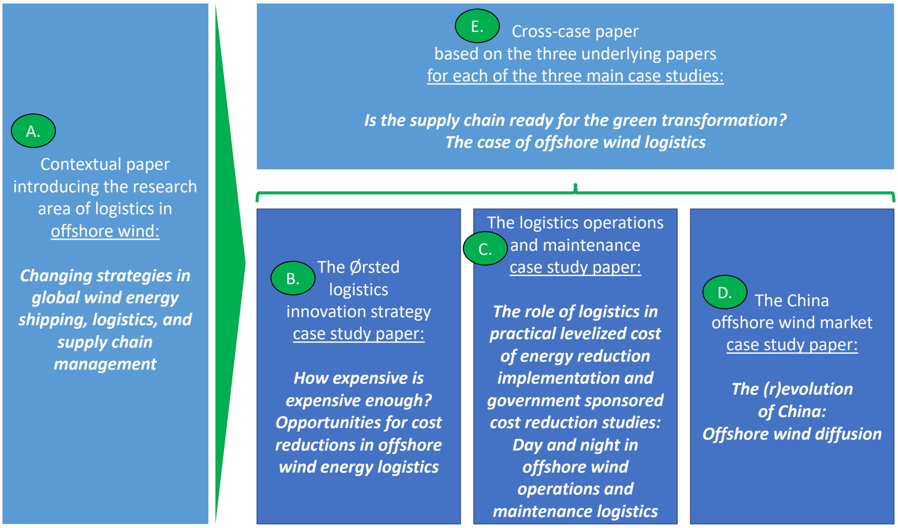

Figure 1. The five peer-reviewed publications forming part of this PhD study. The five papers forming part of this research. Paper titles are highlighted in bold and italics. The letters A-E in the green circles connotate the sequence assigned to the papers in this PhD thesis. Own construct of the figure.

The next chapter pertains to the theoretical positioning of this PhD thesis. Chapter 3 outlines the three research questions forming the objective of this PhD study on logistics in offshore wind. Chapter 4 provides the background of the method selection and the rationale behind this choice. Chapter 5 details how the analysis has been performed and chapter 6 serves as the diagnosis outlining the key contributions. Chapter 7 contains the discussion and chapter 8 concludes. The eight main chapters of this PhD thesis are followed by a section with critical reflections on the research which also provides recommendations about future work.

CHAPTER 2: THEORY

To position this PhD study in relation to the existing academic literature, several key academic terms, definitions, and theoretical frameworks were deemed to be of relevance. These terms and definitions needed a thorough review prior to initiating this research in order to understand if any gaps existed in science.

An understanding of the gaps was critical to position this research to make useful and value-adding contributions to the theory body as well as to enhance the understanding of logistics in offshore wind. The different literature reviews forming part of this PhD study were conducted in a longitudinal manner as this PhD project progressed. The different academic journal texts reviewed were downloaded and stored electronically. In addition, many of the journal articles were printed and organized in a manual filing system to enable this researcher to read and write comments on select articles, manually.

Section 2.1 provides an account of the development of the term logistics in an academic setting. Section 2.2 reviews available academic literature on logistics in an offshore wind setting and contrasts this to what was identified in terms of logistics in related industries. This is followed by section 2.3 which identifies metrics to ascertain the financial implications of logistics in a broader context. Section 2.4 provides an academically founded background for how costs are measured in the offshore wind industry. Section 2.5 concludes the review of academic literature by presenting the theory available on emerging offshore wind markets with a focus on logistics.

2.1 LOGISTICS IN ACADEMIA

To be able to trace back the original definition of the term 'logistics' and what it encompasses, much academic literature across many different scientific fields of study must be reviewed as logistics has an extensive pedigree. It was the physical distribution of agricultural products which was first scientifically accounted for by Crowell in 1901 and then subsequently supplemented from a marketing perspective by Clark in 1922 (Stock & Lambert, 2001).

Logistics as a managerial discipline and more technical term was not specifically defined within academia until much later (Magee, 1956) including optimum lot sizes, goods moving as a flow, and inventory control. Others reviewed logistics definitions (Heskett, et al., 1973), strategic implications (Heskett, 1977), operations, structure, composition (Shapiro, 1984), and logistics as a means to become more customer centric (Lambert, 1992).

One scholarly account discusses the evolutionary journey of the term 'logistics' from 1960 to 2000 (Hesse & Rodrigue, 2004): The logistics discipline is presented as having emerged from a number of prior academic disciplines that each competed, evolved, and ultimately replaced one another such as 'materials handling', 'inventory management', 'materials management', and 'physical distribution'. These earlier disciplines are defined by Hesse and Rodrigue (2004) as antecedents to 'logistics' as a new and main discipline. Hesse and Rodrigue (2004) also define the term 'supply chain management' (SCM) as the academic successor of the logistics discipline. In their 2004 academic article, Hesse and Rodrigue argued that the evolution in terminology from 'logistics' to 'supply chain management' as the name of the key academic discipline had to do with the addition of sub-disciplines such as information technology, marketing, and strategic planning to the logistics discipline.

The first written account of the term 'supply chain management' and 'the supply chain' is believed to be an interview given by Keith Oliver of consulting firm Booz, Allen and Hamilton about a major study performed regarding inventory management and flow of materials involving 1,500 companies on a global basis (Kransdorff, 1982a; Kransdorff, 1982b). In the two Financial Times articles detailing the findings of this interview about SCM and the logistics of the supply chain, the key attributes of the study of the consulting firm are described. Later that same year, an academic paper on the topic was published as part of a book on logistics (Oliver & Webber, 1982). However, in a much later account (Laseter & Oliver, 2003), Keith Oliver advised that the term 'supply chain management' was originally coined by Booz, Allen and Hamilton not as SCM but rather as 'integrated inventory management' with a catchy abbreviation, 'I2M'. However, I2M never caught on and it was at a meeting with electronic appliance firm Philips that one manager there, Mr Van 't Hoff, helped coin the term 'total supply chain management'.

The term 'supply chain management' caught on and just like its antecedents such as logistics, physical distribution, materials management, inventory management, materials handling, and other academic disciplines, SCM literature has branched out. This caused a number of sub-disciplines to be created such as internal versus external optimization within the firm (Stevens, 1989), putting focus on business processes (Christopher, 2011), using SCM to improve customer satisfaction (Cooper, et al., 1997), considering flows of products / services / finances / documentation in parallel (Mentzer, et al., 2001), impact of demand variability on supply chains (Germain, et al., 2008), and studies pertaining to networks and relationships within the supply chain (Harland, 1996). Also topics like designing the physical product to match the supply chain (Lee, 1993), supply chain cyber security (Khan & Estay, 2015), supply chain sustainability (Linton, et al., 2007), supply chain agility (Christopher, 2011), supply chain benchmarking (Lee, 2004), supply chain risk management (Manuj & Mentzer, 2008; Khan & Burnes, 2007), and reverse supply chains (Guide & Wassenhove, 2002) formed part of different SCM research agendas within academia. It was argued by some that it is not firms that compete – it is the supply chains of firms that compete (Christopher, 2011).

The replacement of one academic discipline by another is not easily managed (Cooper, et al., 1997; Mentzer, et al., 2001). However, it seems that also the defenders of the former discipline, 'logistics' in this case, would slowly succumb to the new reign (Larsson, et al., 2007), 'supply chain management' in this case. And that logistics would therefore live on as a part of or subset of the SCM definition. The SCM definition would in turn continue to broaden over time.

'Logistics', 'supply chain', and 'supply chain management' are terms actively utilized within academia. It follows that to fully understand what is meant by the term 'logistics' in any academic setting, several antecedent academic disciplines would need to be reviewed along with successors such as 'supply chain' and 'supply chain management' in a particular context. The different disciplines researched would be encompassed by a current definition of logistics or SCM in 2018.

2.2 A REVIEW OF SCIENTIFIC LOGISTICS LITERATURE IN AN OFFSHORE WIND SETTING

The literature review revealed that from a policy and planning perspective, different countries take different approaches regarding offshore wind, including logistics in a broad sense (Söderholm & Pettersson, 2011). Studies had also emerged where countries in different regions were being compared mainly from an onshore wind perspective and with some implications in a supply chain context for logistics in offshore wind (Lema & Lema, 2013). Reviewing OWFs based on different lay-out and location scenarios (Athanasia, et al., 2012), results from simulations of the logistics involved in the installation life-cycle phase (Lange, et al., 2012) as well as the spare parts logistics flow during the operations life-cycle phase of an OWF (Schuh & Wienholdt, 2011) have been discussed. Similarly, cost simulations were developed e.g. for offshore wind turbine installation vessels (WTIVs) (Kaiser & Snyder, 2012) and service vessels involved in the operations phase (Kaiser & Snyder, 2010) in the US market, albeit at an early stage of the offshore wind industry evolution there.

The offshore wind industry was still undergoing a dramatic evolution and academic research pointed towards OWF projects moving farther from shore and into deeper waters (Athanasia, et al., 2012) which would present significant logistical challenges. From the perspective of offshore wind logistics (defined widely and limited to the O&M life-cycle phase), a literature review paper revealed that 50% of all academic literature available on the subject from 1990 through mid-2014 had been published during a 19-month period spanning January, 2013 up to and including July, 2014 (Shafiee, 2015) (p. 184).

Offshore wind diffusion was expanding to new markets and in the United Kingdom (UK), the government commissioned an industry study (BVG Associates, 2014) on how to develop the UK supply chain to create jobs and retain knowledge locally. Published in January of 2014, the study was developed to understand existing capabilities of the UK industry and looked to six other industries that were deemed to resemble or represent parts of the offshore wind supply chain, i.e. aerospace, automotive, composites, nuclear, oil & gas, and rail (BVG Associates, 2014). This benchmarking approach against six different industries was in contrast with the commonly held opinion among industry practitioners in the more mature Danish market (Holst, 2014a) that offshore wind was a very unique industry which could mainly be benchmarked against the automotive industry (Holst, 2014b). Key learnings from the automotive industry were actively shared in a series of workshops for members of the Danish Wind Industry Association in 2010 (Richter, 2010) and the key focus was similarities and heterogeneities of the supply chain network (Richter, 2014).

Based on a literature review of the maturity of other yet related industries it did, however, become clear that the offshore wind industry was less developed than a number of these other industries. The lack of industrialization seemed clear when the offshore wind industry was compared to findings on SCM relationship justice practices in the oil and gas industry (Olsen, et al., 2005), the alignment of critical success factors including SCM in the construction industry (Chan, et al., 2004), the engineering/procurement/construction industry where SCM benefits were being highlighted (Yeo & Ning, 2002), the automotive industry where advanced logistics and SCM processes had been utilized for decades (Womack, et al., 2007), the truck/airplane assembly industries where flexibility existed in different parts of the supply chain (Fisher, 1997), other turn-key project industries where the procurement aspects of SCM were being refined (Ahola, et al., 2008), the industry of delivering one-of-a-kind construction projects where lead time and other logistics factors were analyzed for further optimization (Hameri, 1997), and megaprojects notorious for poor overall management for different reasons including SCM aspects (Flyvbjerg, et al., 2003). Specifically, for project logistics in the construction industry, one study in a Polish context discussed how logistics planning at the early stage of a project could help decrease costs and mitigate important logistics constraints later in the project (Sobotka & Czarnigowska, 2005). Across all of these industries compared to offshore wind in the above, the complexities are great, as is also the case with offshore wind. Conversely, the scope and scale of the supply chains as well as involved logistics operations are different for continuous supply chains like automotive, that are somewhat ‘perpetual’ in nature, compared to bespoke projects where no logistics set-ups are ever identical.

During 2014, parallel work of this researcher on a conceptual paper, not forming part of this research but also peer reviewed and published (Stentoft, et al., 2016), teased apart different aspects of the SCM literature stream. The goal of the conceptual framework created was to benchmark offshore wind against other relevant industries. SCM initiatives described as part of the academic literature would qualify for inclusion in the conceptual model included in the paper if these proven constructs from other industries were deemed to have potential to generate cost savings within offshore wind. Academic accounts of areas where the offshore wind industry could advantageously look to other industries were provided:

- Defense industry: The upgrade and development of suppliers is common in more mature industries where the company Raytheon assisted one of its suppliers to upgrade their cost performance and quality levels. This was done by Raytheon actively helping the supplier to implement lean manufacturing and six sigma (Narasimhan & Narayanan, 2013). To aid their own technological innovation capabilities, Raytheon actively increased technological knowledge sharing at a strategic level in 'annual supplier council' meetings which aligned streams of innovation efforts with the suppliers and increased mutual absorptive capacity as well as joint innovation output.

- Pharmaceutical industry: A high degree of supplier integration in a mature market was studied in the case of Johnson & Johnson as they had identified 'supplier enabled innovation' as a key strategic management discourse of the firm (Malotte, 2014).

- Automotive industry: From a perspective of value chain integration, Toyota had outsourced design, production, and worldwide logistics of some systems to their supplier Nippon Denso and GM had outsourced seating systems to Lear instead of procuring the parts for seats and assembling them on their own (Liker & Choi, 2004). This kind of 'systems buying' or procurement of a full solution suite had enabled manufacturers in the automotive industry to innovate more quickly, cut costs, and speed up new product development (Narasimhan, et al., 2010). In an extensive longitudinal study within the automotive industry spanning more than a decade (Henke & Zhang, 2010), results from the analysis revealed that the higher the 'relational health index' score of firms were compared to that of their competition, the better these more relationship-healthy firms did in terms of innovation, cost, and quality performance.

- Consumer electronics industry: South Korean LG Electronics steered through the financial crisis of 2008 in terms of solvency and supply for their operations by assisting a group of small- to medium-sized suppliers to secure loans in order to keep operating (Narasimhan & Narayanan, 2013). This was done based on LG's own financial might and to further develop the suppliers as well as the buyer-supplier relations.

- Computer manufacturing industry: The Dell 'pull system' in the computer manufacturing industry and ensuing superior innovation and cost performance has been subject to academic scrutiny (Dyer & Singh, 1998).

In addition, work on the conceptual paper (Stentoft, et al., 2016) also spanned several more broadly defined sub-disciplines of prior academic study within the SCM discipline:

- Supplier relationship management: An account of the key dimensions included in 'supplier relationship management' has been provided in an academic setting and includes strategic integration through 'early supplier involvement', deep relationship development with suppliers, relational health, supplier perception audits, annual supplier councils, and relational norms (Liker & Choi, 2004).

Several of these dimensions have been subjected to further scientific scrutiny including relational norms (Narasimhan, et al., 2008) and different justice practices to govern the relationships (Narasimhan, et al., 2013).

- Buyer-supplier relationship: More mature firms in a SCM context pursue a greater degree of supplier partnering (Narasimhan & Narayanan, 2013) and this deepening of the 'buyer-supplier relationship' has been scientifically explored along a number of dimensions. Concepts such as 'transaction-cost economics' have been developed for maturing industries to address the opposing relational forces of how to minimize costs from suppliers on the one hand while using contractual frameworks to prevent supplier opportunism on the other (Dyer, 1997). As buyers proceed along the maturity path, 'resource dependency theory' within SCM deals with how buyers avoid being too dependent upon suppliers (Mahapatra, et al., 2010).

- SCM maturity models: In line with 'product life-cycle' theory and scientific work on 'industry life-cycle' models (Klepper, 1997; Peltoniemi, 2011; Jensen & Thoms, 2015), 'maturity models' also exist in the SCM literature body and these maturity models project a trajectory of SCM evolution as the underlying industries evolve and industrialize (McCormack & Lockamy, 2004). Different SCM attributes are associated with more mature industries such as four evolutionary states of strategic sourcing (Engel, 2004) as well as an evolution of procurement from focusing on cost only to also focus on other factors such as innovation, market responsiveness, competitiveness, and ultimately strategy in more mature stage of supplier partnering (McCormack & Lockamy, 2004).

In conclusion, the literature review revealed that gaps existed for logistics in offshore wind coupled with the availability of significant learning from other industries as well as the SCM academic discipline. This pointed towards further research of logistics in offshore wind being useful.

2.3 METRICS TO MEASURE THE FINANCIAL IMPLICATIONS OF LOGISTICS

A similar evolution in terminology as described above in section 2.1 can be traced in industry. In the US, with the largest group of organized logistics and SCM industry practitioners in the world, the National Council of Physical Distribution Management was founded in 1963. The name of the organization was changed twice after that (CSCMP, 2018): In 1985, the name was changed to Council of Logistics Management and effective January 1, 2005, the name was again altered to Council of Supply Chain Management Professionals (CSCMP) which is still used today.

Their (CSCMP, 2018) original definition of 'logistics' from 1991 stated: "*Logistics is the process of planning, implementing and controlling the efficient, effective flow and* *storage of raw materials, in-process inventory, finished goods, services, and related information from point of origin to point of consumption (including inbound, outbound, internal, and external movements) for the purpose of conforming to customer requirements*." Today, their (CSCMP, 2018) definition of SCM states: "*Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies*."

To measure the importance of logistics and the impact logistics has from a financial perspective, the Council of Supply Chain Management Professionals publishes an annual report with key metrics pertaining to logistics (CSCMP, 2015). One such measure is to compare national US logistics spend to US gross domestic product. When comparing logistics as a percentage of gross domestic product at a national level in the US over time, a reduction from 15.8% in 1981 to 8.3% in 2014 had incurred (CSCMP, 2015).

This implies that defining logistics in a certain way, set in a particular context, and by measuring the total logistics costs against a meaningful value would be a useful unit of analysis.

According to the review of the academic literature on logistics in offshore wind, academia had not provided an answer to the question of what the cost of logistics in offshore wind was when this research was initiated in the beginning of 2014. This gap in literature would be useful to fill in order to determine if logistics was a significant part of the overall costs of offshore wind and if cost reductions would seem to be feasible.

2.4 MEASUREMENT OF OFFSHORE WIND COSTS INCLUDING LOGISTICS

In the energy industry, costs are measured according to international standards developed to be able to simulate and compare costs for generating electricity across different energy forms (IEA, 2005). Termed 'Levelized Cost of Energy' (LCoE), academic scholars have defined the term specifically in an offshore wind setting (Heptonstall, et al., 2012) and broken down the cost part of the equation into upfront expenditure as well as recurring variable costs (Blanco, 2009). Academics have appealed to policy makers to use the LCoE calculation methods more broadly such as altering the UK government focus on cost to also consider the revenues generated from offshore wind (Gross, et al., 2010). The past cost trajectory has been seen by some academic literature to unexpectedly increase over time in a particular market subjected to analysis (Heptonstall, et al., 2012) whereas other research (Blanco, 2009) has used mainly industry reports as source data and recorded a downwards sloping cost trajectory over time.

Several (often government funded) industry reports on costs of offshore wind provide a granular view of the overall cost composition across different OWF life-cycles in different markets, such as the UK (The Crown Estate, 2012). Especially when cost studies are performed at an industry level and with financial resources available for the study to include the involvement of an extensive cross-section of firms, a high level of detail can be made available as was the case in a German study on offshore wind costs produced by two consulting firms (Prognos and Fichtner Group, 2013). Important trends also within the area of logistics are revealed in these cost studies and, e.g. in a study for the Danish government (Deloitte, 2011), it was determined that costs for WTIV hire would increase because of OWFs moving into deeper waters farther away from shore.

When moving from overall trends to a more detailed analysis of individual cost drivers, industry reports on offshore wind costs lacked logistical details. Furthermore, there was a lack of agreement on assumptions, amounts, or the structuring of the different cost line-items pertaining to logistics. To analyze and compare at a cost line-item level across different studies was a necessary task to be performed for logistics in offshore wind and this represented a gap in the academic literature.

2.5 OFFSHORE WIND LOGISTICS PRACTICES IN EMERGING MARKETS

Offshore wind was set to expand further into new markets. Based on an analysis, it was shown (Poulsen, 2015) that 94.6% of all offshore wind capacity had been installed in Europe by the end of 2013. Of the 73 OWFs installed and grid connected on a global basis by that time, 62 OWFs with a total capacity of 6.5 giga-Watt (GW) had been constructed in European waters, 10 in China with a rated capacity of 356 MW, and one in Japan with an ability to yield a total of 16 MW. During the first decade with offshore wind from 1991 through 2000, 8 OWFs were installed in Europe with a consolidated capacity of 86 MW yielded by a total of 87 offshore WTGs according to the analysis. From 2001 to 2010, 3.4 GW of offshore wind capacity was added from a total of 1,213 WTGs erected across 33 new and grid connected OWFs. It was not until 2009 that a steady tact of more than five OWFs were constructed and grid connected per annum globally (Poulsen, 2015).

In connection with the Shanghai World Expo in 2010, the first Chinese OWF was completed in 2009 and grid connected in 2010 (Feng & Y. Qiu, 2013). Essentially a high profiled showcase OWF project, the Donghai Bridge Phase 1 OWF (Xie, 2014) consisted of 34 Chinese-produced offshore WTGs. In Japan, several bottom-fixed and floating offshore wind test sites were, more or less successfully, put into operation from 2003. The first site which can be categorized as a true OWF, consisting of eight offshore WTGs, was put into operation and grid connected in Kamisu in 2013 (Poulsen, 2015).

In China, the plans to develop offshore wind were grand with the government decreeing, in connection with the 12th Five Year Plan spanning the timeframe from 2011 to 2015, to have 5 GW installed by 2015 and 30 GW offshore wind capacity completed by 2020 (Hong & Möller, 2012; Poulsen, 2015). The actual speed with which the OWF projects were moving forward seemed to be quite a bit slower than what would be required to reach the government targets. According to the analysis made as part of this research (Poulsen, 2015), the Donghai Bridge OWF was expanded further with two additional Chinese-made test machines in 2011, and that same year, a test site was completed by developer Longyuan near Rudong in the Jiangsu province where 38 European made Siemens Gamesa (then Siemens Wind Power) WTGs were installed initially. During 2012 and 2013, the Longyuan test site in Rudong was expanded with more WTGs produced by different offshore WTG manufacturers. Also in 2013, Longyuan's parent company, China Energy Investment Corp. (then China Guodian), completed an OWF (Guodian Binhai Intertidal Project) where 18 of the Group's own United Power 1.5 MW offshore WTGs were erected (Poulsen, 2015).

The ambitions of China and Japan were supplemented by offshore wind aspirations of governments in other Asia-Pacific and North American markets including South Korea, Taiwan, India, Vietnam, Australia, Canada, and the US. The academic literature covering these markets was scarce and using South Korea as an example, no logistics content was identified in the studies reviewed from 2012 (Oh, et al., 2012) and 2013 (Lee, et al., 2013), respectively. No logistics content was detected in academic literature on offshore wind across the emerging markets of Asia-Pacific (Leary & Esteban, 2011). The empirical data collection efforts of this research in South Korea during 2014 indicated that the reason for the lack of logistics content was that logistics typically would be a consideration to be made when OWF projects are closer to being constructed and operated (Poulsen, 2015). Given the scope and scale of China compared to the rest of the emerging markets, the Chinese market seemed the most interesting market to research in order to determine if logistics tasks could be characterized and subsequently compared to the more mature markets in Europe. Based on the gap identified in academic literature pertaining to logistics in the emerging offshore wind markets, one proposition developed at the beginning of this research was that logistics could be one of the reasons why diffusion of offshore wind was seemingly considerably slower than what was desired by the government in China.

CHAPTER 3: RESEARCH QUESTIONS

Based on the review of scientific theory and with the objective to study logistics in offshore wind, three research questions were developed as propositions for this PhD study on logistics in offshore wind.

RESEARCH QUESTION ONE: HOW IS OFFSHORE WIND ORGANIZED IN TERMS OF LOGISTICS, AND IS LOGISTICS OF IMPORTANCE?

Across different life-cycle phases of the life-span of an OWF, the rather limited academic literature available suggested that logistics was organized differently (Poulsen, 2015):

- During the development and consent life-cycle phase (Söderholm & Pettersson, 2011), various weather reporting equipment was installed at sea and numerous surveys made. The weather reporting equipment was utilized by governments and prospective bidders for particular OWF sites to understand wind speeds as well as other factors such as wave heights. The surveys were carried out to map out animal life above water as well as under water and also to check the seabed in terms of boulders and unexploded ordnances (Poulsen, et al., 2013b). These factors were important for governments to award concessions and for developers to prepare their bids including the logistics portion.

- In the installation and commissioning life-cycle phase, the supply chain lead firm (Heptonstall, et al., 2012; Ricther, 2012; Blanco, 2009) was different depending on the country of installation, and which part of the OWF was to be analyzed. In Denmark, the government would construct and operate the grid (Deloitte, 2011) including the offshore substation but this was not the case in the UK (The Crown Estate, 2012). Similarly, the European manufacturers of WTGs had managed to convince developers that the manufacturers would sell WTGs fully installed and with a certain number of years of operational warranty included in the purchasing price. This was not the case e.g. for WTG foundations which in many cases would be installed by the developer directly (Renewables Advisory Board, 2010). As such, the supply chain lead firm could be the government, the developer, or a WTG manufacturer.

- In the O&M life-cycle phase, the expiry of the warranty phase triggered a hand-over of operational responsibilities including logistics from the WTG manufacturer to the operator of the OWF and this seemed to happen quicker for more experienced operators than e.g. for financial investors (Prognos and Fichtner Group, 2013).

- Decommissioning had not yet been tried out in earnest and the dismantling of an OWF along with the abandonment of the site was being contemplated by the responsible operators including deliberations pertaining to e.g. reverse as well as sustainable supply chains (The Crown Estate, 2012).

Different, and often tailor-made, offshore wind transport assets were utilized throughout the various life-cycle phases (Kaiser & Snyder, 2012; Kaiser & Snyder, 2010), making logistics complex and costly (Deloitte, 2011). During the installation and commissioning phase, heavy lift cranes and custom-built WTIVs were often used to construct the OWFs at their respective sites in the sea (Lange, et al., 2012). Conversely, fast personnel transfer boats were used to transport technicians, tools, and spare parts to the offshore site during the ensuing O&M phase (Schuh & Wienholdt, 2011). Also the land-based logistics set-ups were different during the life-cycle phases: For installation and commissioning, an installation or marshalling port was utilized to stage, prepare, and load out the individual WTG and balance of plant (BOP) components which in turn had to be transported there (Athanasia, et al., 2012; Prognos and Fichtner Group, 2013). A port with a warehouse near the OWF site was used as the O&M base, duly housing technicians, tools, spare parts, personal protection equipment, and crew boats. The logistics assets utilized in the early OWFs now faced dramatic change as WTG sizes were set to increase and OWF projects were being projected much farther offshore.

In terms of procurement (McCormack & Lockamy, 2004) and supply chain buyer-seller relations (Narasimhan & Narayanan, 2013), a number of logistics chains seemed to exist with very different composition, structure, and degree of standardization (Poulsen, 2015). When the decision to go ahead and actually build the OWF was taken by the developers during the development and consent life-cycle phase, the actual contracts were awarded, and purchase orders issued by these supply chain lead firms. This signaled the commencement of the installation and commissioning life-cycle phase and meant that the process of manufacturing WTGs, offshore sub-stations, foundations, cables, and onshore facilities would commence. In turn, this would trigger the activation of the various inbound and tiered logistics chains from sub-suppliers to the WTG manufacturing or assembly facilities, from sub-sub suppliers to the sub-suppliers, and so forth. Involvement of different kinds of logistics constituencies was observed across the various logistics chains (Poulsen, et al., 2013a) and when this research was initiated, early signs of industry consolidation was starting to be seen within the area of shipping, logistics, and port management (Poulsen, 2015).

When benchmarked against other industries, offshore wind logistics was often compared to automotive logistics (Holst, 2014a). Indeed, the inbound supply chain for a nacelle would appear to be similar to that of an automobile or truck supply chain (Hagleitner, 2015) whereas the construction process for foundations or substations require a lot more space coupled with water access as offered e.g. by shipyards or used in the oil and gas industry (BVG Associates, 2014). Similarly, blade manufacturing resembled airplane construction and the cable manufacturing process was different for cables utilized in the arrays connecting WTGs at the offshore site versus for the export cables between the substation and the land-based grid. The outbound supply chains from the different assembly facilities appeared to be a rather complex project logistics task transporting out-of-gauge, heavy, and voluminous items similar to e.g. power plant or turn-key factory removals with mostly a break-bulk logistics chain on road, through ports, and onto vessels (Sobotka & Czarnigowska, 2005).

Clearly very different in nature and mechanics, the characteristics and duration of the individual offshore wind related logistics chains would vary greatly (Poulsen, 2015). The OWF construction logistics chain is a one-off chain of events to construct the wind power asset over a period of 1-3 years. The O&M logistics chain is an on-going collection of processes that will repeat annually over a 20-30 year period during which the offshore WTGs are in operation.

RESEARCH QUESTION TWO: WHAT ARE THE OFFSHORE WIND LOGISTICS COSTS?

When reviewing industry and academic studies on logistics costs in offshore wind, it was found that the field of logistics had not been well covered within available studies and reports (Blanco, 2009). Because offshore wind was not competitive with fossil fuels, the commonly used manner by which costs were computed, collated, and compared seemed to move in a direction towards becoming the measure of 'Levelized Cost of Energy' (Heptonstall, et al., 2012; Liu, et al., 2015). Essentially a full life-span calculation comparing costs of the energy asset to the total power generation output yielded, the LCoE calculations were eventually broken down into different cost line-items across the different life-cycle phases that, when combined and after discounting of cash-flows, make up the total lifetime costs as measured at the present time (IEA, 2005). Logistics costs for offshore wind could be 5-10 times higher than logistics costs for onshore wind as a 'rule of thumb' (Poulsen, 2015).

It was found that scientific literature was almost silent on the topic of logistics costs in offshore wind and industry-wide LCoE studies (The Crown Estate, 2012; Prognos and Fichtner Group, 2013) seemed to use incomparable assumptions to compute costs in general. The (often government sponsored) major LCoE studies only included very limited information pertaining to logistics costs (Scottish Enterprise, 2013) such as key-cost drivers like daily hire rates for WTIVs which were generally included as these cost line-items were viewed as being very high (Deloitte, 2011).

RESEARCH QUESTION THREE: AS THE OFFSHORE WIND INDUSTRY GLOBALIZES, WHAT CHARACTERIZES LOGISTICS IN ESTABLISHED MARKETS COMPARED TO EMERGING MARKETS?

When compared to the developments in Europe, the emerging markets in Asia-Pacific and the Americas held future growth potential but faced early scaling challenges. Japan seemed set on developing offshore wind after the Fukushima nuclear incident, and with very deep waters, targeted WTGs with logistically complex floating foundations. Through its national legislation, China had mandated a significant offshore wind build-out (Hong & Möller, 2012) as part of the 12th Five Year Plan (2011-2015), yet available literature (Hong & Möller, 2011) indicated that the supply chain was not built out and critical logistics infrastructure (including ports, shipping, and personnel) seemed to be lacking. Additionally, the US had boasted grand offshore wind plans although actual progress was slow (Snyder & Kaiser, 2009), logistically hindered by the protectionist Jones Act (Givens, 2005).

It was therefore of great interest to ascertain how these different emerging markets would ultimately open up and by when. Several academic scholars openly questioned the viability of the official offshore wind plans of China (Hong & Möller, 2012; Hong & Möller, 2011) and in Europe, industry practitioners seemed pre-occupied with the expansion and development across the European region. For many larger firms, going global was of interest (Poulsen, 2015), although questions were being debated such as protection of intellectual property rights, which business model (Zott, et al., 2011; Nielsen & Lund, 2013) to apply in each market, and possible local partner selection (Trompenaars & Asser, 2011).

From the outside looking in and based on the actual number of OWF projects forecasted for each emerging offshore wind market, it would seem that knowledge management and transfer of assets as well as best practices would initially be beneficial from Europe to Asia-Pacific and then subsequently to the US.

CHAPTER 4: METHOD

The research design of this PhD project was along a subset of 21 research consideration dimensions (see appendix 2 for a full listing). To consider these 21 dimensions of the research in the planning phase characterizes a comprehensively structured overall PhD study process (Parente & Ferro, 2016).

The figure in appendix 2 summarizes the overall research design and within the figure, several of the individual dimensions have been highlighted and/or expanded upon. The 21 smaller sized square boxes, mostly in dark blue color, represent the 21 dimensions of the research design framework applied (Parente & Ferro, 2016). Some of these boxes have been highlighted in different colors (dark orange/red, green, light blue, and golden yellow) with bold frames and the meaning of this is expanded upon here. The green and light blue square boxes furthermore point with arrows to additional text boxes in those same respective colors that further elaborate key topics of relevance to this research. The structuring of the figure in appendix 2 as well as the color codes deserve additional explanation.

Firstly, the dark orange/red square boxes are linked and have to do with the connectivity of the different disciplines such as 'materials management', 'logistics', and 'supply chain management' discussed in chapter 2. Several gaps were identified from the literature review, and on this basis, three research questions were formed. The state of the science was identified at the beginning of this research and continuously reviewed as part of this PhD project in connection with the different publications and the overall progression of the research.

Secondly, the green square box with research strategy refers to the choice of the case study as the method of this PhD project. From a specific case study research design perspective, the five commonly misunderstood dimensions of case study research (Flyvbjerg, 2006) served as a constant guide to the design of the different case studies. This work of Flyvbjerg has been summarized in the big green box under the green arrow and will be further expanded upon in section 4.1.

Thirdly, the light blue square boxes are important in terms of the empirical data collection and analyses. This is to a large extent discussed in chapter 5 and expanded further in chapter 6. With a focus on empirical data collection using interviews, the eight challenges posed to the researcher or research team (Potter & Hepburn, 2012) provided a useful framework and structure for this researcher to evolve the interview part of the case study work continuously. The four challenges prior to the interview (1-4) and the four challenges after the interview (5-8) are summarized in the big light blue box under the light blue arrow.

Finally, the golden yellow square boxes may be commented on here as examples as well. The square box with ethos refers to the key limitations of this research which from a method perspective will be discussed in sections 4.1 and 4.3 (for example validity, reliability, and the access to the case studies chosen for this research versus other case studies somewhere else in the world not available to this research). The trust box has been highlighted because of the support from academic partners such as co-authors, supervisors, and lecturers at the doctoral courses attended as well as industry experts from e.g. the Reference Group (plus the cultural trust barrier which was overcome in the Chinese setting).

Section 4.1 reviews why the case study was chosen as the research strategy of this research and this section also discusses the reliability of the data collection process and the validity of the empirical data used as the basis of this research. Section 4.2 outlines the method used in the first academic paper which sets the contextual frame for this research. The process of how case studies were actively procured and the funneling process to prioritize the ideal case studies for this research is described in section 4.3. Section 4.4 describes the research design chosen and method applied for the three main case studies of this research which have each yielded a separate academic paper. This is followed by section 4.5 which describes the method and research design for the fifth academic paper which presents a cross-case built on the three case studies and related publications.

4.1 THE CASE STUDY METHOD UTILIZED IN THIS RESEARCH

In this PhD project, the case study method was selected as the research strategy (see the figure in appendix 2). A case study is useful when a complex social phenomenon needs to be examined to generate a better understanding of the topic at hand (Yin, 2014) whilst maintaining a real-world perspective in a holistic manner.

The advantages of using a case study is that it is rooted in reality, and it may therefore assist in being able to change reality, whilst at the same time assisting with the exploration of different opinions, interpretations, and expressions (Neergaard, 2010). Conversely, some of the disadvantages of case studies are that they take a long time to complete and that it is hard to negotiate case access to organizations and/or individuals (Neergaard, 2007).

Scholars are divided when it comes to the use of case studies in terms of whether findings from case study research are generalizable, or not. One book on the case study method argues that a "…case study is about the particular rather than the general. You cannot generalize from a case study" (Thomas, 2014). Another concludes that "…it is incorrect to conclude that one cannot generalize from a single case. It depends upon the case one is speaking of and how it is chosen" (Flyvbjerg, 2017).

Many definitions of a case study exist, and an elaborate and two-fold definition by Yin (2014) distinguishes between the scope and features of a case study:

- Scope: Boundaries between the phenomenon subjected to investigation and the context of the phenomenon may not be clearly evident and therefore the contemporary phenomenon, or case, is researched in depth and in a real-world context.

- Features: In terms of data collection and analysis, the case study design can advantageously be based on prior academic state-of-the-art, such as theoretical propositions, which may support the triangulation of data of interest to the research consisting of multiple variables originating from many sources.

When conceived, this research fitted the above case study characteristics (Neergaard, 2007; Neergaard, 2010; Thomas, 2014; Yin, 2014; Flyvbjerg, 2017). Expressed differently, the case study method was appealing because it offered flexibility to combine different ways of obtaining empirical data and an opportunity to choose the analyses tools that would be best suited to match whatever empirical data that would by yielded from the case studies. As it was unknown at the beginning of this research which case studies would become available, what empirical data would be collected, and therefore also what analyses options would be useful, flexibility was critical (Yin, 2014) as little available scientific literature existed on the topic of logistics in offshore wind. In real life, OWFs were being constructed and operated already and the phenomenon pertaining to logistics warranted further academic scrutiny based on the global projections for this new industry.

There were, however, several additional reasons for choosing the case study method (research strategy box of the figure in appendix 2). One reason was that the three research questions of this PhD study could not be answered by using either quantitative or qualitative analysis only (Yin, 2014). As the objective of this research was to examine the research questions in depth, the first and third research questions seemed more prone to a qualitative research approach. Conversely, quantitative analysis seemed to be more realistic when considering the second research question on logistics costs in offshore wind.

In addition, and as outlined in section 2.2 above, the reviews of available academic literature had revealed that significant gaps existed within the area of logistics specifically set in an offshore wind context and the case study method seemed very conducive to being able to allow the performing of research in a somewhat exploratory setting (Kvale & Brinkmann, 2012; Morse, 2012; Potter & Hepburn, 2012; Roulston, 2012). Exactly this exploratory element is agreed by most case study method scholars (Flyvbjerg, 2006; Thomas, 2014; Yin, 2014) to be an advantage of the case study method and some method scholars even argue that the case study can do much more "… While a case study *can* be used in the preliminary stages of an investigation to generate hypotheses, it is misleading to see the case study as a pilot method to be used only in preparing the real study's larger tests…" (Flyvbjerg, 2017).

According to different academic method scholars such as Flyvbjerg (2006) and Thomas (2014), the case study method would still enable the inclusion of qualitative as well as quantitative analysis. In the case of this research, quantitative analysis was expected to be necessary based on the literature review on the logistics costs (see section 2.4 above). On the qualitative side, interviews alone would not be able to yield sufficient understanding on the part of this researcher due to the complexity of the scope and scale of logistics in offshore wind. Therefore, it was expected that participant observation / action research would be needed especially for emerging markets.

The case study also allowed for the use of participant observation and action research to the extent this would be required as part of the empirical data collection process and/or to ensure validity and reliability of the research (Yin, 2013; Thomas, 2014). For case studies with a complexity as experienced within offshore wind, Yin (2014) (p. 119) outlines that multiple sources of data strengthens the validity and reliability of the case studies if triangulation is done for example combining interviews with observations and documents. Yin (2014) also discussed what he refers to as 'the chain of evidence' where the research procedures of the case study closely tie the research questions to the interview protocols to the empirical data collected and finally to the results obtained (Yin, 2014). The Yin (2014) 'chain of evidence' corresponds well with the research design of this research depicted graphically in the figure in appendix 2.

Participant observation seemed useful in several instances where this researcher needed to form an active part of the phenomenon to be able to truly understand the reality e.g. in the emerging market offshore wind logistics setting (Thomas, 2014). Similarly, action research seemed to be useful in instances where it would become necessary to take an active role in advancing work of practitioners working with logistics matters daily (Kristiansen & Bloch-Poulsen, 2017). The advantages of participant observation and action research are that the researcher gets within very close proximity of the processes making up the phenomenon being subjected to study, and the researcher gets to deliver the results of the research directly to the research constituencies (Henriksen, 2016). As far is this research is concerned, the ability to interact with the case study firms and the individual case study participants was a way to generate real value in return for case access and time spent on the research by the case participants.

When it comes to reliability and validity of this research (the quality criteria box within the figure in appendix 2), comments cutting across the five publications forming part of this research will be provided in what follows here.

The publication providing the contextual frame for this research (Poulsen, 2015) based itself on a large quantity of semi-structured interviews and participant observation encounters. Most of these interviews as well as participant observation conference attendances and site visits were conducted alone only by this researcher, mainly because of budgetary constraints. From a reliability perspective, the fact that the interviews were performed only by a single researcher was not optimal (Yin, 2014): There is a risk that the researcher would directly or indirectly bias the empirical data gathered towards the understanding of the researcher at any given time or perhaps even a certain pre-desired outcome such as hypothesis validation (Flyvbjerg, 2006). With a team of more researchers being part of the encounters, the objectivity would be greater (Yin, 2014), and this was achieved in the three main case studies forming part of this research (see section 4.3). As an example, the Ørsted case study had two interviewers in each interview meeting. To further increase the validity of the ensuing analysis phase, 14 of the 15 Ørsted interviews were audio taped and subsequently transcribed using a process of having different research team members validate the transcription quality (Seale & Silverman, 1997).

The exploratory nature of the early empirical data gathering efforts necessitated that the encounters were semi-structured in nature and in many cases with open-ended questions spurring a conversational and discovery-prone setting (Poulsen, 2015). This again required the interview protocols to be designed broadly and structured more specifically to contain open-ended keywords and not specific questions per se (Kvale & Brinkmann, 2012). As the interviews were exploratory in nature and designed also to yield learning on the part of this researcher, the interview protocols were not static as they were updated concurrently as knowledge was cumulatively amassed. This iterative process of continuously improving the interview protocols made the last used interview protocol version more effective and comprehensive than some of the earlier versions. This improvement made the interviews smoother and the dialogue more focused.

From a reliability point of view, more expansive conversations generated by the structure of the interview protocols made the requirements for capturing the interview data greater and more complex (Kvale & Brinkmann, 2012; Yin, 2014). This would increase the possibility for introducing bias on the part of this researcher which would be challenging to validate as this exploratory phase did not include audio taped and transcribed accounts of the conversations had (Flyvbjerg, 2006). In the three main case studies forming part of this research, more reliability and objectivity was achieved as the interview protocols were more refined and clear: Each interview protocol was designed specifically with the overall objectives of this research in mind at a meta level and with the propositions of each case study in mind a more tactical level (Thomas, 2014). This more focused design did not limit the interviews in terms of creativity and openness; on the contrary, the interview design provided a more productive environment where shorter yet more productive interview time would yield better and more comprehensive empirical data (Yin, 2014). Increasing validity was also the fact in the embedded China market study case, where the interviews were attended by four, three, or at a minimum two interviewers.

When it comes to validity of the knowledge created by this research, Flyvbjerg (2006) describes how preconceptions of some researchers would most likely exist in terms of results from qualitative work efforts always being more ambiguous and less unequivocal than results of more quantitative science. Further critique is levied upon single-case studies which are argued by some as being incapable of producing results that can be used to generalize in any way (Thomas, 2014). And finally, statisticians would argue that a point of saturation in terms of repeated qualitative input would be impossible to reach without a very high interview sample size difficult to obtain in a case study setting (Silverman, 2017).

Conversely, proponents of case studies and qualitative research methods would beg to differ along the lines of a several key dimensions important to the method applied specifically in this research. One paper discussing the case study method focused on five common misunderstandings about case studies (see the figure in appendix 2) and refuted them accordingly (Flyvbjerg, 2006). The clarifications by Flyvbjerg (2006) of three of these common misunderstandings are important to highlight in relation to this research:

a) That context dependent practical knowledge is not necessarily less valuable than context independent theoretical knowledge. In this PhD project, action research has enabled this researcher to add value to the constituencies involved in the different case studies. This was achieved by actively engaging in ways that may further the understanding of logistics in offshore wind of the case study constituencies and thereby reciprocate in terms of their time and efforts allotted to the objectives of this research.

b) That it is indeed possible to generalize from a single case study which is therefore able to contribute to the development of science. To some extent, this entire PhD study is an example of how the very heavy and voluminous components for WTGs and BOP cause significant logistics complexity which had not yet been researched well in academia. As such, the exploratory part of this research as well as the case studies ought to be generalizable at least within offshore wind.

c) That case studies are not only useful for generating propositions but also suitable for testing these propositions - and building theory. Whereas theory building has not formed part of this research, propositions in the form of the research questions have been tested out especially through the participant observation / action research type work efforts rendered. This continuous feed-back loop from testing out the propositions, also from the regularly scheduled Reference Group meetings (see appendix 3), has been useful for this research and increased reliability.

The body of empirical data assembled in the early stages of this research has been useful from a reliability and validity perspective. This was illustrated in one advance publication (Poulsen, et al., 2013a), where personnel from different organizational levels within firms as well as from different supply chain constituencies were interviewed. This diversity in interviewee background, perspectives, and relative position within the supply chain helped the empirical data to be triangulated in a concurrent manner throughout the progression of the work efforts where knowledge was generated on the part of this researcher. And the knowledge obtained was subsequently tested, in a real OWF environment as one example (Poulsen, et al., 2013b).

As it became clear that several logistics chains exist across the life-span of an OWF, and especially when the structure of the four life-cycles emerged to separate the logistics task (Poulsen, 2015), subsequent data collection was performed recognizing this. Examples of deliberate research designs catering to the logistics chains and life-cycles include the horizontal Ørsted case study focus across all life-cycles (Poulsen & Hasager, 2016), the vertical focus into the single O&M life-cycle phase (Poulsen, et al., 2017), and the horizontal view of all life-cycles and ultimate focus on just the two main life-cycles from a logistics perspective (Poulsen & Lema, 2017). This made the reliability of the empirical data better as the collection process was more focused, ultimately increasing the validity of the subsequent analysis, because the data was grouped, sorted, and organized more adequately within life-cycle phases and individual logistics chains (Seale & Silverman, 1997).

As the quantity of semi-structured encounters was rather high when this research was initiated, some of the same findings started to be repeated across multiple interviews. This led to a change in focus of subsequent interviews and the termination of some on data-saturated topics (Yin, 2013). The high quantity of semi-structured encounters carried out during the beginning of this research enabled this researcher to be able to more objectively compare and contrast the empirical data gathered during the entirety of this PhD study (Arbnor & Bjerke, 2009). The contextual settings of different interviewees became more understandable and it became possible to distinguish comments and statements made in an isolated or 'silo' manner pertaining to a narrow sliver of a logistics sub-chain versus broader life-cycle phase, or strategic OWF, or portfolio points of view. Again, this type of understanding, built on the part of this researcher, led to an improvement of especially the validity of the analysis performed on the empirical data mass.

It was challenging to convert the data analyzed into an interesting and digestive format for the different outlets of this PhD study. A qualitative data set presented in a paper on the creation of the Scandinavian Nordea bank through a series of mergers and acquisitions (M&A) (Vaara, et al., 2005) was of great inspiration to this researcher. This paper mixed text written by the authors with verbatim statements quoted directly from interview transcripts, creating a varied and interesting read, whilst also improving reliability (Vaara, et al., 2005). This approach was replicated in the Ørsted publication (Poulsen & Hasager, 2016). From a method perspective, Vaara et al. (2005) presented a complex and extensive case study where data was triangulated through participant observation, thematic interviews, and an external media analysis. This triangulation method to increase validity and reliability was mirrored in the O&M logistics publication (Poulsen, et al., 2017) where the action research / participant observation method was supplemented with the data from the 18 semi-structured interviews as well as the desktop study on 11 largely government sponsored cost studies. This way of performing triangulation efforts was in line with recommendations from Yin (2014).

In terms of presenting quantitative numerical data obtained as part of a large qualitative effort yielding interview transcripts and survey responses in the Ørsted case study, several frameworks were used (Patton, 1990; Huberman & Miles, 1994). These frameworks provided useful ways to present numerical data from qualitative sources like an interview coupled with numerical responses to the same question taken from a survey response. Some of this was presented in the Ørsted journal article (Poulsen & Hasager, 2016) and also utilized towards Ørsted when the logistics innovation strategy was presented to their steering group in September, 2015. For several publications, empirical data was summarized and made visible using models, case comparison tables, and case narratives supported by output from the required quantitative models (Voss, et al., 2002).

A key objective of the Reference Group of this research was to act as a sounding board for the findings generated as well as the process applied. Based on a premise of having extensive industry experience continuously available with strong managerial knowledge and subject matter expertise, the Reference Group forum acted as a means to ensure that the results of the research were not biased, and that validity and reliability was improved.

4.2 METHOD USED IN THE PUBLICATION PROVIDING THE CONTEXTUAL FRAME OF THE PHD STUDY

The first publication of this PhD study (Poulsen, 2015) was written to provide an account of the wind energy industry in general and the structure of the derived logistics market supporting the wind market. This was done mainly to provide a contextual frame of reference for the ensuing progress of this research and to provide an account of key findings of the exploratory empirical data collection efforts rendered. The publication was written as a cross-case comparison based on empirical data collection efforts in mainly European and Asian geographical settings.

The key part of the empirical data forming part of this publication (Poulsen, 2015) is a total of 160 semi-structured interviews and 28 participant observation encounters at conferences and derived from site visits performed to key nodes in the logistical chains related especially to offshore wind. The interviews took place mainly in Europe, but also in Asia, and the US. These interviews mainly used semi-structured interviews and open-ended questions in the interview protocols (Kvale & Brinkmann, 2012). The interviews lasted between 45 minutes and 2 hours, and the Asian participant observation site visits sometimes included extensive transportation time and could last up to a full day with time spent during conveyance or over a meal in a more informal manner to supplement the formal interviews.

4.3 PRIMARY AND SECONDARY CASE STUDIES

A 'perfect' or 'ideal' case study for this research would contain several attributes, dimensions, and features in order to yield useful input to the three research questions in line with the 'chain of evidence' logic described by Yin (2014) and the dimensions described in appendix 2. To support the research objectives, an important feature of such perfectly suited case study would be to enable the research of logistics in a broadly defined logistics setting and throughout the different life-cycle phases of an OWF as well as across a portfolio of several OWFs. Moreover, finding a case study with a varied organizational access as well as a global dimension in terms of the expected diffusion of offshore wind in new markets would ideally also be preferred. And finally, an important attribute of the efficacy of 'the right' case study would be for it to have an element of logistics costs understanding, preferably with an ability to be viewed in the context of LCoE. From a research design perspective (Parente & Ferro, 2016), a single or fewer case studies would be desirable as this would make the research more manageable and focused given the available resources.

To be able to answer the three research questions with the 'optimal', 'perfect', and 'ideal' case study, several possible case studies were actively procured during the early stages of this research:

- Based on the literature reviewed, a case study was procured in China for a major state-owned shipping conglomerate and in the US through a rail logistics operator.

- Facilitated by this researcher actively working with some of the organizations forming part of the Reference Group of this research, case study opportunities were procured with Ørsted (then DONG Energy Wind Power), Siemens Gamesa, and Offshoreenergy.dk.

- To find challenging and real problem-based learning projects for master's students in the department to work on, student projects were procured and, in some instances, completed. To the extent possible, these student projects were meant to act synergistically as case studies also forming part of this research.

The cases procured became available based on the efforts of this researcher to actively pry out different avenues of access to situations that would yield an opportunity to observe and study the real world from a perspective of logistics in offshore wind (Flyvbjerg, 1991). As such, the case studies procured yielded different options to pursue in further detail and these particular case studies of course represented only a fraction, as available to this particular researcher, of what the actual real world looked like in totality in terms of global offshore wind developments from a logistics perspective. The case studies procured therefore represented only a subset of case studies available, based on what was theoretically and practically feasible to procure given the network, background, and overall position of this researcher (Flyvbjerg, 2017).

As it turned out, one single and ideal case study able to answer all three research questions was not identified. Instead, several possible case studies were procured and table 4 provides a high-level review of the different options that became available as well as some of the key parameters for the prioritization of the case studies into primary / secondary / tertiary case studies for this research.

	Firm or case	Geo-graphy	Case access type	Summary of case oppor-tunity	Pros	Cons	Decision	Outcome
1	China Ocean Shipping Company	China	Empirical data collection efforts	Understanding of leading shipping group's involve-ment in domestic China and import/export business of wind	Insight into key emerging market of China	Mainly onshore wind focus with offshore plans	Secondary case study	Case ultimately abandoned; firm sub-sequently entered offshore wind
2	Rail logistics	US	Empirical data collection efforts	Understanding of domestic US use of railroad logistics	Unique to the emerging US market	Mainly onshore wind focus	Secondary case study	Some case work done, case ultimately abandoned
3	Ørsted	Global	Reference Group	Understanding the need for a global logistics innovation strategy	Broad logistics scope, ability to construct research design, global scope	Relatively ex-tensive and time consuming case study	Primary case study	Paper published (Poulsen & Hasager, 2016)
4	Siemens Gamesa	Global	Reference Group	Understanding of site parts logistics flow in containers	Global scope, focus on WTG manufacturing	Very narrow logistics chain 'silo' focus	Tertiary case study	Case abandoned after initial analysis
5	China market	China	Reference Group	Understanding of the China offshore wind market inclu-ding embedded case study	Cluster organi-zation with di-verse members, access to China market	Extensive case study with cul-tural challenges 'built in'	Primary case study	Paper published (Poulsen & Hasager, 2017)
6	Blue Water Shipping	Global	Student supervision	Understanding of wind port operations to enable expan-sion globally	Port as the 'con-nector' between land and sea operations, glob-al scope	Organizational changes mid-stream	Secondary case study	Student project finalized; case aban-doned
7	Offshore-energy.dk	Europe	Student supervision	Understanding of O&M logistics with an aim to re-duce costs in industry-wide initiative	Identification of practical cost-out initiatives; LCoE context	Transition from student super-vision to actual industry support-ed project	Primary case study	Paper published (Poulsen, et al., 2017)

Table 4. The case studies procured including selection process summary.

After scrutiny and thorough evaluation, some of the cases procured were found to have more of an onshore focus and, although also interesting in principle, the key focus of this research was logistics in offshore wind. Also, the scope and focus of the logistics chain of the procured case studies were factors subjected to an evaluation and a broader field of study was sought as opposed to a more 'narrow' logistics focus. Organizationally, stability within the case study organization was not a prerequisite for case study prioritization. However, as some of the case study endeavors were extensive in nature and therefore expected to take a long time and considerable effort to complete, this researcher deemed that firmly structured organizations with clear ownership of the research project would be preferable from a research risk management perspective.

Coupled with the characteristics of the ideal case study outlined above, the case study prioritization process may be described as follows:

- The China Ocean Shipping Company Group case study was procured through networking efforts in China. It did, however, become clear that whereas offshore wind was clearly an interesting market for the Group, the focus was onshore wind for the bulk shipping division part of the group set to own the possible case study. The container division transported onshore as well as offshore wind parts, components, and modules to/from China, the shipyard division had constructed several offshore WTIVs for European ship owners, and the bulk shipping division had concentrated mainly on onshore wind domestically in China as well as internationally. In dialogue with the organization, it became clear that the path to offshore wind for the bulk shipping division was indeed laid out, however, the timing was not a good fit with this research. The case study was therefore assigned a secondary priority. In 2016, after the empirical data collection efforts of this research had been completed, an offshore wind joint-venture was announced between the bulk shipping division of China Ocean Shipping Company Group and Belgian DEME-GeoSea (www.offshorewind.biz, 2016).

- Also procured through networking efforts, the unique US rail set-up for wind component transport was investigated through this research and a case study opportunity procured with a major US rail logistics firm. However, due to the infrastructure size limitations when wind components expand to offshore wind weight/scale, rail was possible mainly as an onshore wind application. In addition, the US offshore wind market was not deemed to start in earnest within the timing of empirical data collection efforts of this research. Accordingly, the US rail case study was therefore assigned a secondary priority.

- A case study about offshore WTG site parts was procured from Siemens Gamesa as a member of this research project's Reference Group. Global in scope, the site parts were shipped in standard ocean containers alongside the main wind components and fitted into the WTGs during the pre-assembly and commissioning processes. A fairly standard supply chain within the outbound logistics chain, this opportunity was found to have a very narrow logistical scope upon further study: Set in the installation and commissioning life-cycle phase, the site part movements were fixed from a set warehouse location in Denmark to mainly a pre-assembly site, also in Denmark. Although Siemens Gamesa was posited as the global offshore wind market leader with a 96.4% global WTG market share (WindEurope, 2017), the case study was assigned a tertiary priority due to the very narrow logistics scope.

- The Blue Water Shipping student supervision project held a lot of promise and potential because it was an expansion project with global potential focusing on process, people, and knowledge replication across heterogeneous markets. Organizational changes within the firm caused the initial student project to be finalized in a reasonable manner whereas the continuation of the work, as part of this research, was deemed to be too risky. Consequently, the case study was assigned a secondary priority.

In terms of overall ability to meet the criteria for a successful and ideal empirical data collection setting (Seale & Silverman, 1997), three of the procured case studies were identified as primary case studies for different reasons. When prioritized as primary case studies, focus was put into furthering the work on each of these three case studies significantly and the cases were meant to be able to generate data which would be able to answer one of the three research questions respectively (see Table 5 for the high level case study selection rationale). The three primary case studies were the Ørsted, O&M logistics, and China market case studies.

	Primary case study	**Description of case study**	**Main reason for prioritization as primary case study**	**Link to research questions of this research**
1	Ørsted	Global offshore wind logistics innovation strategy	Work with world's leading offshore wind developer to define what 'logistics' entails	#1 - The organization of offshore wind logistics and the relative importance of logistics
2	Offshore-energy.dk	Offshore wind O&M logistics cost reduction	Work with an industry-wide consortium on cost reductions within a very defined scope	#2 – Analysis of costs in offshore wind logistics
3	China market	China offshore wind market understanding	Access to a Chinese WTG manufacturer driven case study in China	#3 – The characteristics of logistics for offshore wind in an emerging market

Table 5. Rationale for primary case study prioritization and link to the three research questions.

Work had already been done to varying degrees on the secondary as well as tertiary case studies and the knowledge amassed from this activity was utilized in this research project going forward to the extent possibly, mainly as background knowledge. For example, work with Siemens Gamesa on their case was useful to understand their overall logistics approach as this firm had a very significant market share of WTG supply in offshore wind (WindEurope, 2017). Similarly, the work on port operations with Blue Water Shipping yielded an important insight into the mechanics of this node of the supply chain essentially serving as the 'switch-board' between the land and sea-based logistics chains. And so forth. However, after the prioritization process had been completed, work on the three primary case studies became the focus of this research.

4.4 RESEARCH DESIGN OF EACH OF THE THREE PRIMARY CASE STUDIES

Each of the three primary case studies forming part of this PhD study had a separate and unique research design (Yin, 2014). Each case study research design was deliberately crafted to symbiotically form part of the overall research design of this research. Each case study led to the publication of an academic journal article focusing on that particular case study (Poulsen & Hasager, 2016) with some additional desktop analysis involved in two of the cases (Poulsen, et al., 2017; Poulsen & Hasager, 2017) as well as a positioning compared to academic literature in all cases. The details behind the research design of each case study has been described in the respective associated academic journal publications as well as in the separately published and fifth academic journal article of this research with the cross-case analysis (Poulsen & Lema, 2017). The research design of the three primary case studies may be summarized in what follows next.

The Ørsted global *offshore wind logistics innovation strategy case study* was the background for an academic journal publication (Poulsen & Hasager, 2016) which generated a proposed definition of offshore wind logistics on the basis of a single company case study (Flyvbjerg, 2006).

- Based on a 7-step plan as a framework (Roulston, 2012), this case study included 15 formal interviews that lasted 60-90 minutes each and were audio taped for the most part (only one of 15 interviews was not audio taped), transcribed, coded, analyzed, and ultimately interpreted (Neergaard, 2007; Thomas, 2014). The Ørsted case study also contained a survey which was designed with use of input from Yin (2014) that was sent to 115 respondents in the firm and yielded 38 useable survey responses. This took the total sample size to 53 useful answers of 130 possible (~41%). One of the interviews had two interviewees and another interview had three interviewees which took the total number of interviewees during the 15 interviews to 18 people. One interview included a participant observation/action research site visit to a key logistical shore base facility used for O&M functions.

- Prior to carrying out the interviews, focus group meetings (Thomas, 2014) with Ørsted personnel yielded an understanding of how the firm was organized.

There was no horizontally focused logistics department as such which complicated matters. In addition, complexity was added because much autonomy pertaining to logistics had been assigned organizationally to the individual OWF projects during the installation and commissioning life-cycle phase as well as during the O&M life-cycle phase akin to the middle-up-down management style described by Nonaka and Takeuchi (1995). The firm was organized with different layers of hierarchical management each with unique decision-making powers and authority at a middle-management level (Nonaka & Takeuchi, 1995).

- The ideal interviewee composition structure was therefore put forward to Ørsted as being a cross-section of the different vertical managerial layers across the different firm functions orchestrated along the 4 sequentially structured, horizontal life-cycle phases of an OWF (Poulsen, 2015). Based on the ideal interviewee composition structure and overall interview activity plan (Booth, et al., 2008), an Ørsted project team member was given authority to suggest the different personnel in respective positions to be interviewed. After a process of negotiation to ensure a match to the objectives of this research, Ørsted personnel arranged the different interview meetings.

- All the interviews utilized an interview protocol (see appendix 4) which was used in the same manner for every interview. The interview protocol had two sections of which section one for office-based personnel was used 15 times and section two for site visits was used one time only.

- The opening sections of the interview protocol were performed by the Ørsted interviewer and supported by a brief hardcopy presentation reviewed in the same way for each interview to explain the context and background during each session in an identical manner (Kvale & Brinkmann, 2012). Given the academic objectives of this research, the Ørsted participant in the interview meetings agreed to have a supplementary role and not lead the interviews nor carry the conversation in line with recommendations from Yin (2014). As such, this researcher led the interviews after the opening sessions were completed and the interview handed over. In addition to the audio taping, which was done only with explicit permission, interview notes were taken by both interviewers directly on to a hardcopy version of the interview protocol utilized (hardcopies were printed for each interview). Besides the different interview questions across the topical sub-sections, the interview protocol contained an ex-post section intended for the interviewers to utilize immediately after the interviews to capture key items of major importance revealed during the interview.

- Crafted after the interviews had been performed, and based on the learning generated from the interviews, the survey was initially created in a draft format and sent to 15 firm respondents for feed-back. After an adjustment process catering to some of the direct feed-back received to the draft format and contents, a final version of the survey (see appendix 4) was issued to 100 respondents in the firm. The 100 respondents to the final survey were chosen without involvement of the Ørsted team and based on full organizational transparency as outlined by Booth, et al. (2008) in terms of the 1,600 Ørsted employees working in the wind power market segment at that time. Ørsted then organized for the link to the survey to be emailed to the 100 selected employees along with a cover email citing the context, background, and key objectives. Two reminders for responses were issued to the population of 100 Ørsted employees. Between the test survey and final version, 38 useable responses were received from the 115 respondents equal to a 33% response rate.

- Along with Ørsted personnel, a total of four master's students participated in the analysis phase of the research which in turn was applied by a total of five master's level students in getting their semester exams with this researcher as their supervisor. Examiners for the master's level exams included a co-author of this researcher and both formal Aalborg University advisors of this PhD project. Ørsted personnel also participated in the focus group sessions where the data was reviewed. At one interactive focus group session conducted in a workshop setting with Ørsted personnel on November 28, 2014 to validate the interview protocol after having conducted the initial seven interviews, a collaborating professor from Boston University also attended and provided input.

- To enhance learning, one master's student was allowed to participate as an observer in one of the interviews.

The *Offshoreenergy.dk offshore wind O&M logistics cost reduction case study* was a major enabler of one publication article (Poulsen, et al., 2017) which presented a practical offshore wind business case to reduce logistics costs in the context of LCoE cost reduction analyses derived from 11 largely government sponsored cost studies.

- Case study participation spanned a total of 20 months. The case study formed part of an overall industry-wide initiative to reduce LCoE for offshore wind (Høg, 2015). The case study was based on 14 initial interviews and four additional phone interviews performed by a master's student as part of a master's level student supervision project where one of the advisors of this research was the main supervisor at master's level and this researcher the co-supervisor.

- The interviews utilized an interview protocol designed for semi-structured interviews with open-ended keywords forming part of the interview protocol instead of fixed questions (Kvale & Brinkmann, 2012). The interview planning process was made jointly ahead of a major conference event and a list of ideal interviewees from a number of firms in the offshore wind industry was jointly crafted. The interview protocol design and interview planning process efforts were jointly rendered by the master's student and this researcher. Out of 25 ideal interviewee candidates at firm or person level, the student was able to conduct 14 interviews in person during the conference. Four more interviews were deemed to be critical in nature and as such, phone interviews were jointly arranged for the master's student to carry out immediately after the conference.

- Each interview lasted between 20 and 80 minutes. The interviews were not audio taped or transcribed verbatim and instead, interview summaries were subsequently made by the student based on his notes. The interview summary notes were utilized for the master's student and this researcher to jointly and qualitatively collate a gross list of cost reduction ideas produced from the 18 interviews. The main tool used for coding and producing the list of cost reduction ideas was Excel.

- The gross list of cost reduction ideas was subsequently supplemented by focus group working sessions and sub-group business case crafting sessions where the research angle of this researcher was maintained through action research that involved participant observation directly within the actual work sessions. The focus group sessions were planned, managed, and led jointly by this researcher and the master's student.

- The student project yielded a total of two semester exams for the student with one of the advisors of this research as the main supervisor in both cases and this researcher as the co-supervisor in one and supporting in the other. After the second exam and student graduation, the student was hired by Offshoreenergy.dk and the project transitioned to become a real-life industry project under the realm of Offshoreenergy.dk and with this research as the only academic anchoring point (no longer part of an Aalborg University Master education program).

The *China offshore wind market case study* was a major contribution to an academic journal article (Poulsen & Hasager, 2017) which provided a gap analysis at industry level of offshore wind in China, including logistics. Besides the empirical data collection efforts, the publication also included a desktop study rooted in the literature which reviewed the related national legislative and firm level policy execution in China.

- Spanning 33 months in total, including all five trips to China, the crux of this case study was an embedded case conducted in collaboration with Offshoreenergy.dk during two visits to China, that lasted approximately four weeks in total. The embedded case study yielded a total of 15 formal and structured interviews as well as 34 participant observation site visits. Of the 34 participant observation site visits forming part of the embedded case study, 12 were conducted in direct continuation of or in connection with the formal and structured interviews. The site visits were encouraged and sought for by this researcher to gain a real-life supply chain view. This action research approach of understanding and participating in the actual logistics chain seemed to be a good way to compare the maturity of logistics in offshore wind in China to particularly Europe.

- The encounters of the embedded case study were organized mainly by a leading Chinese manufacturer of offshore WTGs. This manufacturer of WTGs opened up their supply chain to include meetings with their end customers in the form of developers/operators as well as meetings with their sub-suppliers. As such, the interview activity planning as well as the design of the interview composition was done jointly by this researcher and the Chinese manufacturer of WTGs. A great degree of interview planning autonomy was transferred to the Chinese WTG manufacturer. Interview meetings with ideal industry constituencies of relevance to the academic objectives of this research were furthermore arranged jointly by this researcher with the Chinese WTG manufacturer. In addition, formal interviews with 'ideal' industry constituencies were arranged independently by this researcher based on the literature review as well as prior empirical data gathering efforts of this research, preceding the embedded case study.

- Most of the interviews within the embedded case studies were carried out jointly with the Chinese manufacturer of WTGs. The 15 formal interviews were organized in a semi-structured manner as outlined by Kvale and Brinkmann (2012) using a bilingual interview protocol which contained a mix of more specific as well as open-ended questions (see appendix 4). The interview setting as well as the actual approach were quite different from that experienced in a European context as outlined in the European case studies separately. The two approaches were contrasted in the cross-case analysis (Poulsen & Lema, 2017). As such, the Chinese interviews lasted between 45 minutes and 7.5 hours with the higher end of the range applicable if a participant observation site visit and/or meal formed part of the interview. The embedded case study participant observation site visits each lasted between 30 minutes and 5 hours.

- Although based on interview protocols that were bilingual in nature and in some cases forwarded to the interviewees in advance, the Chinese interviews contained situations where discussion items needed clarification during the interview meetings and/or where translation efforts were insufficient. In several cases, the interviewees also requested to respond to the topics contained in the interview guides separately in writing after the interview had been finalized.

- Due to the academic objectives of this research, each interview was led by this researcher and conducted in English with support from a native Chinese speaking translator. 2-8 interviewees attended the interviews. The relatively high number of interviewees was because the count included observers and translators. Audio taping was either not practical or feasible in the Chinese setting due to the number of people participating in the meetings, due to the meeting room setting, or due to the surroundings (e.g. a manufacturing site).

In some cases, audio taping was not permitted.

- During interview-linked participant observation site visits, supplementary oral dialogue could be had during transportation and/or informally over a meal: Prior points raised could be clarified through actual showcasing, identification, as well as demonstration at the site as intended with this action research setting. Questions could sometimes be answered more comfortably in a more private setting as opposed to a group context.

- In addition to the embedded case study described above, this researcher also conducted a total of 47 semi-structured interviews and six participant observation site visits forming part of this research in advance of the embedded case study. Furthermore, an associate researcher conducted a secondary data gathering process consisting of 41 semi-structured interviews (Poulsen & Hasager, 2017).

4.5 RESEARCH DESIGN OF THE FIFTH ACADEMIC PAPER – THE CROSS-CASE STUDY

The fifth publication of this research (Poulsen & Lema, 2017) was crafted as a cross-case analysis which set out to compare the logistics set-up of the more mature offshore wind market of Europe to the emerging offshore wind market in Asia. This publication was intended to be published last and after the publication of the two European case study outcomes and the China market case study publication. However, as it turned out, the publishing process was altered slightly for exogenous reasons which altered the publication sequence slightly. The original premise of the article still stands and the multiple-case design in line with Yin (2014) could perhaps have stood even clearer now that all three underlying case studies each have had a separate journal article duly published.

This fifth cross-case publication recapped the methodology used primarily in the embedded Ørsted case study and contrasted that to the embedded case study further embedded within the China market case study as outlined by Neergaard (2007). In this way, 15 formal interviews in Europe (Poulsen & Hasager, 2016) were correlated and contrasted also in terms of validity and bias (Potter & Hepburn, 2012) to 15 formal interviews in China (Poulsen & Hasager, 2017). Based on different opinions about the relevance of findings from a single company case study (Flyvbjerg, 2006), the fifth cross-case study publication also made reference to the O&M logistics publication (Poulsen, et al., 2017) in order to ensure that the European side of the research presented contained an industry-wide perspective to supplement that of market leader Ørsted.

The fifth cross-case study publication (Poulsen & Lema, 2017) was largely crafted based on a review of scientific state-of-the-art along different dimensions: It was identified that a gap in academic literature existed regarding the supply chain as a barrier, bottleneck, and/or constraint to adequate diffusion of wind energy as part of the ongoing global renewable energy transformation. The supply chain of wind energy was analyzed and the concept of 'supply chain lead firms' explored from an academic literature perspective. A literature review of renewable energy supply chains was included and revealed a gap.

Based on this positioning in an academic context, the empirical data collected in the three case studies was used to present the findings in a supply chain context with a logistics angle across the life-cycle phases of an OWF. This was done to illustrate the different types of logistical chains, different logistical challenges, and logistics bottlenecks accounted for mainly during the construction and operations OWF life-cycle phases. The empirical data was finally used to compare the more mature European markets to that of the emerging Asian markets from a supply chain readiness perspective and here, logistics findings were used to generalize across the supply chain disciplines.

CHAPTER 5: ANALYSIS

This chapter will present the analysis performed as part of this research in more detail (the analysis techniques box in the figure in appendix 2 refers to this).

The initial publication within this PhD thesis (Poulsen, 2015) was written to create a contextual introduction to the research area, to introduce the area of logistics in offshore wind, as well as to review some of the involved constituencies both in the offshore wind industry and the derived logistics market. The paper was more exploratory in nature and based on an extensive empirical data collection process. The analysis performed made use of widely acclaimed theoretical frameworks and was as such less rooted in the academic literature.

For the three case studies each forming the foundation of the subsequent three respective publications of this research (Poulsen & Hasager, 2016; Poulsen, et al., 2017; Poulsen & Hasager, 2017), the analysis processes were organized in a more structured and specific manner to yield substantive answers to the three research questions of this research. Each of the three papers were positioned based on reviews of the academic literature for key scientific terms relevant to the publication (see Table 6).

Journal publication	Key academic term #1	Key academic term #2	Key academic term #3
Ørsted logistics innovation strategy case study (Poulsen & Hasager, 2016)	Levelized cost of energy	Logistics	Logistics innovation
Logistics O&M case study (Poulsen, et al., 2017)	Offshore wind operational expenditure	Offshore wind operations and maintenance	The logistics share of offshore wind operations and maintenance costs
China offshore wind market case study (Poulsen & Hasager, 2017)	Industry maturity (industry life-cycles)	Chinese state-owned enterprises	Mergers and acquisitions

Table 6. Key scientific terms reviewed within the journal publications of the three case studies.

The fifth cross-case study (Poulsen & Lema, 2017) was built upon a review of academic literature and a repositioning of the empirical data gathered mainly as part of the work with the three case studies. This fifth cross-case study paper was crafted mainly in response to the third research question of this research about emerging offshore wind markets. To the extent required, the main empirical data gathered from the three case studies were supplemented by the prior exploratory empirical data collection process. Details of the actual analysis performed has been included in the individual publications and will be summarized in what follows here. Section 5.1 summarizes key analyses considerations for all five publications forming part of this research. Section 5.2 provides further insight into the analysis process for the initial paper of this research which set the contextual research frame of this PhD study. Section 5.3 provides an account of the analysis process performed in the Ørsted logistics innovation strategy publication as well as the separate analysis yielding input for Ørsted to utilize internally for their logistics innovation strategy. Section 5.4 outlines how the analyses performed for the logistics in the O&M life-cycle phase were carried out both as part of the work performed with Offshoreenergy.dk as well as the desktop analysis of 11 major and mainly government sponsored cost studies. Section 5.5 details the analyses of the China offshore wind market case study in terms of the different 'waves' of empirical data collected as well as the separate desktop study on the legislative and political context at a national level including firm-level execution with full institutional orchestration by the government. Section 5.6 outlines the analysis process of the fifth cross-case study of this research which is based on a literature review and an application of the empirical data body to establish, compare, and contrast supply chain readiness for offshore wind in Europe versus Asia generalizing based on the lens of logistics applied in the research. Finally, section 5.7 elevates the analysis to a meta-level, cutting across all five publications to illuminate how the different analyses were intertwined and to provide an insight to the levels at which the analyses were conducted including a summary of the key implications.

5.1 ANALYSES CONSIDERATIONS FOR ALL FIVE PUBLICATIONS FORMING PART OF THIS RESEARCH

To summarize and elaborate further on the analyses described in the initial paper (Poulsen, 2015), the individual case study publications (Poulsen & Hasager, 2016; Poulsen, et al., 2017; Poulsen & Hasager, 2017), as well as the cross-case publication (Poulsen & Lema, 2017) respectively, it is necessary to first introduce how the actual analyses were performed across the five papers.

The process applied and the setting of the three case studies was unique and bespoke in each case. A common trait across the three case studies was that this researcher was given the opportunity to be instrumental in the crafting of the research design, to lead the actual empirical data gathering process, to design the analysis phase, to lead the analysis process itself, and finally to be instrumental in the interpretation of the results amassed.

As such, the empirical data collection process of the first paper (Poulsen, 2015) was mainly carried out by this researcher whereas the Ørsted data collection process was done by a team of two interviewers, including this researcher. The Ørsted analysis was performed by a research team that initially consisted of three members and subsequently was expanded to six core team members, including this researcher (Poulsen & Hasager, 2016). The Offshoreenergy.dk O&M logistics case study consisted of this researcher and one additional core team member to do the empirical data collection and design the practitioner analysis process which was largely done using focus groups and workshops. The desktop analysis comparing 11 cost studies (largely government sponsored) was performed by this researcher alone and the research Reference Group provided feed-back to the results (Poulsen, et al., 2017). The empirical data gathering process of the embedded case study in the China market case study consisted of this researcher and two core team members initially during the initial trip and then one core team member during the last trip. The desktop analysis of the regulatory and political setting of China was performed by this researcher alone. The analysis for the embedded China market case study was subsequently performed by this researcher alone and the research Reference Group provided useful feed-back to the results. Additional feed-back to the research on China was also generated from several 'after work' sessions open to the public (Poulsen & Hasager, 2017).

A graphical display of the key analysis elements across the five publications of this research has been provided in table 7.

Publication	Data source	Primary analysis	Secondary analysis
Contextual research frame (Poulsen, 2015)	Exploratory setting with large quantity of semi-structured interviews	Role of nation states as entrepreneurs at industry level	Business models of pure play wind firms versus conglomerates using logistics as parameter to evaluate success
Ørsted logistics innovation (Poulsen & Hasager, 2016)	Ørsted case study	Offshore wind market leader input on how logistics is defined, organized, and what the costs are	Logistics innovation strategy input generated for Ørsted internal use
O&M logistics deep-dive (Poulsen, et al., 2017)	O&M logistics case study	Interviews and focus groups with broadly assembled group of industry practitioners yielding real-life cost savings business cases	Desktop analysis of 11 largely government sponsored major studies on offshore wind costs
China offshore wind market (Poulsen & Hasager, 2017)	China offshore wind market case study	Three main 'waves' of empirical data collection efforts interpreted with a focus on industry gaps for offshore wind	Desktop analysis of the legislative and political environment supporting offshore wind and firm-level execution
Cross-case on supply chain readiness (Poulsen & Lema, 2017)	Ørsted / China and to some extent O&M case studies	Review of academic state-of-the-art to position the analysis	Supply chain readiness comparison between Europe and Asia based on a logistics perspective

Table 7. High level view of the analyses elements forming part of this PhD study.

5.2 THE ANALYSIS OF THE ACADEMIC PAPER PROVIDING THE CONTEXT OF THIS RESEARCH

The paper providing the contextual research frame of this PhD study (Poulsen, 2015) was based on semi-structured interviews conducted from February 1, 2013 through May, 2014. The empirical data collected were subjected to analysis using different sets of existing academic frameworks:

- A proposition that nation states can actively lead industry evolution with a positive impact for private firms was analyzed by subjecting the empirical data collected to the revised ‘diamond model’ framework on how nations compete (Porter, 1998). Further supporting the analysis was a more recent account of specific examples of nation states as entrepreneurs at an industrial level including an account of the wind energy industry (Mazzucato, 2014).

- A proposition about the wind market increasingly being split between two business models (Nielsen & Lund, 2013) was analyzed by subjecting the empirical data collected to the ‘resource based view’ thinking (Wernerfelt, 1984) and more specifically the ‘valuable-rare-imitable-organization’ framework (Barney, 1985). Across the wind energy industry, pure play firms only competing in this market are competing against several conglomerates viewing the wind market as just one of many industries within which they are involved.

- A proposition pertaining to conglomerates being able to integrate derived support industries such as logistics into their main portfolio of products and services using M&A as well as joint-venture creation was reviewed (Haspeslagh & Jemison, 1991; Reed & Lajoux, 1999; Trompenaars & Asser, 2011). This was done by subjecting the empirical data collected, as well as a desktop study on M&A / joint-venture activity pertaining to logistics, to a framework on how to create firm level alignment of corporate strategy with supply chain strategy (Chopra & Meindl, 2013) as it specifically pertains to logistics. The objective was to determine whether conglomerates had a greater ability to use varying degrees of M&A and/or joint-venture creation (Narasimhan & Nair, 2005; Reed & Lajoux, 1999), even with nation state owned firms, in order to integrate competencies viewed as core, scarce, or critical.

This was different from the analysis performed for the three primary case studies of this research. The analyses for these case studies will be presented in the following sections.

5.3 THE ØRSTED LOGISTICS INNOVATION STRATEGY ANALYSIS

The Ørsted global offshore wind logistics innovation strategy case study comprised an analysis phase spread across different major academic and firm related milestones within the project and detailed in an academic journal article published as part of this PhD study (Poulsen & Hasager, 2016).

The empirical data collection was based on interviews as the initial source and after the completion of the first seven interviews, the interview protocol was validated to ensure that it indeed had the desired functionality and to ensure academic construct validity (Yin, 2014). As such, un-coded and not yet fully transcribed interview findings were analyzed, based mainly on the note taking of the two research team interview participants. The preliminary review of the seven first interviews was conducted together with Ørsted personnel in a focus group setting organized as a workshop where the different findings were grouped based on the original interview protocol. After the workshop where storyboards were drawn in line with Thomas (2014), several changes were made to the interview protocol which was then utilized in the slightly altered format (see appendix 4) for the remainder of the interviews.

Upon completion, the interviews were transcribed by different members of the research team. The transcript was reviewed and edited / completed by another research team member and a final review was performed by the transcriber, the reviewer, and this researcher. The interview data were finally reviewed and compared to the notes taken by the two interviewers across all 15 interviews.

In terms of whether to use a software for organizing, coding, and analyzing the data, the research team reviewed different available options like NVivo, WebQDA, ATLAS.ti, XSight, and f4analyse in accordance with considerations about this by Yin (2014). Each of the tools required training which was deemed by this researcher to be well beyond the scope and scale of the curriculum in terms of the part of the research team which included four master's students. Instead, Microsoft Excel was used to analyze the interview data across three dimensions to form line-items in the spreadsheet used for analytics. Key contents from the transcripts were copied and coupled with the corresponding interview notes from the interviewers and combined with quotes from the interviewee where required. Three columns were added to attribute keywords to each line-item in order to group the different interview data line-items.

Another focus group was organized after the completion of all 15 interviews. Using a slightly improved approach, the themes and groupings of findings were identified using the constant comparative methodology for analysis supplemented by the visualization methodology referred to as drawing storyboards (Thomas, 2014). It was during this focus group session that the structure of the subsequently issued test survey was created and a need for training on survey mechanics was identified. During one training session on April 14, 2015, a fellow PhD student from Aalborg University conducted a course for the research team on basic survey composition, data collection, and analysis. This training aided the research team to translate the qualitative interview data to a survey format organized in terms of questions to be able to ease the subsequent analysis process of incoming responses. To ensure academic construct validity, a test survey was issued to a total of 15 Ørsted employees chosen by Ørsted based on the open mind and willingness on the part of the Ørsted test survey employees to voluntarily support the endeavor. It was based on the direct feedback to the survey contents, structure, and look-and-feel from these 15 employees that the final survey for the wider population of 100 Ørsted employees was ultimately created (see appendix 4). A total of 38 useable survey responses were received.

Based on the empirical data body collected from the interviews and survey responses described above, the analysis process included several different work streams that formed part of the subsequent academic publication:

- Quantitative computations on the relative share of logistics costs of total capital expenditure (CapEx), of total operating expenditure (OpEx), as well as of total LCoE.

- Qualitative work efforts rendered on the specialized vocabulary and terminology utilized in the offshore wind industry in general as well as the case study firm in particular.

- From the qualitative data collected in the interviews and survey response texts, the analysis efforts yielded many logistics innovation ideas which were subsequently prioritized together with firm representatives.

- The qualitative analysis also yielded several organizational implications for the firm to consider in terms of logistics as the offshore wind market was globalizing.

- Finally, the analysis produced a logistics innovation strategy report for Ørsted. This strategy was produced under strict confidentiality between Aalborg University and Ørsted (subsequently expanded to include the Technical University of Denmark for publication purposes). To set the scene, this logistics innovation strategy report contained a contextual background section on why Ørsted had determined that they needed a logistics innovation strategy, background on the wind power market, Ørsted as a firm in a wind power market contextual setting, and a perspective on the competition, partners, and main suppliers of Ørsted. The logistics innovation strategy contents included a funnel for evaluation of innovation ideas generated from the interview and survey process, input on organizational improvement opportunities for the logistics field, input on ambiguous terminology used for logistics, macro level trends as key impact areas for logistics, and data on the importance of logistics as a share of LCoE.

As an example of the detailed analysis process, a total of 28 useful answers from interviews and surveys were yielded that each pertained to the relative logistics costs measured as a percentage and seen in relation to a specific cost grouping. The definition of ‘useful’ cost groupings for the analysis in an academic context was that the answers should be based very distinctively on either CapEx (14 answers), OpEx (eight answers), or LCoE (six answers). These useful answers were grouped and analyzed to calculate the minimum, mean, and maximum values for each of the three datasets. Whereas it was easy to understand the percentage as a stated and absolute number either from an interview transcript/taped conversation or as a response to a survey, the qualitative context was harder to ascertain. The context of the interview and/or survey response would need to clearly reveal if the logistics spend expressed as a percentage was intended as a vertical life-cycle phase answer such as installation and commissioning (CapEx) or O&M (OpEx). In other cases, talking to different people produced different types of cost expressions (LCoE). Ensuring that the context was correct was critical for the data to qualify for inclusion in the analysis. As part of the 15 interview transcripts and 38 usable survey responses, it was not possible to ascertain the correct grouping of logistics costs in all cases and several responses were therefore discarded leaving behind the 28 useful answers for the analysis.

5.4 THE DEEP-DIVE INTO OPERATIONS AND MAINTENANCE COST CALCULATIONS TO REDUCE COST

The Offshoreenergy.dk offshore wind O&M logistics cost reduction case study paper included two sets of analysis efforts: The first set involved participants from a cross-section of firms active in the offshore wind O&M logistics arena and the firms and background were detailed in a newspaper article by Høg (2015). The second set of analysis efforts was a desktop study performed only as part of this research by this researcher (Poulsen, et al., 2017).

As for the analysis efforts with the firm participants, the gross list of cost reduction ideas generated from the interviews was reviewed during two focus group meetings organized in a workshop setting where storyboards were drawn (Thomas, 2014). The focus group meetings featured active participation from the involved industry practitioner volunteers who had been invited through their respective firms to participate in the wider industry initiative to identify cost savings for offshore wind. To have direct access to the process from a research perspective, participant observation with direct action research involvement of this researcher in the different focus group meetings was deemed to be the more effective way to continue to be part of the process (Kristiansen & Bloch-Poulsen, 2017). The work process was made further complex as efforts with the practitioner group were split between two separate sub-groups that worked on the two respective business cases thus increasing the need for participant observation/action research (Snyder, 2009; Thomas, 2014).

The work with the two sub-groups led to the creation of two separate and comprehensive business cases which were in turn validated with expert opinion holder interviews either in individual meetings and/or via phone. The process of creating and validating the business cases was jointly performed by the master's student (at that time working for Offshoreenergy.dk) and this researcher. One of the business cases – working both during daytime and at night offshore or 24/7 – was part of the ensuing journal article publication (Poulsen, et al., 2017) and therefore subjected to extraneous scrutiny.

In the publication, the business case was further supplemented by an account of the second set of analysis efforts which was an in-depth desktop analysis of the logistics cost calculations featured in 11 different major studies pertaining to cost reductions in offshore wind (Poulsen, et al., 2017). The desktop analysis was performed by analyzing logistics costs at a line-item level with the O&M life-cycle as the key delimitation in terms of scope given the extent of the 11 major cost studies reviewed.

The primarily quantitative 24/7 business case, obtained qualitatively in the focus group setting, was built on input from the project sub-group members and put into an overall cost context by utilizing a commonly accepted LCoE calculation tool developed by Megavind (2015).

Conversely, the quantitative analysis of the 11 cost reduction studies (largely government sponsored) was limited in terms of scope to the O&M life-cycle phase only and contained three layers of data:

1. The core part and inner layer of the analysis was the logistics costs which were compared both in terms of definitions, scope, and monetary amounts at an individual cost line-item level.

2. The second layer was the ensuing findings in terms of how the 11 cost reduction studies (largely government sponsored) made use of rather different assumptions, dimensions, and units of analysis as the basis for their calculations.

3. The third layer of the desktop analysis was a comparison of annual OpEx for offshore wind across all 11 studies restating the individual minimum/maximum ranges in a directly comparable manner, using a single currency.

The 11 cost studies were found to vary significantly and as a result, the most detailed study from a logistics perspective in terms of line-items (GL Garrad Hassan, 2013) was chosen as a base case.

5.5 THE CHINA OFFSHORE WIND MARKET ANALYSIS

The China wind market case study had to be adapted to the Chinese context and interview setting as outlined in section 4.4. The analysis consisted of an empirical data analysis portion as well as a desktop analysis (Poulsen & Hasager, 2017).

The analysis of the empirical data collected through interviews and participant observation site visits (Kvale & Brinkmann, 2012) was based on a less rigorous foundation than that of the European case study settings:

- As it was difficult to lead the interview in a dynamic translation environment and take notes simultaneously, supplementary interview notes were made by two additional interviewer team members as well.

- Through an interactive meeting note review using email and online meetings, a merge process was initiated once back in Europe. Based on discussions and dialogue, a single set of interview summary data was created through a series of calls, emails, and documents exchanged.

- The analysis activity forming the crux of the merge process was based on the individual meeting notes with the objective to create a unified set of combined interview / site visit meeting notes which was achieved.

Based on different vantage points and degrees of cultural experience with China, many details and topics had to be clarified and discussed in order to create alignment between the notes of the three members of the interview team (Potter & Hepburn, 2012). From the combined interview and participant observation site visit notes, a gap analysis at industry level was assembled by this researcher. The gap analysis was organized into three levels:

1. The core of the analysis was the WTG manufacturer level and here, logistics featured as a prominent challenge to be resolved across all life-cycle phases. Compared to Europe, a major difference was that the WTG installation process is controlled by the major developers in China; not the WTG manufacturer. This made the logistics scope of the WTG manufacturer less complex.

2. The next layer of the analysis was that of the developers/operators responsible to construct and operate the OWFs in China and here, a desire to collaborate with and learn from European experiences was expressed across different functions and disciplines. For major developers, the logistics scope was more complex than in Europe as the WTG installation process was part of the developer scope.

3. The last layer was the macro level national layer where the offshore wind industry ambitions of the government of China were reviewed and synchronized with relevant parts of the legislative environment. The desktop analysis of the offshore wind industry focused on how legislation and policy measures were translated into firm behavior based on a review of specific examples of Chinese state-owned firms and actual actions taken.

The government designed road map for offshore wind in China was finally compared with and contrasted to the actual diffusion of onshore wind in China since 2000 including the role of domestic Chinese firms versus international constituencies in the Chinese market.

5.6 ANALYSIS PROCESS OF THE CROSS-CASE STUDY PAPER

The analysis for the fifth cross-case study publication (Poulsen & Lema, 2017) was performed by both authors jointly and concurrently as the three underlying case study results emerged over the life-span of this PhD study.

Based on the academic literature, the first objective was to analyze to what extent the offshore wind supply chain was ready for the dramatic build-out projected by the different regions and countries (Hong & Möller, 2012) as well as on a more global basis (Global Wind Energy Council, 2014). This was done by contrasting the logistics findings of Europe (Poulsen & Hasager, 2016) to the findings for China (Poulsen & Hasager, 2017):

- The first step to the analysis was to plot the different case study constituencies into a structure that would adequately describe how the four life-cycle phases were further broken down into logistics chains, tiered with supply chain lead firms, suppliers, sub-suppliers, and sub-sub suppliers. The Ørsted case study (Poulsen & Hasager, 2016) had revealed that inbound supply chain was different for the WTG and key BOP components during the installation and commissioning life-cycle phase. Similarly, the outbound supply chain was organized in such a manner that installation and commissioning efforts were split between landside construction and offshore construction with the offshore part separated between different BOP components and that of the WTGs. Similarly, the Ørsted case study had identified that the O&M life-cycle phase consisted of three different supply chains for predictive, unscheduled, and contingency maintenance respectively (Poulsen & Hasager, 2016), and this was mirrored by the O&M case study (Poulsen, et al., 2017).

- The analysis on supply chain readiness was performed purely based on logistics as well as constituencies within the logistics market. The logistics results were used to generalize for the supply chain. In Europe, the industry-wide case study on O&M logistics formed part of a broader cost reduction setting organized by Offshoreenergy.dk and where required, this was used to justify providing a scope broader than just one company (Ørsted) and a single country (Denmark). In Asia, China was used to represent the region due to the Chinese offshore wind market being more developed and more mature than the rest of Asia.

- The empirical data was analyzed with a view towards assessing the relative size of challenges faced and gaps that existed within logistics. All Chinese and European interviews included questions pertaining to logistics challenges, and gaps in the supply chain. This was addressed in a context of what would keep the interviewees awake at night (logistics challenges) and what was on top of their imaginative wish list (gaps).

- To be able to portray this complexity across the different supply chains for Europe and Asia respectively, a ranking was used (0-1-2-3) which was translated into a traffic light color scheme. This traffic light approach, with green indicating sufficient supply and a positive impact on offshore wind diffusion contrasted to red with non-existing supply constituting a diffusion bottleneck, was used in different ways in the paper to illustrate the supply chain readiness in Europe (the Ørsted and O&M case studies) versus Asia (the China case study).

The second objective was to address the supply chain constraints and try to come up with ways to mitigate the challenges faced. For this purpose, the work was condensed to the two most critical and costly (Deloitte, 2011; The Crown Estate, 2012; Prognos and Fichtner Group, 2013; Scottish Enterprise, 2013; BVG Associates, 2014; Megavind, 2015) life-cycle phases in the life-span of an OWF, i.e. construction logistics and operations logistics. Essentially a discussion of the underlying analysis presented as part of the three case studies, this part of the analysis was somewhat less founded in academic literature and based on the empirical data available.

5.7 THE ANALYSIS AT A META-LEVEL

To elevate the analyses of this research to a meta-level, it is important to first understand that the individual parts of this research are intertwined to some extent as the research efforts were rendered in parallel.

The first example of how the analyses were intertwined is the work on the Ørsted case study and the work on the O&M logistics case study:

- The work with the Ørsted case study yielded answers as to the percentage of logistics costs expressed as part of a useful cost grouping such as CapEx (installation and commissioning life-cycle phase), OpEx (O&M life-cycle phase), or LCoE (end-to-end full life-span costs of an OWF). An analysis of the useful responses provided minimum, mean, and maximum levels for each of the groupings and the grouping with the largest disparity was OpEx (Poulsen & Hasager, 2016).

- This was benchmarked against available academic literature on LCoE with focus on offshore wind (Blanco, 2009; Heptonstall, et al., 2012) and here, four main government sponsored studies were also analyzed in detail: A Danish cost study (Deloitte, 2011), a UK cost study (The Crown Estate, 2012), and a German study (Prognos and Fichtner Group, 2013) together with a well-respected industry study which produced a LCoE calculation tool (Megavind, 2015).

- Simultaneously, the logistics O&M case study was on-going with action research / participant observation attendance of this researcher to the different focus groups and sub-work streams forming part of that project with industry practitioners to yield business cases with practically implementable cost savings in offshore wind. To put this much more practitioner-oriented case study on O&M logistics into an academic perspective in terms of the scientific literature, the Ørsted literature review on LCoE was expanded significantly (Poulsen, et al., 2017).

- Upon expanding the analysis of academic literature, it turned out that many academic studies used only a single (Blanco, 2009), or very few (May, 2016; Petersen, 2016), references to LCoE cost sources and then went on to generalize and / or make extensive computations based on, for example, the OpEx share of LCoE. The studies did not concentrate on making their own cost models and cost studies within offshore wind and instead referred to various industry cost studies (Dinwoodie, et al., 2015).

- The different industry cost studies were reviewed by this researcher and cross-checked in terms of extent, scope, and frequency of being used by academic researchers as useful and credible sources. This resulted in a total of 11 cost studies (largely government sponsored) being selected and subsequently subjected to much more detailed scrutiny as part of a desktop study performed by this researcher (Poulsen, et al., 2017).

- Based on the disparity observed through the Ørsted case study work as well as based on the more detailed knowledge and understanding obtained through the O&M logistics case study, this researcher was able to perform the desktop analysis of the 11 cost studies in a detailed manner. The analysis was performed at a per line-item level with a review of the logistics costs as the example used and with a key delimitation being that the analysis would take place only within the O&M life-cycle phase part of the 11 cost studies.

- One of the many key findings from the analysis of the 11 largely government sponsored cost studies was that reference to 'operating expenditure' was sometimes used interchangeably with a reference to 'operations and maintenance' costs in different studies (Poulsen, et al., 2017). When taking a closer look at just this topic alone in more detail, it was found, through the different studies analyzed, that O&M costs constitute roughly half of the total OpEx of an OWF on an annual basis and this was supported by calculations made by academia as well (Blanco, 2009). This kind of ambiguity in terminology and definitions determined from the detailed desktop analysis of 11 cost studies, made as part of the work with the O&M logistics case study, could possibly explain the exorbitant disparity in answers obtained in the Ørsted case study pertaining to the OpEx of OWFs (Poulsen & Hasager, 2016).

- This research has, however, not included an ex-post review to go back to the interviewees and/or survey respondents who provided the eight useful responses about OpEx as part of the Ørsted case study. However, the desktop analysis of the 11 largely government sponsored studies on OWF costs did confirm that great disparity exists in terms of the overall share of OpEx as a percentage of LCoE depending on which cost model assumptions and/or what study is being applied in the calculations (Poulsen, et al., 2017).

Another example of intertwining in the analysis is that the initial semi-structured ‘bridge interviews’ and participation observation site visits forming part of the China offshore wind market case study (Poulsen & Hasager, 2017) are also part of the body of exploratory and semi-structured work efforts rendered to be able to produce the contextual paper (Poulsen, 2015). This empirical data gathered in China, that subsequently led to the 15 formal interviews as part of the embedded case study, has been teased apart twice:

- First in the context of the paper setting the contextual research frame of this PhD study with the objective of providing a contextual basis within which to position the further work (Poulsen, 2015).

- And second as an important part of the paper on offshore wind in China where the initial ‘bridge interviews’ provided critical knowledge on the part of this researcher in order to be able to design, lead, and interpret the embedded case study work including interviews and participant observation site visits (Poulsen & Hasager, 2017).

As a third example of how the analysis was intertwined, most of the analysis dealt with literature reviews of key academic terms useful to the analysis process supplemented by several layers of interpretation of the empirical data obtained. As such, analysis to reveal findings for different constituency groupings included the policy/national perspective, the developer/operator constituency point of view, the WTG manufacturer stake holder view, as well as a perspective as seen by different constituencies in the derived logistics market serving the offshore wind industry. The five papers forming part of this research operate at three levels of analysis to provide different dimensions to the publications. At the macro level, the papers deal with national or regional topics which have to do with mainly policy or legislative matters. Conversely at the meta level, the papers deal with logistics matters within the offshore wind industry as a whole, whereas the micro level deals with logistics at the firm level. As well as being academically relevant, the analyses also focused on ensuring that the work could have real managerial impact as applied research. This was a condition of the funding from the Danish Maritime Foundation. Table 8 summarizes this third example of how the different analysis dimensions of the five peer-reviewed and published papers of this PhD study are intertwined.

Case study / paper	Macro level	Meta level	Micro level	Academic implications	Managerial implications
Contextual paper setting research frame (Poulsen, 2015)	Nation states as entre-preneurs	Wind industry largely invented by nation states	Competition of different firm types as well as industry consolidation	Gaps revealed in terms of knowledge of logistics market serving the wind industry	Competition in wind industry not straight-forward; emerging markets for offshore wind holds potential
Ørsted logistics innovation strategy (Poulsen & Hasager, 2016)	Policy, governance	Industry expansion into new markets	Knowledge management and replication of skills	Further studies on methods to use innovation to generate logistics cost reductions	Logistics as area to reduce costs; organization of logistics; calculation of logistics share of LCoE
Logistics O&M (Poulsen, et al., 2017)	Linkage between government sponsored cost studies and practitioner implementation; cultural barriers	O&M logistics cost savings are possible for the offshore wind industry; cultural barriers	O&M logistics strategies; cultural barriers	Further studies on a new measure to compare energy forms to replace LCoE; unified assumptions for cost studies	Logistics cost-out to reduce LCoE
China (Poulsen & Hasager, 2017)	Open, engaging, and collaborative environment instead of strict local content rules	Institutional alignment at industry level including banking industry to support national goals	Role of central state-owned enterprises controlled by the central government; use of M&A to fast-track the infusion of overseas knowledge	Further studies of the actual pipeline of on-going OWF projects in China beyond those included in national planning documents	Risk to have onshore wind experiences repeated; opportunity to benefit not only from Chinese domestic offshore wind market but also future export offshore wind market from China
Cross-case (Poulsen & Lema, 2017)	European Union (EU) legislation for offshore wind until 2030; China legislation to enable learning from offshore wind in Europe	Supply chain development and readiness in Europe and Asia; areas of potential improvement identified	Opportunities for firms to set strategies to expand from mature markets in offshore wind to emerging markets	Gaps revealed in terms of government policy and research efforts, corporate investment, and knowledge transfer	Knowledge management and skills upgrading efforts within Europe can be replicated to also be applied to emerging markets

Table 8. Dimensions of analysis in the different papers forming part of this research.

CHAPTER 6: RESULTS

The three research questions of this PhD study were defined based on a literature review which revealed several gaps. The case study yielded the promise of a flexible method for the somewhat exploratory data to be collected, interpreted, analyzed, discussed, and presented. Three case studies became the cornerstones of this research. A total of five publications form part of this research and analysis went into each of these papers along with analysis at the meta level across all the case studies and across some of the five papers.

As part of the analysis performed for each of the three primary case studies as well as during the process of crafting of the five papers, results were gathered which jointly provide a diagnosis of logistics in offshore wind. The three research questions have directed the analysis along the three offshore wind tracks of creating a better understanding of how logistics is organized as well as whether logistics is important, what the logistics costs are, and what the characteristics are of logistics in established versus emerging markets.

In the following, the key contributions of this research will be discussed. Section 6.1 outlines how the findings of this research point to a definition of logistics which may be utilized for offshore wind. Section 6.2 deals with results from this research which provide a better understanding of what logistics costs may comprise. Section 6.3 presents findings on the characteristics of logistics in the globalizing offshore wind market and in section 6.4, the results on the readiness of the supply chain in more established markets are compared to the readiness in new and emerging markets. Section 6.5 presents the results on how logistics seems to be a discipline which is maturing within the industry of offshore wind which – as an industry – is itself seemingly undergoing a significant process of maturation.

6.1 THE BASICS: DEFINITION OF LOGISTICS IN OFFSHORE WIND

The literature review of the term ‘logistics’ revealed that it had a number of academic antecedents such as ‘materials management’ and ‘physical distribution’. The literature review also yielded an understanding that logistics as a term had been replaced by and included in the broader definition of ‘supply chain management’ which would encompass logistics as well as the antecedents of logistics. SCM furthermore included several additional disciplines on top of logistics effectively making the area of logistics a subset of the SCM discipline. The findings from literature inferred that logistics could mean different things to different academic scholars depending on the context and that by pointing to SCM, some could in fact be referring to a different and more traditional meaning. The review of developments within the practitioner community confirmed a parallel development of terminologies utilized.

The work with the Ørsted case study on logistics innovation (Poulsen & Hasager, 2016) revealed that 'logistics' as a term, function, or discipline was not defined within the firm. The obvious implication for the case study was that it was difficult to provide an innovation strategy for a phenomenon which was not defined let alone agreed upon within the firm. Obvious questions around the scope, scale, and extent of such a logistics innovation strategy presented themselves at the onset of the work with Ørsted. The lack of a definition also meant that there was no logistics organization within the firm as logistics did not exist as an individual management discipline, competence center, or horizontally organized function of the firm. Yet logistics in terms of movement of freight, port operations, and land side transportation work was part and parcel of every activity across all life-cycles of an OWF and logistics considerations were being made also at a wind farm portfolio level, i.e. across several OWFs combined.

The empirical data obtained in the Ørsted case study reflected that logistics was not defined within the firm and that significant ambiguity existed in terms of vocabulary used. In addition, inconsistency was registered for specific terminology applied. This meant that empirical data responses had to be interpreted in a more holistic manner to be able to understand the position of the respondent within the logistics chain, within the firm, and in many cases based on their prior experience. For example, a financial manager in a Group function, who had always worked within the case firm, had one firm-centric and bespoke way of articulating logistics topics and this was quite contrary to a member of the top management team just recruited to provide best practices from a world-class firm in a completely different industry.

Defining 'logistics' in an offshore wind setting for the case firm therefore became an important task to create the innovation strategy for this area of the business. Instead of working actively upfront with the firm to establish a definition, so that the work with crafting the logistics innovation strategy became feasible, interviews and surveys were carried out. The terminology from the empirical data generated was used to establish the dimensions of what a proposed definition of logistics in offshore wind would encompass.

It was important to contrast general industry terminology to the somewhat bespoke terminology of the firm to clearly understand the logistics related terms and expressions used within the firm. This was done by comparing the frequency of company vocabulary used in the interviews to the generally understood industry vocabulary selected as the basis for the survey. Three different word groupings stood out in the interviews as being used very frequently in relation to 'logistics' topics, i.e. 'shipping', 'parts/components', and 'supply chain management'. When examined using the interview tapes and transcripts, other words were attributable and connected to each of these three frequently used words. This in turn led to a categorization of the related words as well as industry vocabulary (Poulsen & Hasager, 2016) along twelve dimensions as well as key questions to be answered by a definition (see Table 9 for a full listing). A definition of logistics in offshore wind was proposed to Ørsted and an academic definition was proposed also in the publication of the case study work (Poulsen & Hasager, 2016).

Question considered	Dimension involved	Empirical data obtained
What does shipping mean?	1. Mode of transport	Vessel or helicopter
	2. Means of transport	Truck/ship/boat/vessel/helicopter
	3. Activities performed	Transport of personnel, performing a survey, installing, servicing, preparation, loading, unloading
What do we ship?	4. What is involved	WTG components, BOP components, technicians, provisions, tools, personal protection equipment, and spare parts
		Should we include the transportation of power to the grid?
Wider definition of logistics and supply chain management	5. Competencies	Skills and knowledge in general
		What are our core competencies? What does this mean in terms of what we outsource or do ourselves? What does it mean in terms of in-house versus outsourced ownership of transport assets and transport equipment?
	6. Who is being served	Who is the end customer being served?
	7. Number of supply chains	Single supply chain involved or multiple
	8. Extent of the supply chains	Are the starting points and ending points of logistical chains similar or different across different discussions and scopes?
	9. Information technology and data management	Use of key performance indicators and computers
	10. Weather	Wind, waves, currents, visibility, and general weather conditions
	11. Health, safety, security, environmental, and quality	Considerations about health and safety of people, the overall project and personnel security, environmental considerations, and quality of work rendered
	12. Logistical focus	Whether the unit of analysis considered is an individual WTG or an entire OWF

Table 9. The 12 key dimensions and associated questions considered to get to a definition of logistics in offshore wind.

The academic definition of logistics in offshore wind proposed and accepted in the publication of the Ørsted case study is a theoretical contribution of this research as it fills a gap in academic literature. The slightly updated definition has been recapped in figure 2.

> *"Parts, modules, components, people, consumables, and tools are responsibly stored and moved safely, weather permitting, onshore, as well as offshore by air/ocean/land using various transportation assets and transport equipment with a focus on an individual wind turbine generator, an offshore wind farm asset project, or across a portfolio of projects by means of different in-house and outsourced logistics skills/capabilities/IT systems used across multiple supply chains spanning different starting and ending points, also duly considering inventory carrying costs."*

Figure 2. Definition of logistics in offshore wind (Poulsen & Hasager, 2016)
The definition of logistics in offshore wind slightly modified compared to the version first proposed in Poulsen & Hasager (2016). Reproduced from (Poulsen & Hasager, 2016) with permission from MDPI AG.

The dimensions considered to be able to craft the definition of logistics in offshore wind provide an opportunity to review the detailed findings of this research as included in the different publications. It is relevant to provide a brief diagnosis of logistics in offshore wind and this may be seen in relation to the factors of logistics complexity defined as part of the trend for OWFs to move farther offshore (see Table 3 above) coupled with the key themes of offshore wind globalization as well as the different degrees of logistics maturity in established versus emerging markets. Several of the findings specific to logistics in offshore wind are as follows (please also refer to Table 10):

1. As OWFs move farther offshore, the distance from ports to the offshore site increases and shore-based personnel such as technicians can no longer go back and forth the same day and must remain offshore for extended periods of time. This means staying aboard the vessels for periods of up to two weeks at a time with vessel crews managing operations and accommodation requirements. This results in the disparity between technicians and vessel crews increasing (Poulsen, et al., 2017).

2. Vessel steaming time from port to site increases and depending on the actual OWF life-cycle phase, logistics chain involved, and specific task across the logistics sub-chains (Poulsen & Lema, 2017), different vessels and different types of vessel crews as well as technicians are utilized. The actual flows of WTG and BOP components in the different logistics sub-chains vary in terms of degree of standardization from regular ocean containers to out-of-gauge and dimensional break-bulk project cargo (Poulsen & Hasager, 2016).

3. Inability to work offshore because of the weather is constantly being challenged. In terms of wind speeds and wave heights, continuous logistics innovation is needed for vessels, crews, and technicians to be able to work in harsher weather conditions as well as during the night. Careful balancing, especially in terms of health and safety conditions, is required (Poulsen, et al., 2017).

4. As operations bases move offshore to become sea-based rather than land-based, vessel requirements change. Vessel stability is challenged because of the harsh weather conditions and the use of dynamic positioning systems ensures that technicians do not become seasick from the vessel movements. In addition, more technicians, parts, and supplies need to be stored on board the vessels for longer periods of time. The different logistics sub-chains will be altered in terms of their extent as they now increasingly have an offshore point as the place where they begin and end (Poulsen & Hasager, 2016).

5. As the number of WTG positions is increased in each of the larger OWFs now emerging, inexorable demands for a more efficient logistics process are put forward both during the installation process and the ensuing O&M life-cycle phase (Poulsen, et al., 2017). A faster pace, more optimized ways-of-working, and leaner processes are implemented alongside different quality and process improvements to increase effectiveness.

6. The MW yield of the offshore WTG is constantly being challenged and larger yield means heavier machines, bigger components, and increased BOP component sizes. For example, the nacelle of the Siemens Gamesa 3.6 MW WTG weighed 140 tons and the future 15 MW machine is expected to weigh approximately 1,000 tons according to the empirical data gathering process of this research. Similarly, the 3.6 MW WTG blades were 58.5 meters long whereas it is expected that the 15 MW machine will have blades of 125 meters in length. In addition, offshore WTGs are now starting to be equipped with floating foundations (Castro-Santos & Diaz-Casas, 2014; Castro-Santos & Diaz-Casas, 2015; Andersen, 2016). From a product life-cycle perspective, the very fast upscaling in terms of yield causes product maturity to not be achieved which again means that industry maturity is not achieved as seen from of an industry life-cycle perspective (Utterback & Abernathy, 1975; Abernathy & Utterback, 1978; Klepper, 1997; Jensen & Thoms, 2015). Platform leadership is also not achieved (Gawer & Cusumano, 2002; Cusumano & Gawer, 2002) and the separation of the China offshore wind market from the rest of the world is exacerbating this dimension (Poulsen & Hasager, 2017). The impact on logistics is negative as logistics asset obsolescence occurs very quickly for major transport equipment investments such as vessels (Poulsen & Hasager, 2017; Poulsen & Hasager, 2016) and this dichotomy is counter-productive for motivating continuous logistics innovation (Manso, 2011), especially in terms of asset investments.

7. From a procurement perspective, the emergence of more financial OWF developers with a goal of outsourcing the construction and maintenance portions of the OWF life-span has caused contracting scopes, including the monetary scale, to increase significantly, also for logistics (Poulsen & Lema, 2017). This means that it generally takes a stronger balance sheet, more extensive insurance coverage, and an expanded risk profile to compete for larger contract scopes in the offshore wind logistics market (Poulsen & Hasager, 2016).

8. The widening of the logistics solution scope and agglomeration of logistics services demands a greater ability to manage risks on the part of the logistics firms serving the offshore wind industry. Changes in the set-up of logistics constituencies have therefore taken place where industry consolidation through M&A and joint-venture creation has caused the 'traditional' smaller niche type entrepreneurs to slowly be replaced by more global firms (Poulsen, 2015).

9. The role of the logistics firms is viewed differently by supply chain lead firms such as developers and WTG manufacturers compared to how the logistics firms serving the offshore wind industry view themselves. The logistics firms must adhere to how the supply chain lead firms split up the logistics work scope across different procurement structures and contract scopes. This means that the logistics firms must navigate the constantly evolving structure devised by the supply chain lead firms coupled with the contract infrastructure for each individual OWF project (Poulsen & Lema, 2017; Poulsen, 2015; Poulsen & Hasager, 2017).

10. As offshore wind globalizes, more OWFs are constructed and maintained on a global basis. This means that all logistics activities across all life-cycle phases, all logistics chains, and all logistics sub-chains are scaled up, increased, and expanded. This presents a need for logistics competencies, experience, and knowledge to be identified, mapped out, and replicated across different markets and geographies (Poulsen & Hasager, 2016).

11. Different offshore wind markets have different degrees of maturity and different characteristics in terms of logistics (Poulsen & Hasager, 2017). Different logistics practices and logistics ways-of-working exist in more mature offshore wind markets versus in new and emerging offshore wind markets (Poulsen & Lema, 2017).

Offshore wind logistics complexity factors	Offshore wind logistics complexity factors	Logistics implications	Dissemination outlet of this PhD study
1. Proximity port to site	Distance increases from ports to site; greater use of helicopters and vessels that can remain at sea for prolonged periods of time	Greater disparity between vessel crews and land-based technicians with a need to stay at sea for prolonged periods of time	(Poulsen, et al., 2017)
2. Vessel steaming time	Different vessels and personnel used for different tasks across four OWF life-cycle phases, nine logistics chains, and 53 logistics sub-chains identified in this research	Standard and non-standard flows in different logistics chains and logistics sub-chains	(Poulsen & Lema, 2017; Poulsen & Hasager, 2016)
3. Weather	Continued demand to increase productivity by working in harsher weather conditions as well as during daytime and night	Logistics innovation constantly needs balancing with health and safety considerations	(Poulsen, et al., 2017)
4. Operations base	The extent of the logistics chains, in terms of where they begin and end, is altered as land-based operations bases are moved offshore to become sea-based	Different requirements for vessels in terms of ability to house more land-based technicians, parts, and supplies	(Poulsen & Hasager, 2016)
5. Number of positions	Larger OWF areas mean a higher number of WTG positions in each OWF	Increased demands for logistics efficiency and effectiveness	(Poulsen, et al., 2017)
6. WTG yield	WTGs are getting bigger due to need for increased yield; this means larger WTG and BOP components; first WTGs in operation with offshore wind floating foundations	WTG product maturity is not achieved; no WTG platform leadership; short WTG product life-cycles; lack of industry maturity. This creates significant negative downstream challenges for logistics in terms of asset management and obsolescence	(Poulsen & Hasager, 2017; Poulsen & Hasager, 2016)
7. Procurement	More extensive contract scopes with a greater need for stronger balance sheets of firms wishing to compete	Multi-contracting and single-contracting procurement strategies affect the logistics scope	(Poulsen & Hasager, 2016)
8. Logistics service scope	Wider logistics solutions demanded with a more significant risk profile leading to industry consolidation	Changes the logistics constituency set-up from ‘traditional’ entrepreneurs to more global firms	(Poulsen, 2015)
9. Logistics firms	Different vantage points by developers, WTG manufacturers, and providers of logistics services	Supply chain lead firms split up the logistics work scope and logistics firms must adhere and navigate this structure	(Poulsen & Lema, 2017; Poulsen, 2015)
10. Globalization of offshore wind	More OWFs on a global basis means that all logistics activities across all life-cycle phases are expanded / increased	Competencies, experience, and knowledge, must be identified and replicated	(Poulsen & Hasager, 2016)
11. Market maturity	Degree of maturity in traditional versus emerging markets of offshore wind	Different logistics practices and characteristics in different markets	(Poulsen & Hasager, 2017)

Table 10. Logistics diagnosis and complexity.

Of the above-mentioned diagnosis elements pertaining to logistics in offshore wind, three deserve additional input:

- The work with ascertaining supply chain readiness across mature and emerging markets led to a more granular view of the offshore wind supply chains across the life-cycle phases. As interviewees had talked about logistics in vertical ‘silos’, for example as part of WTG installation or preventive O&M, it was clear that ‘readiness’ was different from a logistics perspective for installation of a WTG component compared to that of BOP components. It also became clear that the logistics scope involved in unscheduled maintenance efforts was very different from the preventive, scheduled, and sometimes predictive O&M efforts (Poulsen & Lema, 2017). Therefore, it was necessary to split the life-cycle phases into different logistics chains. In addition, the individual logistics chains could be teased apart to reveal different logistics sub-chains akin to a Matryoshka nesting doll. A total of nine logistics chains were identified across the four life-cycle phases and it was found that the nine logistics chains in turn contained a total of 53 logistics sub-chains.

- Weight, dimensions, and volume of the individual WTG as well as BOP components utilized in an OWF project varied significantly or even exponentially as WTG yield was increased (Poulsen & Lema, 2017). As different measurements and data were collected, cross-checked, and validated throughout the empirical data gathering process, a log was kept in order to be able to contrast and compare different machines over time. Attributes such as nacelle weight, hub weight, blade length, blade weight, hub height, and tower weight were maintained in this log for comparison purposes across nine different existing and planned WTGs with a yield from 2.3 MW to 20 MW.

- Industry consolidation was always present both in the offshore wind industry itself as well as for the shipping and logistics firms serving the offshore wind market (Poulsen, 2015). Just within the PhD research project Reference Group, a number of changes occured: Danish J Poulsen Shipping resolved their Combi Lift joint-venture with German partners after which they exited the wind market (and the Reference Group), Danish engineering firm Per Aarsleff dissolved their joint-venture with a German partner which took Aarsleff from a leadership position to almost inactive in offshore wind installation, Ørsted together with Siemens Gamesa sold their A2Sea subsidiary to a Belgian firm, A.P. Møller-Mærsk sold off most of their wind-related activities, and Give Goodwind went bankrupt. BTM Consult was acquired by US-based Navigant Consulting with the key BTM Consult personnel ultimately joining FTI Consulting after serving a period with non-competition clauses. Also, more straightforward M&A activities took place as Siemens acquired Gamesa, AH Industries was sold by one private equity fund to another private equity fund and then ultimately to two individuals, and Wilhelmsen Group acquired Danbor via their Nor-Sea Group subsidiary which gave birth to NSG Wind including the acquisition of Øer.

6.2 LOGISTICS COSTS WITHIN OFFSHORE WIND

The literature review of the logistics costs in offshore wind revealed that LCoE was a measure starting to gain some popularity when this research commenced (Stentoft, et al., 2016). Different academic scholars had started to make LCoE calculations for offshore wind showing different actual or projected cost development trajectories over time (Poulsen & Hasager, 2016). The progress within academia was compared with and contrasted to three government sponsored activities from Denmark (Deloitte, 2011), the UK (The Crown Estate, 2012), and Germany (Prognos and Fichtner Group, 2013) respectively to further demonstrate the usefulness and functionality of the LCoE measure (Poulsen & Hasager, 2016) as well as how to calculate it (Megavind, 2015).

The literature review forming part of the Ørsted case study publication revealed that the discipline of logistics was becoming gradually more visible in terms of importance of costs across the three studies (Poulsen & Hasager, 2016). As such, the UK study contained four different scenarios where logistics would play a key differentiating role (The Crown Estate, 2012) and the German study identified the need for a land-based logistics set-up for near-shore OWFs and sea-based logistics set-up for far OWFs (Prognos and Fichtner Group, 2013). The literature review (Poulsen & Hasager, 2016) also showed that the offshore transmission assets and grid were handled differently in the three countries which greatly impacted the logistics scope for the developer: In Denmark, the government would construct all land-based transmission assets and also be responsible for the export cable and offshore sub-station. In the UK, the developer would have to first construct these assets and subsequently auction them off to a different constituency.

Further scrutiny of LCoE impact studies (Poulsen, et al., 2017) revealed that the source of the academic baseline utilized for further calculations was often just a single or two industry generated cost studies (Blanco, 2009). It was furthermore determined that academic studies of LCoE did not exist in terms of comprehensive analysis across a portfolio of OWFs and with focus on the different life-cycles within a single OWF project. The most comprehensive cost studies were British (The Crown Estate, 2012) and German (Prognos and Fichtner Group, 2013) government sponsored studies where a useful LCoE calculator had been developed based on cost models from key developers and WTG manufacturers (Megavind, 2015).

The continuous literature review of LCoE, which took place throughout this research, resulted in three contributions which will be described in what follows.

6.2.1 THE INITIAL RESULTS SETTING THE SCENE

The empirical data collected in the Ørsted case study were compiled in such a way that minimum/mean/maximum ranges of the useful interview and survey responses were portrayed displaying logistics costs as a percentage of CapEx, OpEx, and LCoE respectively (see Table 11). The mean numbers were used as a directional indication of what the cost of logistics is for offshore wind and whether logistics is an important cost factor within the life-cycle phases that have to do with CapEx and OpEx. The cost of logistics as a percentage of LCoE was a metric which could be immediately evaluated and understood by scholars as well as the offshore wind industry. The logistics share of LCoE would be directly comparable in a benchmarking process with the logistics share of total costs of other industries.

Logistics costs as a percentage of	Minimum	Mean	Maximum
CapEx	10%	23%	55%
OpEx	15%	26%	85%
LCoE	5%	18%	35%

Table 11. Initial findings pertaining to the relative size of logistics costs from the Ørsted case study (Poulsen & Hasager, 2016)

The findings from the Ørsted case study pertaining to the relative cost of logistics in the offshore wind industry (Poulsen & Hasager, 2016) form a contribution of this research both from a theoretical and practitioner perspective. From an academic perspective, the steadily decreasing relative share of logistics costs measured over time as a percentage of gross domestic product at a national level in the US (CSCMP, 2015) indicates that if organized properly and focused on, logistics is an academic discipline which contains potential for cost savings. With a relatively high mean and very high maximum percentage of LCoE, it is a theoretical contribution to academic literature that the cost of logistics is now better understood in offshore wind.

For scientists, it is interesting to note that the mean share of logistics as a percentage of LCoE is almost equal to the total cost of all BOP items combined and more expensive than the nacelle without tower/blades (BVG Associates, 2014).

For practitioners, the relatively high shares of logistics as a percentage of different cost groupings such as CapEx, OpEx, and LCoE is a contribution because this would indicate that logistics as a discipline of the firm should be organized in a manner that reflects the relative cost importance.

6.2.2 DETAILED REVIEW OF LOGISTICS COSTS IN THE OPERATIONS AND MAINTENANCE LIFE-CYCLE PHASE

As part of the publication efforts of the logistics O&M case study (Poulsen, et al., 2017), the literature review of logistics and SCM was continued in terms of the offshore wind O&M setting. A comprehensive literature study of logistics in the O&M life-cycle phase was identified (Shafiee, 2015) along with a PhD thesis where logistics operations were part of the safety (sub-assembly and crew transfer) and efficiency (organizational optimization) dimensions respectively (Dai, 2014). In addition, other academic papers provided input on a simulation tool to optimize offshore fleet operations (Dalgic, et al., 2015) and one study verified and validated four O&M models of which three had a significant logistics / shipping / maritime component (Dinwoodie, et al., 2015).

The analysis made of the logistics costs at a per line-item level revealed that the three studies from Denmark (Deloitte, 2011), UK (The Crown Estate, 2012), and Germany (Prognos and Fichtner Group, 2013) were very different. In addition, other scholars (Blanco, 2009; May, 2016; Petersen, 2016) had utilized only a single industry study or very few such studies as their baseline. Therefore, this researcher opted to expand the analysis and include 11 major studies performed by different and mainly government related entities over a 10-year period in different countries (Poulsen, et al., 2017). The delimitation of the analysis was to only focus on logistics for the O&M life-cycle phase and this decision was made based on the results generated from the empirical data interpretation of the Ørsted case study: The 28 useful responses from the interview and survey generated from the Ørsted personnel had revealed the biggest disparity in the answers pertaining to OpEx (Poulsen & Hasager, 2016). At the same time, the work to gather empirical data in the logistics O&M case study also focused on the O&M offshore wind life-cycle phase which was useful for this researcher to be able to triangulate and better understand the available data.

The results of the analysis showed that the 11 cost studies were made based on different assumptions at a macro, micro, and individual cost line-item level. The results for the primary focus of the analysis were those at the per line-item logistics cost level (Poulsen, et al., 2017). Several studies contained line-items that were immediately comparable in terms of description of what the line-item costs comprised, for example, 'port operations' and 'vessel costs'. Although similar in terms of description, an immediate comparison showed significant variation, and it became clear that some studies saw logistics costs as a percentage of OpEx whereas other studies computed logistics costs as a share of the O&M cost sub-set of OpEx. When these differences had been neutralized, 'vessel costs' were found to vary from 18% to 38% of O&M costs across three different studies with immediately comparable definitions. Similarly, port operations would vary from 1.2% of O&M costs to 62%.

These deviations were significant and a full review of all logistics cost line-items across all 11 studies was carried out. The level of detail and number of cost line-items varied greatly in each study and in order to be able to ascertain the relative share of logistics costs in the O&M life-cycle phase, the results revealed that one of the studies (GL Garrad Hassan, 2013) contained a significant level of detail which would be useful to focus on. Of the 18 cost line-items of this study, not all descriptions were equally clear. When primary line-item descriptions and additional explanations were perused, five of the line-items could be fully attributed to logistics whereas four line-items could be completely excluded from having any logistics component whatsoever. The remaining nine line-items had to be subjectively assessed in terms of the relative share of the line-item when it comes to logistics, i.e. whether logistics would account for e.g. 10%, 40%, or 80% of the costs in a particular line-item. Each line-item had an estimated minimum and maximum cost attached to it within the study (GL Garrad Hassan, 2013) which in turn meant that the total OpEx in absolute monetary terms was higher in the case of the maximum cost range being applied compared to that of the lower minimum cost range. From this, the result was a range of total logistics costs as a percentage share of OWF operational expenditure. This was calculated separately for the five line-items which were 100% attributable to logistics as well as for those same five line-items and the nine line-items to which logistics could be attributed in a partial manner (see Table 12).

Logistics costs	At the minimum cost range	At the maximum cost range
Operating expenditure per MW per year	EUR 116,194.-	EUR 269,942.-
Line-items with a cost 100% attributable to logistics	17% of OpEx	17% of OpEx
Line-items with some or 100% cost attributable to logistics	32% of OpEx	31% of OpEx

Table 12. Logistics costs as a percentage of operating expenditure for offshore wind (Poulsen, et al., 2017).

The results clearly show that logistics costs are not properly defined, let alone accounted for, in (often government sponsored) offshore wind cost studies. The results also show a large variation, as well as logistics accounting for a significant percentage of operational expenditure. These contributions clearly point in the direction that logistics should be treated as a separate cost discipline in the studies of LCoE for offshore wind and that logistics should feature in future studies both as a horizontal end-to-end cost item as well as vertically within each life-cycle phase. Academia should contribute to making this a reality in the future.

6.2.3 COST MODEL AMBIGUITY AND BIAS

To elevate the comparison efforts to the level of the 11 different studies meant that the quantitative analysis first had to cleanse the data structurally in order to make the different data comparable. Unfortunately, the individual studies were biased and provided strong argumentation e.g. on why they were based on a particular unit of analysis (see Table 13). With such differing units of analysis, any attempted comparison would require detailed preparatory work (Blanco, 2009; Dinwoodie, et al., 2015).

Examples of units of analysis from different cost studies	Implication on calculations
OpEx as a percentage of CapEx	Total costs of one life-cycle seen in relation to the costs of another life-cycle
OpEx as a percentage of discounted lifetime electricity output	Costs to operate the energy producing asset seen in relation to energy output
Annual OpEx per kilo-Watt hour	Annual costs to operate the asset measured per power unit produced
Total OpEx costs as a percentage of total lifetime costs	Total costs of one life-cycle seen in relation to the total costs of the asset during its' life-span
OpEx per MW per year	Annual costs to operate the asset measured per power unit produced
OpEx costs per year for the OWF	Annual costs to operate the asset aggregated for the entire OWF
Outright costs per OpEx line-item	View of costs per line-item not aggregated or compared to other costs
O&M costs per WTG installed	Costs to operate each WTG asset in the OWF

Table 13. Examples of units of analysis across the 11 largely government sponsored cost studies (Poulsen, et al., 2017).

In teasing apart the different cost studies, it became clear that many factors differed, which could be due to who had produced the study, what the goal of the study was, and how the study was intended to be used by an individual, a firm, organization, or institution. Another way to view the differences from a publication perspective (Poulsen, et al., 2017) was that the process of creating the cost studies could have evolved over time and that this was instead the reason behind disparity in terms of the key dimensions of the different studies. Results from the analysis did, however, point towards several dimensions which could be attributed to bias on the part of the organization or manager designing the cost study (see Table 14 for some key examples).

For example, it would be possible for developer produced cost studies to conceal the parts of the costs from the O&M life-cycle phase related to e.g. the initial warranty period or end-of-life extensions as these cost items could be endogenously moved into the CapEx category instead. This would help distort the reporting slightly and make the data less useful e.g. for competitors to use in terms of benchmarking in situations where operational and financial data were mandated by the seabed concession awarding authorities to be made available for use by the public for a period of time.

Another example could be input from an offshore WTG manufacturer to a government sponsored cost study about the cost advantages of up-scaling the rated output from the WTGs. A higher output per WTG could be projected to save cost if the OWF concession was based on a certain total output in MW. For example, 100 machines of 6 MW would be required to produce 600 MW in total whereas only 60 machines of 10 MW capacity would be required. Or if the concession was based on number of WTG positions, 100 machines each yielding 10 MW would generate 1,000 MW instead of only 600 MW for 6 MW machines, thus producing higher revenues. Whereas a lower number of machines would most likely be portrayed by the WTG manufacturer as potentially leading to lower LCoE, such assumptions in cost studies would to some extent be off-set by perceptions of higher technology risks leading to increases in insurances premiums and a higher cost assumed in the form of weighted average cost of capital (WACC). To put this in perspective, one study (The Crown Estate, 2012) had calculated that a 1% increase in the WACC of an OWF project would result in a 6% increase of the overall LCoE costs for the project.

Finally, OpEx seen throughout the life-span of the OWF asset can be modeled in different ways depending on assumptions. Some of the cost studies argued that the warranty period did not have O&M costs for the WTG because of the warranty from the WTG manufacturer, which reduced OpEx. Other cost studies assumed that the annual OpEx was a fixed amount applied linearly during the 20 or 25-year life-span of the OWF. And yet another group of cost studies argued that the costs would change over time because the machines are less likely to break down during the beginning of their life-span and would be more likely to need severe service overhauls towards the end. Depending on how the cost models are structured, fixed OpEx over long periods discounted back to present monetary values could make the overall costs of offshore wind seem more attractive here and now and therefore help form a favorable public discourse on behalf of governments wishing to promote offshore wind.

Based on the results of the analysis, a theoretical contribution of this research is that it would seem plausible that the many and varied parameters used as assumptions when creating complex LCoE models in offshore wind can to some extent be set subjectively by the institution, organization, firm, or person responsible for the calculation process or parts thereof. Such structuring of the cost model tools can generate cost structures which are biased towards certain predetermined goals or objectives. Academia should assist in ascertaining how cost models are utilized and set up guidelines and definitions to ensure that bias is avoided.

Example of dimension	Variation determined	Implication on cost calculations
O&M warranty period	Sold as part of WTG CapEx and therefore not included in real-life OpEx calculations	Often modeled as part of OpEx and can only appear 1x in either CapEx or OpEx
OpEx costs over the life-span of the OWF asset	Lower in the beginning, then plateauing, and higher towards the end of the life-span of the OWF asset	Often modeled as a linear cost item throughout the life-span of the OWF asset
Repowering or end of service life extensions	Considered a CapEx cost during the O&M life-cycle phase by some operators	Can only appear 1x in either CapEx or OpEx
Insurance	Premiums increase as new technology is implemented	New technology usually causes LCoE estimates to decrease and insurance premiums should be accounted for
WACC	WACC applied to calculations will increase with increased risk and 1% WACC increase equals 6% increase in LCoE	New technology meant to drive down LCoE is usually the key driver of a higher WACC due to perceived higher risk

Table 14. Five examples of variation in key dimensions across the 11 cost studies compared (Poulsen, et al., 2017).

6.3 LOGISTICS IN A GLOBALIZING OFFSHORE WIND MARKET PLACE

A gap in academic literature covering emerging offshore wind markets outside Europe was found during the beginning of this research as outlined in section 2.5 above. From a legislative, policy, and actual installation perspective, China was found to be the dominant force in terms of both intent and execution when this research was initiated. As such, the efforts rendered in this research were concentrated on China although other emerging markets have also been reviewed to a lesser extent. Throughout this research, the review of available scientific literature on emerging markets was developed continuously and academic accounts of offshore wind diffusion have started to emerge (Rodrigues, et al., 2015).

An early account of the initial empirical data gathering efforts for South Korea was part of the paper setting the contextual frame for this research (Poulsen, 2015). This initial account of the contextual setting for offshore wind in South Korea provided a high-level view of the 7.5 GW projection for the market by 2030 coupled with a view to key firm composition and geographical focus on the area around Jeju Island in the Southern part of South Korea. In addition, a large offshore test WTG had been erected in the UK by one South Korean manufacturer of WTGs (BTM Consult, 2014). On this basis, the South Korean market seemed to be the most vibrant emerging market outside China and market coverage was initiated. A further account of the on-going literature review was provided in a subsequent paper (Poulsen & Lema, 2017) where a review of key South Korean firms was also provided. The on-going review of scientific literature revealed a view of different academic research efforts pertaining to different offshore WTG support structures (Shi, et al., 2015), an assessment of wind potential at a demonstration OWF site (Oh, et al., 2012), and a review of the offshore wind energy potential within an entire region of South Korea (Lee, et al., 2013). This work was supplemented by case study empirical data collection efforts which included travels to South Korea (Poulsen & Hasager, 2017), conference attendance (Paik, 2014a), and personal correspondence with several constituencies (Paik, 2014b). The first South Korean OWF of commercial scale went online towards the end of 2017 which was later than what had generally been expected (Offshorewind.biz, 2017). South Korea turned out to be somewhat closed off in terms of the domestic market for a five-year period and this hampered further research efforts.

Instead, some market coverage for Taiwan was initiated (Poulsen & Hasager, 2017) and the on-going literature review revealed that the Taiwanese market for offshore wind was indeed in the process of being established. Typical early-stage engineering type studies began to be published within the areas of WTG foundations (Chen, et al., 2016; Ku & Chien, 2016) as well as the rather extreme weather situations with typhoons (Lian, et al., 2016) and high wind speeds (Chang, et al., 2015). Researchers across the Strait of China/Taiwan in China performed similar weather analysis as well (Liu, et al., 2017a; Liu, et al., 2017b).

Market coverage in terms of India was limited and consisted of a continuous literature review (Govindan & Shankar, 2016), academic conference attendance (Narain, et al., 2014a; Narain, et al., 2014b), and semi-structured interviews forming part of the exploratory empirical data gathering process (Poulsen & Hasager, 2017).

Non-exhaustive coverage of the Japanese, Canadian, and US markets formed part of the empirical work of this research as well.

Whereas the review of the above academic literature across different markets supplemented by empirical field work provided useful contextual knowledge about the emerging offshore wind markets in general, the case work did not yield any significant contributions from a logistics perspective apart from China. The work on the China market case study yielded several key areas of additional understanding of logistics in offshore wind there of which the seven most important ones can be described as follows (please also refer to Table 15).

- Experience to perform logistics related studies of different kind was called for (Poulsen & Hasager, 2017). The study types mentioned as part of the empirical data collected included road conditions, seabed studies, and environmental studies including animal protection opportunities.

- Experience pertaining to vessels custom-built for the offshore wind industry was actively sought for at different levels. The results from the empirical data collection efforts (Poulsen & Hasager, 2017) revealed that such bespoke vessels would need to be customized to China because of the very special conditions including inter-tidal zones, installation in delta areas of major rivers, and extreme weather conditions. Specific knowledge was sought for pertaining to particular vessel types such as piling hammer vessels, cable laying vessels, WTIVs, and crew transfer vessels. Also, very specific capabilities important to the operation of wind vessels were sought including the operations of jacking equipment, dynamic positioning, and different types of cranage. Especially for the very costly WTIVs, also overseas investment was sought to ensure that China would have sufficient capacity to install the many planned OWF projects along the extensive coast line.

- Because of a wish on the part of the major developers to first control, learn, and understand the entire supply chain before deciding on what to outsource, the area of WTG installation had a contract and execution scope controlled by the Chinese developers, not the Chinese WTG manufacturers (Poulsen & Lema, 2017). This was different from Europe where the WTG manufacturers would sell the WTG fully installed and commissioned and thereby take full control over the WTG installation scope (Martinez-Neri, et al., 2015). The China market case study revealed some possible differences for smaller local OWFs compared to large state-owned utilities.

- The BOP supply chain was a gap in itself because manufacturing facilities for different types of cables, offshore substations, and WTG foundations had not been fully built out in China (Poulsen & Lema, 2017). As a result, only limited experience had been gained from the related logistics tasks (Poulsen & Hasager, 2017). Many early OWFs had been near-shore and small in terms of total power output and therefore, e.g. offshore substations had only started to be needed at a later stage.

- The area of offshore wind O&M logistics was a frequent topic within the China market case study. The corresponding area of onshore O&M suffered from poor WTG performance and this was being admitted to also publicly at conferences and as part of bilateral projects between China and other countries such as Denmark. In order not to bring onshore challenges offshore and exacerbate those same challenges in the much harsher sea environment, offshore logistics strategies were sought (Poulsen & Hasager, 2017). It was specified that these strategies should be specific and include offshore wind O&M logistics concepts, be based on real experience, and it was important to be able to make use of factual operational data from OWF operations elsewhere.

- The decommissioning life-cycle phase was just starting to emerge as an area of focus especially for the major state-owned utilities (Poulsen & Hasager, 2017). This meant that they had started to develop a nascent understanding for the reverse logistics chain involved in dismantling and ultimately abandoning an offshore wind site.

- Early OWF cost models and business cases in China had focused more on CapEx for key assets such as the WTG, the WTG foundations, and cables. The cost models and planning efforts had focused less on a full OWF life-span. Cost modeling and OWF project planning was therefore sought at a more granular level to include logistics and also with a horizontal structure including the O&M as well as decommissioning life-cycle phases (Poulsen & Hasager, 2017).

Key logistics challenges	**Type of understanding yielded**	**Detailed description of attributes and implication**
Logistics related studies	Logistics knowledge and experience needed	Different kinds of studies required to get necessary permits from authorities and to plan operations
Vessels	Logistics experience and investment needed	Specific vessel types, specific skills needed for handling custom-made wind energy vessels, and joint vessel investments from overseas investors
WTG installation	Different logistics procurement and contracting scope	Control with the developer in China and not WTG manufacturer like in Europe
BOP supply chain	Supply chain only partially available and lack of logistics experience as a result	Limited experience with logistics for BOP items such as cables, substations, and WTG foundations
O&M logistics	Significant onshore challenges; offshore wind logistics knowledge and experience needed	Need for logistics strategies coupled with real logistics O&M experience and data from live operations overseas
Decommission-ing	Only starting to emerge as an area of focus	No experience with offshore wind decommissioning but emerging awareness that the reverse logistics chain will be important to master
Cost modelling / OWF project planning	Generally sought for; should include logistics also in O&M and decommissioning life-cycle phases	Nascent understanding that logistics across all life-cycle phases of OWF should be included as cost modeling and OWF project planning discipline

Table 15. Key areas of additional understanding of logistics challenges in China.

In applying China as a relevant representative for all emerging offshore wind markets, it is a contribution of this research that the results suggest that logistics will be organized differently in new markets compared to the mature markets of Europe. The scientific implication is that it would not be possible for academics to bring preconceived understandings of how things are organized from a logistics perspective to e.g. China and assume that studies, models, or simulation tools can be readily transferred. Many assumptions and factors would be significantly different, and alterations would be required in order to customize further academic progress to a local setting of the particular emerging market.

From a practitioner perspective, a contribution of this research is that it is important to understand that business models, operating models, and ways-of-working cannot be directly transferred to emerging markets in all cases. Using China as an example, local customization of assets, products, services, skills, and competencies is necessary and actively sought for by the Chinese counterparts.

6.4 OFFSHORE WIND SUPPLY CHAIN READINESS EVALUATED BASED ON LOGISTICS

Based on earlier research efforts on the wind market development in the key Asia markets India (Narain, et al., 2014a; Narain, et al., 2014b) and China (Dai, et al., 2014) as well as Denmark and Germany (Lema, et al., 2014), wind development trajectories in Asia and Europe were compared and contrasted at a regional level (Lema & Lema, 2013; Lema, et al., 2016; Zhou, et al., 2016). A member of this cross-regional research effort from Aalborg University had identified the topic of whether the supply chain was indeed ready for the globally projected build-out of green energy capacity. If the offshore wind industry was used to exemplify this, it seemed clear, also based on the on-going literature review of this research, that only sparse research existed on the topic of logistics within supply chains of renewable energy forms. As the broad definition of logistics in offshore wind was an integral part of the supply chain as well as SCM, the readiness of the overall supply chain of offshore wind would be generalizable based on the readiness of logistics as an integral subset of the supply chain.

To test this proposition, the literature review was expanded to determine if renewable energy supply chains had been subjected to any degree of study within the disciplines of SCM and logistics. This yielded only limited results also within more widely defined search areas such as marine planning where offshore wind planning efforts formed only a small part of the overall outcome (Rodrigues, et al., 2015). In a conceptual paper providing a framework to analyze supply chains from raw materials to consumption, three trajectories were provided linking SCM to energy and one such trajectory is the energy supply chain (Halldórsson & Svanberg, 2013). Only a few additional logistics and SCM papers were identified as dealing with offshore wind such as a logistics strategy decision support tool for the construction process (Lange, et al., 2012), a simulation tool considering vessel costs and weather in the installation and commissioning life-cycle phase (Barlow, et al., 2015), and an account of all decision support tools available in offshore wind across the dimensions of construction, service, as well as the overall project cost segments (Hofmann, 2011). In addition, a detailed guide to OWF installation was identified (Thomsen, 2012).

In this way, it was reaffirmed that a literature gap existed and this gap could possibly be filled by constructing a view of the empirical data collected in a way where the case studies would be nested together as two embedded sub-unit case studies (Neergaard, 2007). Based on the different theoretical gaps identified in chapter 2 above, the literature gap of supply chain readiness was found to be cutting across the total theory body reviewed as well as all three case studies of this research. The results of the literature review of this research confirmed that logistics could indeed be viewed as a functional subset or discipline within the more broadly defined supply chain which again resides within the SCM theory stream. In this way, it was justified to build the cross-case study comparing logistics in emerging markets to that of mature markets and generalize to be able to render an opinion on overall supply chain readiness for offshore wind (Poulsen & Lema, 2017).

The work with understanding existing research for emerging markets outlined in section 2.5 above had concluded that China was the only market of sufficient scope and scale to be able to be representative of all emerging offshore wind markets. Therefore, it was justified to let findings from the China case study of this research represent the emerging offshore wind markets and, in this way, generalize conclusions whilst maintaining some degree of secondary and tertiary case coverage of other markets to ensure that the results found were sufficiently reliable and valid.

At the time of performing the Ørsted case study, Ørsted was the market leader within offshore wind. The firm had a market share of 15.6% of all operating OWFs and a track-record of having constructed 26% of all OWFs built globally at that time (Poulsen & Hasager, 2016). The logistics O&M case study had a cross-industry firm representation and although set in a Danish context, the firm constituencies represented a widespread logistics spectrum of capabilities and were not limited to the Danish market and not all were of Danish origin (Poulsen, et al., 2017; Høg, 2015). The Ørsted case formed the core part of the conclusions made and the O&M logistics case was used mainly to cross-check in terms of validity and reliability. As such, it was found that results from the two case studies set in a European context could adequately represent mature offshore wind markets in general.

Of the seven areas of additional logistics understanding generated from the work with the Chinese market (see Table 15), several could be directly translated to a supply chain readiness measure which could be contrasted to the corresponding European supply chain readiness. To exemplify, the understanding from emerging markets on three of the seven logistics topics (BOP supply chain, vessels, and O&M logistics) could be enriched with context and empirical data analysis already collected. In this way, the emerging market logistics understanding could be translated into general results on supply chain readiness and generate a score (see Table 16). Such further analysis of prior results of the different case studies formed the basis of the publication pertaining to readiness of the offshore wind supply chain based on the offshore wind logistics findings as the lens applied (Poulsen & Lema, 2017).

The BOP supply chain was insufficiently developed in China and as such, Europe possessed the only real BOP infrastructure and supply chain capacity at the time this research was performed (Poulsen & Lema, 2017). This can be contrasted to the WTG supply chain where several Chinese manufacturers of WTGs were active with test machines in the offshore market (Poulsen & Hasager, 2017). Accordingly, it followed that logistics capabilities were less ready for the offshore wind BOP supply chain in China due to the lack of availability of a supply chain in terms of manufacturing footprint and associated people, skills, and processes.

When it comes to vessels, the mature European market had developed vessels over time which were custom-designed to increase productivity, for example, in the installation and commissioning as well as the O&M life-cycle phases. As the European market had increased the annual tact of OWFs being constructed simultaneously and as more offshore WTGs came into operations, the need for more efficient and effective vessel solutions drove innovation efforts and helped to optimize vessel operations (Poulsen, 2015; Poulsen & Hasager, 2016). Chinese academics and firms learned from Europe using different approaches: through scientific projects; remote online study; delegation trips; making use of M&A (Haspeslagh & Jemison, 1991; Trompenaars & Asser, 2011); or observing the vessels as they were being constructed in Chinese shipyards by the European owners. As such, Chinese shipyards were of course aware of what the vessels were made of as well as the costs, especially the WTIVs which are very costly to build.

Furthermore, to operate WTIVs during the OWF construction process or a special operation vessel during the O&M life-cycle phase are not simple tasks (Poulsen & Hasager, 2017). Vessel crews needed training in specialized areas such as heavy lifting to use the cranes of the vessels to move often heavy and voluminous wind components in high wind speeds as well as with significant wave movement. To keep the vessels in a fixed position and to prevent technicians from being seasick, dynamic positioning equipment had to be installed and operated on board the vessels which requires special training. Finally, jacking operations were performed much more frequently in offshore wind (for each WTG) than when compared to offshore oil and gas (a drilling rig only jacks up or down relatively few times during its life-span) and as such, vessel crews needed very different jacking training including the use of a land-based simulator as well as training offshore with an experienced team. At the time of conducting this research, the emerging market of China was consciously aware (Poulsen & Hasager, 2017) of the fact that these important factors for vessels were in need and as a result, the logistics capabilities for vessels across different life-cycle phases of an OWF were less ready (Poulsen & Lema, 2017).

When it comes to O&M logistics, more and more OWFs came online in Europe over time, increasing the number of WTGs actively running offshore. Several governments mandated that O&M data sets be made publicly available as part of seabed concession grants and it was therefore possible for academics as well as firm representatives to use this data for statistical and simulation purposes (Poulsen, et al., 2017). Different maintenance and repair strategies were introduced, tested, and slowly implemented from other industries which started to distinguish the O&M responses along three different dimensions, each in need of a different logistics response (Poulsen & Lema, 2017):

- Preventative, planned, or predictive maintenance of each WTG position topside and subsea to ensure that major components would have as long a life-span as possible. These campaigns can be planned well in advance and therefore done during favorable weather seasons. One objective would be to optimize logistics and try to reduce logistics costs as much as possible.

- Unscheduled or unplanned maintenance where a WTG would malfunction or break down unexpectedly yielding a need for diagnostics either remotely or based on an on-site inspection by a technician to determine next steps including possible repair options. To get a technician to the WTG, a level of logistics preparedness needs to be in place especially during winter months where preventive maintenance campaigns are usually not run. To have a logistics response ready is possible and the cost of the solution needs to be offset by the lost revenue from a WTG not producing any power to be sold by the OWF operator.

- Contingency maintenance where the entire OWF asset is unavailable, for example, due to an export cable being cut or substation malfunction. For an OWF with, for example, 70 WTG positions each capable of yielding 6 MW, a stoppage of the entire OWF is critical in terms of lost revenue per day for the operator. The logistics response must therefore be as efficient, quick, and effective as possible. In these ad-hoc situations, the logistics cost is insignificant compared to the lost revenues from the lack of electricity production.

The evolving review of the available literature revealed that a need existed to evaluate the supply chain from a readiness perspective. Using logistics as the exemplifier, China as the emerging market representative, and the two case studies in a Danish setting as the mature European market representative, a contribution of this research was to present results that indicate the supply chain readiness in emerging versus mature offshore wind markets respectively.

Emerging market logistics understanding	**Further description**	**Critical dimensions**	**Key attributes**	**China (emerging markets) score**	**Europe (mature markets) score**
BOP supply chain	Cables, offshore substation, and WTG foundations	Distance to shore, number of WTG positions in OWF	Subsea, topside, 1 offshore substation versus many WTGs, export versus array cables	0-1	1-2
Vessels	Specific vessel types	Piling hammer vessels, cable laying vessels, WTIV, crew transfer vessel	Customization to Chinese conditions	0-1	1-2
	Specific skills	Jacking, dynamic positioning, cranage	Generically available, bespoke offshore wind settings	0-1	1-2
	Joint investments	WTIV	Major investment	1	2
O&M Logistics	Different responses for different situations depending on whether per WTG or for entire OWF asset	Preventive O&M	Preventive / planned WTG maintenance	1	2
			Return flow / reverse supply chain	1	2
		Unscheduled maintenance	Unscheduled / break-down WTG	0	1
		Contingency maintenance	Entire OWF asset	0	1

Table 16. Emerging market logistics understanding translated to supply chain readiness measure.
Score legend: A score of 0 blocks diffusion of offshore wind, 1 has negative impact on diffusion, 2 indicates supply/demand balance with positive yet limited impact on diffusion, and 3 implies sufficient supply with a positive impact on offshore wind diffusion.

6.5 MATURING OF LOGISTICS IN THE MATURING OFFSHORE WIND MARKET

An aspect not clearly revealed by the literature review performed when initiating this research, and therefore not included as a research question to be answered, is that results from this research indicate that logistics as an academic discipline or area of management focus is in the process of maturing within the offshore wind industry. At the same time, the offshore wind industry itself is in the process of maturing and the trajectory of maturation seems different in markets that are relatively more mature than new markets that are emerging.

The literature review of this research points to the fact that logistics in offshore wind has traditionally been hard to define and that academically, research on logistics in offshore wind has been limited. A managerial implication of the lack of a definition of logistics in offshore wind has been that organizational structures within firms were blurry with a resulting lack of focus on logistics as a managerial discipline and logistics not being considered an area of immediate potential for cost-out efforts.

As a result of this research (Poulsen & Hasager, 2016), it is now better understood that logistics in offshore wind would seem to be costlier and thereby relatively less developed than logistics in other industries which have been better organized and subjected to better optimization for a longer period of time (CSCMP, 2015).

Each of the seven examples of the better understanding of logistics in emerging markets generated from this research (Poulsen & Hasager, 2017) and reviewed above (Table 15) can also exemplify that the emerging market researched (China) is less mature from a logistics perspective than the European offshore wind market. The different task allocation structures identified, the need for knowledge, the desire to share risk by co-investing in key assets, the need for training, the options explored for organization of different functions, the need for infusion of experience, the lack of available data, the need for a build-out of the manufacturing footprint, as well as the development of a holistic and end-to-end asset life-span perspective are all factors that point to the logistics of the offshore wind industry in emerging markets going through a steep maturation learning curve (McCormack & Lockamy, 2004).

This research has also provided evidence that the wind industry itself has been going through a process of maturation. In China, the number of WTG manufacturers peaked in 2014 according to this research (Poulsen & Hasager, 2017) and the ensuing development very much resembles a ‘shake-out’ from an industry life-cycle literature perspective (Klepper, 1997; Peltoniemi, 2011) where buyer-supplier relations (Lutz & Ellegaard, 2015) and supply chain integration become key opportunities going forward (Martinez-Neri, et al., 2015) as also evidenced in Europe (Martinez-Neri, 2016). The finding that the BOP supply chain capacity was almost fully concentrated in Europe when this research was initiated also reveals that a build-out in geographically distant offshore wind markets was on-going, thereby maturing the offshore wind market of

China (Poulsen & Lema, 2017). Finally, as part of the publication providing the research frame for this PhD study, an initial account of the industry consolidation within the offshore wind energy industry as well as the industry consolidation within the derived shipping and logistics market was presented (Poulsen, 2015).

CHAPTER 7: DISCUSSION

Based on the initial literature review, three research questions were defined to address the identified knowledge gaps and further the knowledge on logistics in offshore wind.

The research questions directed this PhD project to attempt to identify how logistics is organized in offshore wind and determine whether logistics is important, what the costs of logistics are in offshore wind, as well as how characteristics of mature markets compare to new and emerging offshore wind markets. Three cases were categorized as warranting primary focus. Thorough and continuous literature review efforts were used as the foundation for the analyses of the different empirical data gathered through the different case studies. This multi-dimensional scholarly literature review was supplemented by extensive desktop studies relevant to each case respectively in case warranted from a contextual, comparative, or subsequent publication perspective. A significant portion of the different analytical work streams yielded results which can be classified as theoretical contributions that have furthered what is ontologically understood within science today.

In what follows, the contributions of this research will be discussed in the setting of each of the three research questions (a summary of contributions outlined in chapter 6 seen in relation to the research question dimensions and the review of scientific theory is provided in Table 17 below). Section 7.1 discusses how the method has continuously improved over time as part of this PhD study. Section 7.2 discusses the theoretical contributions to research question one about the organization of logistics in offshore wind and the importance of logistics. Section 7.3 discusses the theoretical contributions to research question two pertaining to the costs of logistics in offshore wind and section 7.4 discusses the theoretical contributions to research question three about how mature and emerging market logistics practices may be characterized. Section 7.5 touches upon the managerial impact of the contributions of this PhD study.

Gap in academic literature	Contribution of this research	Relevant publication from this research	Link to the three research questions of this research	Academic implications	Managerial implications
Logistics definition can be context dependent Logistics not well researched in an offshore wind setting	Academic definition of logistics in offshore wind was provided and the understanding of how logistics is organized in offshore wind was furthered	(Poulsen & Hasager, 2016)	Being able to define logistics would be a prerequisite for the ability to organize logistics in offshore wind	The definition of logistics now makes it possible to further research logistics in an offshore wind organizational context	Firms can organize in such a way that logistics is a managerial discipline across the offshore wind portfolio, within each OWF, and for the life-cycle phases
Cost of logistics in offshore wind not defined	Understanding of costs of logistics relative to CapEx, OpEx, and LCoE for offshore wind was furthered academically	(Poulsen & Hasager, 2016)	Having an idea of the costs of logistics would help bring forward an understanding of the relative importance of logistics as a discipline	Logistics is an important discipline that warrants corresponding academic focus	Logistics is an important cost factor that warrants specific managerial focus and top management attention
	Share of logistics costs as a percentage of overall costs seems to warrant that logistics be treated as a separate cost discipline in LCoE studies	(Poulsen, et al., 2017)	A better understanding of the logistics costs in offshore wind now exists	Logistics is a major cost area when viewed across a portfolio of wind farms, horizontally across OWF life-cycle phases, and vertically within each phase	Industry initiatives should align LCoE model settings and assumptions usage and industry should ensure that cost studies focus on logistics at all levels to be able to drive down costs
	Use of assumptions and settings revealed that LCoE cost models could potentially be biased by subjective goals of individuals or organizations	(Poulsen & Hasager, 2016; Poulsen, et al., 2017)			

Table 17. Summary of theory gaps, research contributions, and implications in relation to the three research questions of this research.

Gap in academic literature	Contribution of this research	Relevant publication from this research	Link to the three research questions of this research	Academic implications	Managerial implications
Comparison of logistics cost at line-item level across different studies not available	Comparison of 11 cost studies furthered the academic understanding that logistics costs may not be properly defined and accounted for	(Poulsen, et al., 2017)	The improved understanding of logistics costs need to be better translated to logistics cost studies often sponsored by governments	Academia can help ensure that logistics becomes a separate cost discipline within offshore wind	Industry should help ensure that governments do not bias cost studies to impact public discourse in terms of offshore wind
Logistics characteristics in emerging offshore wind markets not well understood	Analysis of the Chinese offshore wind market indicated that significant differences seem to exist in terms of how logistics is organized in emerging markets compared to mature markets	(Poulsen & Hasager, 2017)	Better understanding of logistics characteristics of emerging offshore wind market now exists which enables contrasting and comparison to mature markets	Comparative studies involving researchers in emerging and mature markets can be performed with an aim towards speeding up learning in emerging markets by learning from mature markets	Managers from mature markets involved in making market entry in emerging markets should be aware that best practices and experiences are not immediately transferable as localization is needed
Renewable energy supply chain readiness assessment did not exist	Analysis of the offshore wind supply chain readiness in mature markets revealed that significant differences exist when contrasted to emerging markets using logistics as the lens to evaluate	(Poulsen & Lema, 2017)	Understanding of supply chain readiness from a logistics perspective now improved as part of comparison between mature and emerging offshore wind markets	Readiness of the offshore wind industry, its supply chain, and the maturity trajectory within the associated logistics market can now be subjected to further scrutiny by academia using different available frameworks	Managers in emerging markets can speed up their learning curve and offshore wind diffusion trajectory by infusing technology, personnel, and skills from more mature markets

Table 17. Summary of theory gaps, research contributions, and implications in relation to the three research questions of this research (continued).

7.1 CONTINUOUS IMPROVEMENT OF METHOD APPLIED

Looking back at the methods applied throughout this research, several specific improvements have been made over time:

- The work with the semi-structured interviews with open-ended questions (Poulsen, 2015) served to generate a large volume of mainly interviews in order to provide context at an industry level and contrast the academic literature gaps to practitioner challenges. The Ørsted case was designed with formal interviews as well as a survey. Presentation of the Ørsted case study analysis had to meet academic as well as practitioner standards by way of the subsequent academic publication (Poulsen & Hasager, 2016) as well as the presentation of the logistics innovation strategy within the firm in September 2015 respectively. The research design for the practically oriented action research and participant observation work with the Offshoreenergy.dk O&M logistics case study was supplemented with the desktop study of the 11 cost studies. Again, a significant hurdle had to be passed in terms of academic scrutiny to get the work published (Poulsen, et al., 2017) as well as the review and subsequent implementation of the business cases by practitioners. The Chinese case study design with the embedded case built around the 15 formal and structured interviews after a significant effort with 'bridge' interviews / participant observation site visits was challenging to get to geographically, let alone organize in China. The desktop study on the legislative and policy environment coupled with nation state-led implementation at firm level was a necessary part of making the case publishable (Poulsen & Hasager, 2017). The work on the China case study was separately subjected to additional scrutiny from a practitioner perspective through the extensive discussions with the Reference Group as well as the ensuing after work meetings open to the public. Finally, the most complex research design was the cross-case comparison publication (Poulsen & Lema, 2017). This paper was based mainly on two embedded sub-unit case studies (Neergaard, 2007) built around two leading developers in Europe (Ørsted) and China (primarily Longyuan) respectively.

- If the empirical data collection avenue of interviews is considered (collection techniques box in the figure in appendix 2), an evaluation along a path described academically (Morse, 2012) occurred from a learning perspective across dimensions that this researcher became familiar with only at a later stage in this research after attending several doctoral courses on method. As such, a higher volume of early interviews was based on open-ended keywords instead of questions with the interviews being semi-structured in nature (Poulsen, et al., 2013a; Poulsen, et al., 2013b; Poulsen, 2015) and therefore academically less rigorous. The subsequent Ørsted case study interviews (Poulsen & Hasager, 2016) were fewer in terms of volume yet much more scientifically streamlined and followed strict interviewing guidelines (Kvale & Brinkmann, 2012) in terms of how the interviewees were selected, how the interview protocol was crafted, how the interview data were processed (tapes, transcripts, validation), and how the data was subsequently analyzed (Roulston, 2012). A more advanced method with action research type participant observation was utilized in the work with the cross-section of practitioners from an industry-wide perspective in the O&M logistics case study (Poulsen, et al., 2017) and the China case study was a hybrid of all set in a complex cultural context (Poulsen & Hasager, 2017). The five (unstructured / guided / focus group / semi-structured / quantitative questionnaires) interview categories with different characteristics and dimensions (Morse, 2012) assisted this researcher in directing this evolution throughout the different case studies as this research matured over time. Please refer to appendix 5 for a high-level summary of the empirical data collection efforts of this research.

- The data access got better during the life-span of this research as the primary case studies made work with the three research questions more focused. This meant that the analysis process evolved over time including the ability especially on the part of this researcher to interpret the data collected (see chapter 5). As such, the analysis performed in the paper setting the contextual frame for this PhD study (Poulsen, 2015) was very different compared to that of some of the later publications (Poulsen & Lema, 2017; Poulsen & Hasager, 2017).

- From a digitalization perspective of this research, the use of a literature referencing software like LaTeX or Mendeley may have been useful instead of the more manual process outlined in chapter 2. From an automation perspective, the search for the 'ideal' case study took place (see section 4.3) when this research was initiated, and the use of a multiple-case design as defined by Yin (2014) had not yet been considered. As such, the future coding of empirical data had also not been fully appreciated at that time. Especially with three primary cases of this research, the use of a coding software as discussed in section 5.3 could possibly have been advantageous. The work with coding the empirical data in a spreadsheet format was extensive and the work to merge empirical data for the cross-case study publication could possibly have been more efficient in case a software like NVivo or Atlas.ti had been utilized as part of this research.

- This researcher only became familiar with some of the emergent 'signature' research designs and analytical processes within the area of mixed method research (Teddlie & Tashakkori, 2010; Leech, 2010) relatively late in this research. When looking back, the mixed method kind of research strategy could possibly have been useful. However, this PhD project was already well under way by the time the power of truly mixed method research design started to become understood (Alise & Teddlie, 2010; Biesta, 2010). The case study worked well for this PhD project although the method is criticized by quantitative researchers as not being a stand-alone methodology and flaws are often highlighted, which proponents of the case study have defended (Flyvbjerg, 2006).

A literature review of the use of the case study method involving 93 academic publications within the field of M&A (Reddy, 2015) was a useful inspiration for several of the publications forming part of this research. As such, inspiration was found in this literature review to do things not done frequently such as mixing a single-firm case study (Poulsen & Hasager, 2016) with a case study cutting across multiple firms (Poulsen, et al., 2017; Poulsen & Hasager, 2017) as well as combining the data collection process of interviews with a survey (Poulsen & Hasager, 2016). Also the work to construct the cross-case paper with the objective to analyze horizontally across the three main case studies of this research (Poulsen & Lema, 2017) had not been done frequently within the case study part of M&A literature reviewed (Reddy, 2015).

7.2 THEORETICAL CONTRIBUTIONS ON THE ORGANIZATION OF LOGISTICS IN OFFSHORE WIND AND IMPORTANCE

The theoretical contributions towards the first research question about how logistics is organized in offshore wind and whether it is important were two-fold: A definition of logistics in offshore wind was suggested (Poulsen & Hasager, 2016) and the available scientific understanding was furthered in terms of how logistics is organized in offshore wind as well as whether it is important (Poulsen, 2015; Poulsen & Hasager, 2016; Poulsen, et al., 2017; Poulsen & Hasager, 2017; Poulsen & Lema, 2017).

The research findings were reported across all five publications forming part of this research and the results were generated based on the gaps identified in academic literature. The gaps in academic literature pertaining to the first research question of this research revealed that a definition of logistics can vary and be very context dependent. In addition, the literature review revealed that in an offshore wind setting, logistics was not well researched.

In the work on the Ørsted case study, it was evident that it was hard for the case organization to adequately scope what to include and exclude from their strategy to be formulated on logistics innovation. The logistics innovation strategy input generated for Ørsted was the main contribution in return for gaining case study access (Henriksen, 2016). Through interviews and survey responses, empirical data was collected which suggested that different people had different perceptions of what logistics may or may not mean in an offshore wind setting and Ørsted specific context. Significant ambiguity in terminology was detected and scrutiny of contextual vocabulary within the empirical data collected revealed that some 12 dimensions had to be considered in order to determine what was meant when discussing logistics. It followed that the firm did not have a logistics strategy to form part of the overall firm strategy as recommended by scholars (Chopra & Meindl, 2013; Christopher, 2011). In addition, the firm was not organized with a horizontal logistics function able to make logistics considerations across the portfolio of OWFs, within each OWF life-span, and vertically within each life-cycle phase. This again meant that important logistics lessons learned were not captured and logistics knowledge management challenges were detected.

By using action research (Kristiansen & Bloch-Poulsen, 2017) to facilitate the discussion within Ørsted about how logistics is defined and what this means from a logistics innovation perspective as well as organizationally, continued case coverage through the Reference Group of this PhD project has revealed that the firm later did in fact reorganize and made logistics a more integral part of their business model. From a logistics innovation perspective, the handling of a separate stream of idiosyncratic logistics innovation ideas has now been formalized organizationally within the firm. In terms of vertical life-cycle focus, a 'logistics product line' organization was established for the installation and commissioning phase and a 'logistics concept line' organization established for the O&M phase. In addition, operational departments dealing with vessels, helicopters, and ports have been expanded. A horizontally focused and all-encompassing logistics department cutting across the entire portfolio of offshore wind with a clear mandate across all operational and future OWFs does, however, not yet seem to have been implemented. In terms of how important logistics is in offshore wind, the Ørsted case study has revealed that logistics was not regarded to be very important but that the focus put on logistics through the efforts to create a logistics innovation strategy helped advance how the firm thought of logistics and subsequently also how the firm is organized.

The theoretical implication of these results is that by defining logistics in the particular context of offshore wind, it is possible to start applying the different dimensions of the definition to particular settings across different ontological situations. This again means that depending on what is subjected to scientific scrutiny, academically proven experiences from other industries as well as theoretical logistics related frameworks found within the general literature bodies of 'logistics' and 'supply chain management' can now be more readily applied by academicians. As such, the contributions of this research should support the advancement of further academic research within the field of logistics in offshore wind.

7.3 THEORETICAL CONTRIBUTIONS ON THE TOPIC OF THE COSTS OF LOGISTICS IN OFFSHORE WIND

The theoretical contributions towards the second research question about the costs of logistics in offshore wind were four-fold: 1) An understanding of the logistics costs relative to CapEx, OpEx, and LCoE for offshore wind was furthered academically (Poulsen & Hasager, 2016), 2) the share of logistics costs as a percentage of overall costs seems to warrant that logistics is treated as a separate and scientifically founded cost discipline in offshore wind LCoE studies (Poulsen & Hasager, 2016; Poulsen, et al., 2017), 3) the use of assumptions and settings of (often government sponsored) cost studies for offshore wind revealed that these cost models could potentially be biased and pre-set to generate specific outcomes desired by individuals, organizations, or institutions (Poulsen, et al., 2017), and 4) the comparison made of 11 cost studies yielded further academic understanding in terms of logistics costs not being properly defined and accounted for (Poulsen, et al., 2017).

The research findings pertaining to logistics costs in offshore wind were reported mainly across two (Poulsen & Hasager, 2016; Poulsen, et al., 2017) of the five publications forming part of this research and the results were generated on the basis of the gaps identified in academic literature. The gaps in academic literature pertaining to the second research question of this research revealed that the cost of logistics in offshore wind was not well defined and that a comparison of logistics costs had not been carried out across different cost studies, let alone at a line-item level.

As part of the work efforts on the Ørsted case study (Poulsen & Hasager, 2016), it became evident that personnel within the organization estimated logistics costs quite myopically depending on the actual perspective (operational OWF site related experience and/or office experience), work function (position within a certain life-cycle, work within a particular OWF project, and/or staff function such as finance), and managerial level (specialist, middle management, and/or top management) of each of the respondents. Among 53 useful interview and survey responses, 28 responses provided answers that could be attributed to the main cost groupings of CapEx, OpEx, or LCoE. The remaining responses were either not usable or responses were provided at a level which was too granular such as the cost of logistics seen, for example, in relation to the cost of WTGs, in relation to the cost of an offshore substation, or logistics costs as a share of the total costs to operate a port. From a disparity perspective, it was the Ørsted answers on the cost of logistics in the O&M life-cycle phase that varied the most.

The work with the O&M case study (Poulsen, et al., 2017) was prone to an academic desktop study on available literature on the cost of logistics which could further the understanding of the implications of the Ørsted learnings about O&M costs which had yielded the most ambiguity. The academic literature identified used very few and often industry produced accounts of the relative share of LCoE across different dimensions. The desktop study of 11 cost studies (largely government sponsored) revealed that logistics costs were not properly defined within the cost studies and therefore also not properly accounted for. This meant that different underlying calculations were utilized to calculate e.g. costs for port operations, vessels, and helicopters. Although seemingly comparable, the line-item review showed great disparity which meant that it was not prudent to compare across the 11 studies and instead, one of the studies was used as the logistics ‘base case’ (Scottish Enterprise, 2013). The share of logistics costs as a percentage of the overall OpEx warranted that logistics be treated as a separate cost discipline when future cost studies are generated through academic efforts or by large joint industry projects such as Megavind (2015). Finally, and from a purely logistical perspective, the contradicting setting options and available assumptions meant that the outcome of the cost calculation models could be manipulated so that different biases and discourses could form part of the results. It was found that this could be done both during the data collection phase to assemble input for the cost models as well as when organizing the different mechanics of how the calculations are being performed (Poulsen, et al., 2017).

Being able to credibly place logistics costs into a perspective of either vertically oriented life-cycle phases or a horizontal LCoE context was found to significantly alter the dialogue about logistics. When the mean responses from the Ørsted case were published (Poulsen & Hasager, 2016), logistics suddenly became a cost force to be reckoned with for an OWF project. The sample size of the Ørsted case study (28 useful responses in total) was subjected to some criticism in terms of validity. Subsequently, however, when the in-depth desktop study of the O&M life-cycle phase was performed across 11 cost studies, the corresponding directional figures from the Ørsted case study were confirmed (see Table 18) and the ambiguity of results reduced. Consequently, the results from the Ørsted research were validated through the very detailed desktop study within the single life-cycle phase of O&M and in this way found to be reliable.

Logistics costs as a share of operating expenditure	**Minimum**	**Mean**	**Maximum**
Ørsted case study	15%	26%	85%
O&M logistics case study	17%	24%	31%

Table 18. Comparison of the Ørsted versus logistics operations and maintenance case study results on logistics costs measured as a percentage of operating expenditure.

The theoretical implication of these results is that within the different life-cycle phases as well as across the entire life-span of an OWF, logistics costs are significant. This infers that the scientific discipline of logistics should be included in cost studies going forward and definitions of logistics costs should be made clear at a line-item level for adequate comparative studies to be performed. The methods applied to select different logistics attributes and manage settings of cost model tools deserve specification for transparency to exist so that knowledge amassed by some researchers in academic projects may be utilized and furthered by other scientists. Defining assumptions and model set-up can also help avoid doubt in terms of biased outcomes promoting the agendas of individuals and/or organizations. As more scientific focus is put on logistics, academic studies can make comparisons using the same assumptions, line-item descriptions, and cost modeling settings to be able to reflect whether additional academic focus on the logistics discipline is indeed successful in terms of contributing to the overall cost reduction targets of offshore wind. The contributions of this research ought therefore to be able to help provide an academically founded baseline for metrics to measure the impact of scholarly efforts within the field of logistics in offshore wind.

7.4 THEORETICAL CONTRIBUTIONS ABOUT LOGISTICS IN MATURE AND EMERGING OFFSHORE WIND MARKETS

The theoretical contributions towards the third research question about how logistics in offshore wind is characterized in established versus emerging markets were two-fold: The analysis of the Chinese offshore wind market (Poulsen & Hasager, 2017) revealed that significant differences exist in terms of logistics practices of emerging markets compared to more mature markets. In addition, the cross-case comparison of supply chain readiness of emerging versus established markets (Poulsen & Lema, 2017) based itself on a logistics perspective within the overall supply chain context.

The research findings were reported mainly across two (Poulsen & Hasager, 2017; Poulsen & Lema, 2017) of the five publications forming part of this PhD study. In addition, some initial accounts were provided in the publication setting the contextual frame for the research of this PhD study (Poulsen, 2015). The results were generated based on the gaps identified in academic literature. The first gap in academic literature pertaining to the third research question of this research revealed that the logistics characteristics in emerging offshore wind markets were not well understood at the time this research was initiated. Discovered in dialogue with a more senior researcher from Aalborg University after this research had already commenced, the second identified research gap revealed that an academic account of the readiness of the supply chains of renewable energy power sources did not exist.

In the work with the China market case study, results clearly showed that China was moving ahead with offshore wind diffusion mainly by extending the onshore wind supply chain into the sea and starting very near-shore and in river deltas such as the Yangtze river. Despite not having tailor-made offshore wind assets such as different vessel types and other transport equipment, the construction process in China was initiated and the main focus was to ensure that the cash-outflow in the installation and commissioning phase was considerably lower than corresponding metrics available from the European market. From a shipping and logistics perspective, available experience was used with existing assets and OWF projects were carried out in line with the knowledge obtained from other offshore construction projects such as oil and gas, bridges, and ports. The BOP supply chain was virtually non-existent and started to be built out from the onshore wind manufacturing footprint (onshore tower manufacturing skills were extended to monopile manufacturing) as well as more bespoke greenfield investments (gantry crane specialty skills and shipyard experience were extended to customized offshore wind vessel construction, monopiles, and transition pieces). Most of the offshore wind experience in China was gained somewhat in isolation and without significant infusion of knowledge from more mature European markets. This was particularly visible during participant observation site visits where interview statements could be validated through observations and contrasted to European conditions. Roads from a WTG manufacturing site to the export harbor were in extremely poor condition as a result of most of the road being washed away by rainfall. Towers shipped using a tug/barge solution were loaded directly onto the deck of a vessel with pieces of wood being used to prevent the tower section from moving, and land-based heavy-lift operations were performed in conditions where many people moved around under e.g. the nacelle being lifted. Interviewees knew that their transport and logistics solutions were inadequate and experiences from Europe were continuously requested. Emphasis from the interviewees was put on the fact that European assets and experience would not be directly transferable to the Chinese market because of unique local conditions (e.g. rules and regulations, porous seabed conditions in inter-tidal areas, etc.), pricing considerations (central government mandated cost ‘ceilings’, CapEx focus, etc.), and cultural aspects (for example, the need to have people employed weighing heavier within a municipality than an efficient and quick installation process).

The work with the comparative analysis of supply chain readiness in emerging versus mature offshore wind markets, using logistics as the basis to make the analysis (Poulsen & Lema, 2017), was mainly a desktop exercise. As such, this publication had no particular case study attributed to it as it was a cross-case study where primarily the Ørsted logistics set-up in Europe (based on the Ørsted case study) was contrasted to that of primarily Longyuan in China (based on the China market case study). In addition, the O&M logistics case study data was used to supplement the Ørsted data where necessary. The analysis of logistics costs within the different cost studies had revealed that the installation and commissioning as well as O&M life-cycle phases were – by far – the phases with the greatest overall share of LCoE (The Crown Estate, 2012; Prognos and Fichtner Group, 2013; BVG Associates, 2014; Megavind, 2015). Therefore, the detailed evaluation of logistics readiness had the life-cycle phases of development and consent as well as decommissioning excluded which helped focus the analysis. The installation and commissioning life-cycle phase was split into two logistics chains and the O&M life-cycle phase was split into three logistics chains. Within those different logistics chains, separate work streams with bespoke and distinct logistics sub-chains had been identified through the case study work. As such, the logistics operation to put up, for example, 80 WTGs using a specialized WTIV was completely a topside, above water operation requiring the vessel to jack up and perform at least five heavy lifts for each WTG, i.e. the tower sections (1-2 lifts), the nacelle/hub (1 lift), and the blades (three lifts). Conversely, the logistics set-up for the export cable laying process included a specialized cable laying vessel able to dig and cover the cable using a remotely operated vehicle able to perform those subsea, underwater operations. And finally, the logistics scope of a special operation vessel used in the O&M phase included a bi-weekly or monthly port call to load prepacked 20’ standard containers filled with supplies, parts, and equipment necessary for the vessel to remain offshore for 2-4 weeks complete with vessel crew and 50+ technicians. These types of logistics sub-chains were evaluated further in terms of the empirical data gathered across the three case studies and a readiness score applied for the EU and China representing the mature and emerging offshore wind markets respectively.

The theoretical implication of these results is that as more countries develop offshore wind, researchers should collaborate to focus on difficult areas of the supply chain and encourage knowledge transfer from mature to developing markets. This research was unable to fully confirm whether the slower than planned diffusion of offshore wind in emerging markets has to do with logistics as a barrier, bottleneck, or constraint due to specific logistics supply/demand imbalances. The results of the supply chain readiness study suggest that logistics did hamper the pace of diffusion of offshore wind in China, but other factors need further consideration such as the evidence that the supply chain itself is maturing and that offshore wind is undergoing a maturation process as an industry. This research was not able to irrevocably determine which supply chain elements, at what individual stages of maturation, in fact caused the slower than planned diffusion of offshore wind particularly in China where 2.79 GW of installed capacity was achieved by the end of 2017 (Global Wind Energy Council, 2018). As more scholarly attention is put towards logistics, academia can offer insights into different levels of maturation studies in offshore wind including product life-cycle/industry life-cycle models (Klepper, 1997; Jensen & Thoms, 2015), SCM maturity models (McCormack & Lockamy, 2004), and now also the contribution of this research to split the life-span of an OWF into smaller vertical logistics chains and logistics sub-chains (Poulsen & Lema, 2017) whilst always maintaining the horizontal meta level focus. The contributions of this research should help position academia to develop comparative studies between countries, regions, and offshore wind markets at different stages of evolution in terms of logistics, the supply chain, and as the offshore wind industry overall.

7.5 MANAGERIAL IMPACT

The key theoretical contributions of this research also have a managerial impact (please refer to Table 8 above) in many cases. In general, this research has increased the understanding of logistics and key logistics challenges in offshore wind with the practitioners involved. Some key managerial implications of this research may be summarized as follows:

- The finding that logistics was not well defined nor well researched within academia was exemplified also through the Ørsted case study. Without a proper definition of logistics, Ørsted faced challenges scoping e.g. the innovation strategy for the discipline of logistics. With a definition of logistics for offshore wind now proposed, it is possible for firms to create a strategy for logistics that is synchronized with firm strategy (Mintzberg & Lampel, 1999; Chopra & Meindl, 2013) and it is possible to organize logistics as a separate managerial function. The focus of logistics can be across a portfolio of multiple OWF projects, horizontal within a single OWF project, and vertically within different life-cycle phases of an OWF project down to the level of logistics chains and logistics sub-chains.

- The finding that the cost of logistics was not well defined, well understood, nor well researched within academia was exemplified also across all three case studies. Great disparity was revealed within Ørsted when it was attempted to estimate the share of logistics costs as a percentage of CapEx, OpEx, and LCoE respectively through empirical data amassed from largely qualitative interview transcripts and survey responses. The in-depth analysis of the O&M logistics life-cycle phase revealed that largely government sponsored cost studies did not agree on the scope, scale, and extent of logistics which resulted in significant variance in terms of calculation methods and results within these studies. The China market case study revealed that cost models in China had largely focused on CapEx and less on the O&M as well as decommissioning life-cycle phases of the OWF life-cycle. The sheer size of logistics costs as part of the individual life-cycle phases as well as LCoE makes it visible that logistics is a significant and important part of the overall cost structures within offshore wind. This ought to drive managerial behavior in terms of how to organize logistics within the firms (see above) as well as how to make logistics a cost discipline in firm specific cost models as well as within industry-wide (often government sponsored) cost studies for offshore wind.

- The finding that logistics characteristics, and thereby supply chain readiness from a logistics perspective, vary for emerging markets compared to more mature markets is important for managers in established markets when market entry in new markets is considered: local logistics practices are different, and the application of best practices and ways-of-working may not be immediately feasible without a degree of localization. Conversely, managers in emerging markets can speed up their go-to-market process and enhance the learning curve of their firms by collaborating with research institutions and firms from more mature markets.

Logistics is a significant part of the cost of offshore wind and as such, logistics needs to be treated as a managerial discipline which may be endogenized as part of the overall firm strategy, planning, and operations. This is the case in mature offshore wind markets as well as the new and emerging markets.

CHAPTER 8: CONCLUSION

When initiating this PhD project, logistics in offshore wind was neither well defined by academia nor well understood. Based on gaps in academic literature, three research questions were identified.

Based on these, the seven main theoretical contributions can be summarized as follows:

1. An academic definition of logistics in offshore wind was proposed.

2. A furthering of the understanding of logistics costs in offshore wind was generated as seen in relation to OWF CapEx, OpEx, and LCoE.

3. The high logistics costs as a share of LCoE for offshore wind warrant that logistics be treated as a separate discipline of great importance by academia.

4. LCoE studies and cost models may contain important assumptions leading to bias.

5. Logistics costs are rarely properly defined or accounted for in offshore wind cost studies.

6. The Chinese market analysis pointed to important differences in logistics characteristics between mature and emerging markets.

7. Using logistics as the lens, it was found that the offshore wind supply chain seems to not be ready for the government diffusion plans of the future.

In terms of *the first research question pertaining to how logistics is organized and what importance is attributed to logistics in offshore wind*, this research has pointed towards logistics not being properly recognized within academia as a scientific discipline in the offshore wind industry context. The literature review revealed that logistics has only just begun to emerge as a scientific discipline within offshore wind. Through the case study work forming part of this research, it was found that even the largest developers in both mature and emerging offshore wind markets, as well as their key suppliers and sub-suppliers, did not organize themselves with horizontal and vertical logistics functions able to cut across organizational and project boundaries to any significant extent.

As a further contribution to the first research question, the provision of a proposed academic definition of logistics in offshore wind as part of this research could help scientists get organized better to further the focus on logistics in offshore wind. In terms of managerial impact, findings from one of the case studies of this research revealed that organizational changes within the area of logistics have occurred potentially because of part of this research within the leading global offshore wind developer, Ørsted.

The literature review revealed that logistics costs were not well defined nor properly understood, and this was the reason behind *the second research question on what the costs are for logistics in offshore wind*. As a key theoretical contribution, this research brought forward a better understanding of the cost of logistics measured relatively compared to CapEx, OpEx, and LCoE within offshore wind. Through this improved understanding of logistics costs in offshore wind, another part of the answer to the first research question was to some extent also provided because the relative importance of logistics in offshore wind was not supported by monetary measures to prove or warrant the discipline of logistics to command significant academic attention of scholars. With logistics costs accounting for a higher share of LCoE than the nacelle part of the WTG (excluding the blades and tower) and with the relative logistics costs being almost similar to the costs of all BOP components in total, logistics research was clearly attributed inadequate importance in offshore wind by academia.

As for a *further answer to the second research question*, the literature review of this research pointed towards academics using largely industry generated cost studies to perform simulations, analysis, and modeling. However, the industry sources used by scientists were relatively few and a thorough desktop analysis of 11 such studies over a 10-year period forming part of this research revealed that basic assumptions, structures, and features of the different industry cost studies were very different at best - and quite possibly biased, depending on the desired output. In addition, it was found that the line-item definitions of logistics costs within the 11 offshore wind cost studies varied considerably which made it hard to truly account for and compare logistics costs across the different studies.

The *third research question was based on the globalization of offshore wind which was starting to take place when this research was initiated and here, an understanding of the characteristics of logistics in mature offshore wind markets compared to emerging markets was sought*. When this research was initiated, not much academic literature focused on the new and emerging markets and it was found that only China had significant on-going offshore wind activity supported by a binding legislative framework. Therefore, emerging market related case study work within this PhD project focused on furthering the knowledge of logistics in China especially. Results indicate that logistics practices and characteristics of the emerging offshore wind markets are indeed different from those of the more mature European markets. Key areas of additional understanding of the logistics characteristics of China had to do with the need for transfer of knowledge, experience, as well as investments from Europe. This was coupled with needs for collaboration voiced for several parts of the Chinese supply chain like BOP as well as for the OWF life-cycle phases O&M and decommissioning. It was found that major government-controlled utilities in China wanted to be in full control of the logistics scope, including the WTG installation process, which represented a different task allocation than in Europe where the WTG manufacturers sell WTGs fully installed and with warranty.

As a further answer to the comparative nature of the third research question, the findings of the cross-case paper of this research indicate that the offshore wind supply chain is not ready for the government planned diffusion targets based on supply/demand imbalances within the field of logistics.

In addition to the above answers provided to the three research questions, many additional logistics findings have been derived as part of this research. This includes findings from the five published academic journal articles that each provide an additional level of granularity to the answers to each of the three research questions.

As such, the geographical areas available for near-shore OWFs were found to be saturating and bottom-fixed WTGs are being installed further offshore and in deeper waters which makes logistics operations more complex as installation and O&M operations need to be sea-based instead of land-based. The offshore wind market is one of growth and as such, the market is attracting attention of more and more constituencies wishing to enter the market in order to take part in the growth trajectory, also within derived markets such as logistics. The offshore wind industry was, however, also found to be a market which is still in the process of maturing. This means that the derived support markets, including logistics, are also undergoing a maturation process. The logistics maturation process was, however, found to be not fully controlled by the constituencies in this derived support market to the offshore wind industry because the logistics assets, processes, and skills, to a large degree depend on the freight commodity to be handled. The offshore wind freight commodity has the WTG in a pivotal position because the WTG dictates what kind of BOP components will be required as well as what kind of logistics support assets and skills will be needed during the installation and operational life-cycle phases. It is therefore developer choices regarding WTG selection and the pace of WTG manufacturer innovation capabilities, in terms of WTG MW yield upscaling, that ultimately determine the life-span and obsolescence cycle of logistics assets as well as associated transport equipment, education, and knowledge.

Findings contained in this research highlighted that logistics costs have been generally reduced across different industries when viewed in a US context over time. The constituencies providing logistics solutions to the offshore wind developers and WTG manufacturers (supply chain lead firms) ought to be at the forefront of cost savings within logistics in offshore wind. The alternative is that the supply chain lead firms will drive the cost-out process without full appreciation and understanding of the supporting cost structures of logistics in offshore wind. Costs of offshore wind must be reduced going forward and logistics has a sizeable gap to fill in this respect.

Offshore wind is spreading to more and more markets around the globe and this research confirmed that the globalization of offshore wind generates a need for logistics knowledge transfer. Going forward, floating offshore WTGs will present new opportunities for offshore wind diffusion and a new frontier of logistics operations will emerge as floating offshore wind gains momentum in areas with very deep waters like the

US West Coast, Japan, parts of South Korea and Taiwan, as well as parts of Europe.

To sum up, this research has identified several gaps in the extant academic literature and attempted to further the available academic knowledge on logistics in offshore wind along the three dimensions of research questions, with key theoretical contributions outlined above. It is the hope of this researcher that the efficacy of this PhD thesis will spur interest on the part of other researchers to elevate the relative importance of logistics in offshore wind. Similarly, it is the hope of this researcher that the contributions of this research will also have an applied effect in terms of managerial impact.

PERSPECTIVES

Through this PhD thesis, logistics in offshore wind should now be better scientifically understood compared to the academic understanding before. This improved understanding has been accelerated by providing a view into how logistics has been organized within offshore wind, and how it has not been receiving the attention that this research suggests it should. In addition, the understanding of logistical costs in offshore wind has been furthered in general for logistics costs relative to CapEx, OpEx, and LCoE.

At a detailed level, the O&M life-cycle phase logistics costs have been analyzed in more depth, revealing that major cost studies for offshore wind define and account costs of logistics differently.

In addition, this research has generated an insight into how China, as a representative for new, emerging market logistics characteristics, differs from those of more established/mature markets, exemplified via the Ørsted and O&M case studies. Finally, logistics has been used as a component of the supply chain to exemplify that the supply chain is not ready for the planned diffusion of offshore wind targeted by governments in different markets.

If the results are reviewed from a meta-position, the answers provided in this PhD thesis to the three research questions are believed to be adequate based on the time and resources available to a PhD project in a Danish setting. If significantly more time or more resources had been available for this research, it might have been possible to come up with further results as well as further case studies, quantitative validations, and publications complementing the findings of this PhD thesis. However, it is deemed that the results would most likely not have been materially different if the overall research objectives and method had been maintained.

In case study research, the cases available and prioritizations made can define what is researched and therefore also the sphere of possible results. A choice of different primary case studies may have yielded a different view into a different part of reality, emphasizing the need for maximizing the variety of case studies, both spatially and temporally. Based on the three primary case studies prioritized in this research, the case study method offered the needed flexibility to combine quantitative analysis with qualitative work streams. The case study method provided for the flexibility necessary within this research to combine the use of interviews, surveys, participant observation, action research, and desktop studies / calculations.

The benefits of mixed method research compared to the complexity could outweigh the investment of studying mixed methods in much greater detail. This could be especially beneficial when working in less established research areas such as logistics in offshore wind. Or in research fields where empirical data gathering efforts contain a more exploratory dimension, for example, in emerging markets and the availability of more robust quantitative data in more mature markets would be considered for comparison purposes.

The findings of this PhD thesis revealed that several topics could warrant further study by the scientific community and, in addition, each of the published papers also made recommendations on further research.

For *research question one about how logistics is organized and whether sufficient focus is given to this discipline*, several areas are recommended for further research. First, an understanding of how logistics is defined and organized more broadly across the offshore wind industry should be developed as determined by the results of this PhD thesis. This would be useful to observe if academia and industry now attribute more importance to logistics in offshore wind. Second, because of the high relative logistics cost share of total costs in offshore wind, this PhD thesis concluded that logistics deserves further study by academicians with an aim towards identifying means by which logistics costs can be reduced over time to be more in line with other industries. Third, the derived market of shipping, logistics, and SCM within the wind energy industry is still in need of further research efforts in general (Poulsen, 2015).

In terms of *research question two about the cost of logistics in offshore wind*, this PhD thesis firstly unveiled that scientists could beneficially perform further research of offshore wind cost models with an aim towards establishing key calculation criteria and clear assumptions to be applied for the research area of logistics costs going forward. Secondly, it would be useful for researchers to further investigate if, and to what extent, LCoE calculation models are biased and used to generate output in certain prearranged directions based on the many dimensions and attributes forming part of these studies. This would yield a better understanding of what impact such bias may have had and based on the contributions of this PhD thesis, such knowledge would be of value to academia. Exact logistics cost components of offshore wind need to be fully understood and defined (Poulsen & Hasager, 2016). Thirdly, a number of topics pertaining to research question number two would need further study as pointed out in the different publications forming part of this research such as studies on cost-out initiatives which are needed to reduce logistics cost component groupings to reduce LCoE (Poulsen & Hasager, 2016), further studies across life-cycle phases both in firm-specific cost models and government sponsored LCoE reduction studies on how logistics should be included as a vertical life-cycle and as a horizontal cost component (Poulsen & Hasager, 2016), quantitative studies within OWF projects as well as across a portfolio of wind farms to compare planned logistics costs to actual, book-kept, and realized logistics costs (Poulsen & Hasager, 2016), and research on how to define a standardized methodology for cost modeling including logistics across different LCoE tools should be carried out (Poulsen, et al., 2017).

The *third research question was about characteristics of logistics in emerging markets compared to more mature markets* and this PhD thesis pointed towards comparative academic studies involving researchers from nations with a mature as well as emerging offshore wind industry as such studies would further the understanding of differences in ways-of-working, processes, and available experience within the field of logistics. This is of importance because findings from this PhD thesis indicated that logistics could represent a barrier to offshore wind diffusion in emerging markets. Therefore, a better understanding of logistics across different new markets would help facilitate offshore wind diffusion. Also, in response to the third research question, theoretical contributions from this PhD thesis determined that the available scientific knowledge on how logistics tasks are organized differently in mature offshore wind markets versus emerging markets ought to be expanded. It is important to understand if emerging markets are different because of the process of maturing or if different drivers exist in various emerging markets that cause logistics in these markets to be deliberately organized differently. This would help bring forth an understanding of whether these differences will disappear when the emerging markets become mature or if certain markets will always remain different. Finally, two areas emerged from the publications of this research as needing further research in terms of research question three. Firstly, detailed mapping of the actual OWF pipeline in China is required to academically improve the understanding of how much offshore wind power is expected to be grid connected by when (Poulsen & Hasager, 2017). Secondly, studies should be made to ensure alignment of government policy, research efforts, firm investments, and knowledge transfer collaboration between emerging and mature offshore wind markets (Poulsen & Lema, 2017).

In going beyond the three research questions of this PhD thesis, several additional areas for further research were identified as being useful in terms of research on logistics or building on the logistical findings of this research. One such area is that it would be beneficial for academia to tease apart other parts of the supply chain than logistics to ascertain how supply and demand imbalances can be evened out. This has been uncovered by this PhD thesis and it is important to ensure that government plans for offshore wind diffusion in different markets can indeed be realized. Another area also stemming from this PhD thesis is that there is a need for researchers to overlay the evolution of offshore wind at an industry level with the corresponding logistics maturity evolution trajectory during the same period of time. This could be done by applying e.g. product life-cycle models to offshore WTGs as the unit of analysis seen over time and contrasting these findings to industry life-cycle models for the offshore wind industry as well as SCM maturity models. A third area is that of business models and strategy for the wind energy market which warrants further study for logistics companies as well as other constituencies in the industry (Poulsen, 2015). As a fourth area, cultural differences were identified at different levels of this research and ought to be researched in the offshore wind industry. This should be done to better understand the vantage points of different types of personnel involved in the realization of actual cost savings across the value chain, from governments to utilities to shore based/office personnel to site personnel located either onshore or offshore at sea (Poulsen, et al., 2017). A fifth area of further study comprises studies which should be carried out in terms of how key structural dimensions impacting OpEx may impact the O&M logistics strategy going forward. Such structural dimensions include distance from shore, OWF operational data availability, the existence of different O&M logistics chains, the difference between topside versus subsea work efforts, and finally whether maintenance, inspections, and/or repairs are needed for an individual WTG as opposed to the entire OWF asset (Poulsen, et al., 2017).

As time passes, more countries develop offshore wind in different ways. The case of China, included as part of this research, represents a centralized government approach to a new and emerging industry. Conversely, the approach now being taken at state-level in the US is market-driven and competitive, thus with idiosyncrasies compared to China. In Taiwan, very near to parts of China, the market is being opened up to foreign firms yet still with a strong government focus to build a local supply chain with Taiwanese offshore wind job opportunities. Whether in China, the US, or Taiwan, logistics is an underestimated and underprioritized discipline, with little focus from academia.

Looking ahead to 2020, through the 2020s, and all the way to 2050, it would seem plausible that the offshore wind industry is here to stay. To serve the industry from a logistics perspective, constituencies in the logistics industry need to have strategies in place to meet and exceed the demands of developers, WTG manufacturers, and other supply chain lead firms in the offshore wind industry. The logistics strategies of these offshore wind supply chain lead firms are changing continuously and are different in different markets, as shown in this research. These factors force the logistics industry to innovate, change, and consolidate to keep up the pace - in the home markets as well as globally.

A proactive approach on the part of academia to further the research of logistics as a discipline in offshore wind is hoped to be a key outcome of this research.

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PAPERS

PAPER A: CHANGING BUSINESS MODELS AND STRATEGIES IN GLOBAL WIND ENERGY SHIPPING, LOGISTICS, AND SUPPLY CHAIN MANAGEMENT

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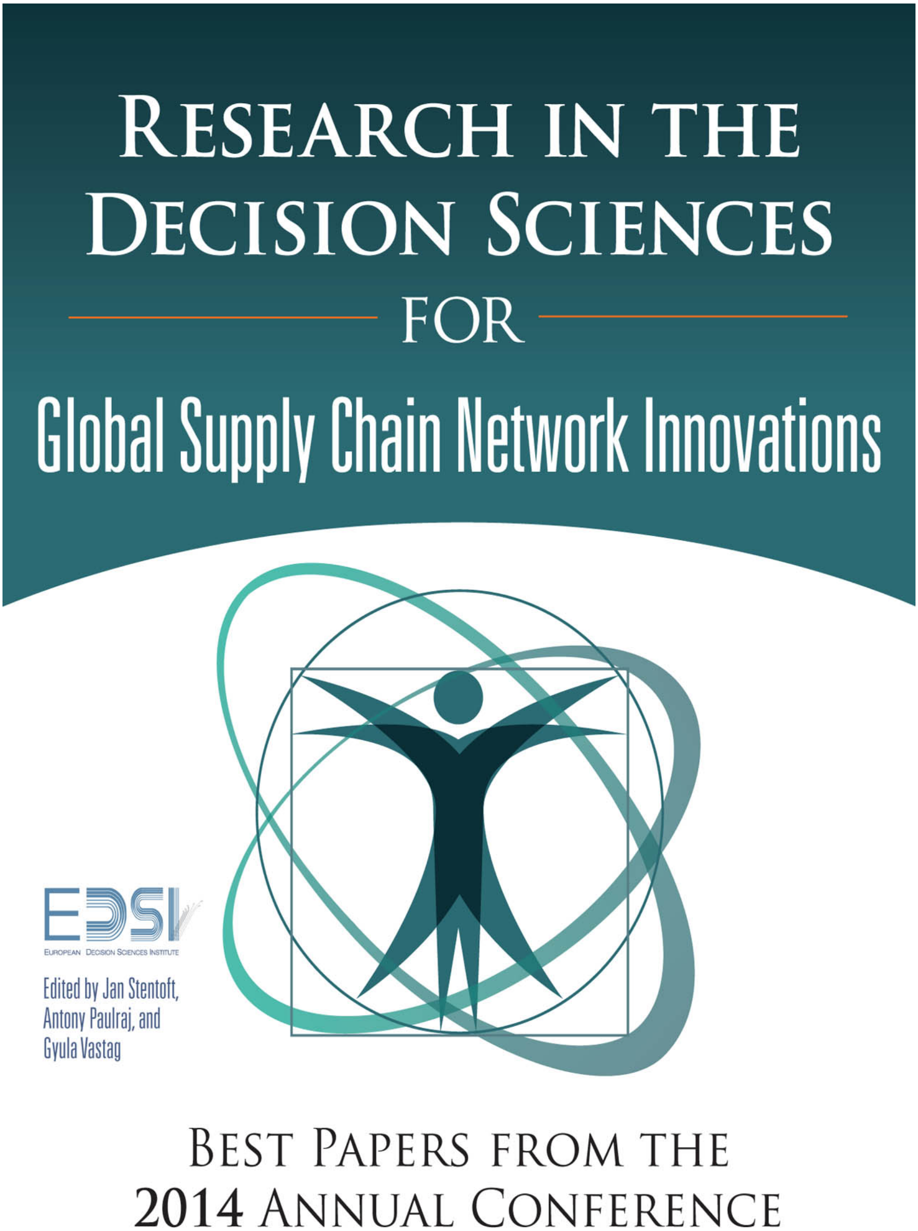

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5

Changing Strategies in Global Wind Energy Shipping, Logistics, and Supply Chain Management

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Abstract

Within the global wind energy market, a number of derived industries support the continued expansion of the ever larger onshore and offshore wind farms. One such derived industry is that of shipping, logistics, and supply chain management. Based on extensive case study work performed since 2009, the paper reviews different wind energy markets globally. Subsequently, a number of supply chain setups serviced by the shipping, logistics, and supply chain management industry are reviewed. Finally, winning business models and strategies of current as well as emerging supply chain constituencies competing in the wind energy marketplace are discussed based on initial analysis.

The Emerging Global Market of Wind Energy

Since the end of the nineteenth century, the market for energy producing wind turbines has been developing rapidly around the globe. Development especially picked up when the first serial production of industry grade wind turbine generators (WTGs) began in the United States and Denmark during the late 1970s, following the global oil crisis in 1973. With onshore WTGs initially being installed mainly in the Organization for Economic Cooperation and Development (OECD) countries during the 1980s and 1990s, they are now being installed in ever increasing numbers in more markets globally. At the end of 2013, there were 321,559 mega-Watt (MW) installed around the world (BTM Consult a part of Navigant, 2014a). It follows that China is now the largest single market for wind energy, the share between OECD countries versus non-OECD countries being 64.1% versus 35.9%, respectively.

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Pioneered primarily by a few early-mover countries in Northern Europe, wind farms have been erected offshore in the ocean since 1991 and over the past five years, this development has increased dramatically in volume and scope. This increase has been driven in large part by the European Union (EU) 20-20-20 climate commitments and the renewable energy targets of especially the United Kingdom, Germany, and Denmark. Over the past years, countries outside the EU such as China, South Korea, Japan, the United States, and India have also developed plans for offshore wind farms, and at present, the largest plans for expansion are those committed by China through its 12th Five Year Plan.

The objective of this paper is to present preliminary observations about the strategies, supply chain structures, and winning business models within the wind energy market. Given that the wind market as such is still quite nascent, it is difficult to predict what it takes to win at this relatively early stage. With no platform leadership (Cusumano and Gawer, 2003) from a production innovation perspective, and with ongoing significant research and development (R&D) efforts to leap-frog the WTG output measured in MW, there is still a lot to be seen. This is further compounded by the lack of process innovation (Abernathy and Clark, 1985) and possible implications are therefore discussed, based on a previously conducted extensive exploratory case study material within the derived industry of shipping, logistics, and supply chain management (SCM) (jointly hereafter the derived SCM industry) serving the wind market. The empirical foundation for this research has been developed since 2009 on the basis of more than 300 interviews performed at individual meetings, conferences, and during site visits (Poulsen et al., 2013a) by the author. Using the derived SCM industry, initial propositions can be crafted about how the wind energy market will develop in the future when it comes to strategy and business models of the organizations involved.

The wind market today is still highly fragmented and most likely about to undergo significant consolidation through mergers and acquisitions (M&A): It remains to be seen which organizations will emerge as winners. The underlying derived SCM industry is of particular interest because throughout the four life-cycle phases of a wind farm (Poulsen et al., 2013a), the derived SCM industry plays an important role as an integrated support industry, which can effectively aid the wind market objectives if functioning smoothly (Poulsen et al., 2013b). Conversely, if not functioning properly, the derived SCM industry can act as a bottleneck to the objectives and progress of the wind energy market overall. A close liaison and collaboration between the core wind energy market and the derived support industries, such as the derived SCM industry, are therefore factors of paramount importance for the wind energy market to meet its ambitious global growth targets as well as its targets to be competitive with, for example, fossil fuels like coal and oil, based on lower or equal levelized cost of energy (LCoE).

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Following this introduction, the paper is structured with a methodology section that explains the qualitative case study approach to the key questions to be answered in this paper. Subsequently, the wind market at a high level is contrasted to other industries on the basis of three propositions for each of which the academic framework is discussed. The research findings are then presented in three parts: First, a section describing the onshore and offshore wind market followed by a section providing background for the concept of derived support industries embodied in the example of the derived SCM industry; subsequently, a section about wind energy supply chain models where a comparison between Europe, China, and South Korea is performed. In the final section, the last part of the findings is reviewed, pertaining to winning business models, leading strategies, and the increasing M&A activity within the derived SCM industry. The paper concludes that when tested, the three original propositions were indeed validated by the empirical data gathered from the different case studies, and the paper ends with a suggestion for other researchers to join up in performing further analysis within this new research area.

Comparative Case Studies Basis: Global Interviews and Site Visits

A general industry understanding of the wind market as well as contextual data has been collected in an exploratory study using mainly semistructured interviews (Brinkmann and Kvale, 2009) from December 2009 until May 2013 (Poulsen et al., 2013a). In addition, the author brings more than 25 years of industry experience with general management, operations management, strategy setting, and M&A from the shipping/logistics/SCM industry. Combined, the practical experience of the author coupled with the extensive exploratory study provide for a thorough contextual understanding.

The data used in this paper is of qualitative nature, and the majority of the particular data used here has been derived from specific field trips, site visits, and interviews conducted in Europe and Asia during 2013 and 2014. This field study activity was supplemented by the author's attendance at a number of both academic and industry conferences where presentations were reviewed and supporting documents were perused.

The data sources used for the analysis were site visit observations, interviews conducted, and various documents gathered. A comparative case study method was used, designed to compare the initial research propositions (shown below) developed through the exploratory study, to reality as experienced in various actual, live wind farm cases as represented to the author by personnel from the companies and organizations included in the research. The core qualitative data collection was done primarily through interviews and site visits, with a carefully selected mixture of different supply chain constituencies,

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each presenting a different supply chain vantage point and perspective. The different companies and organizations were selected to be able to provide a differentiated mix of constituencies within the wind energy market as well as the derived SCM industry. In selecting the companies and organizations interviewed, it was essential that dialogue could be had about all three propositions, which range from macro level (market, industry, government relations, and subsidies) to company level both in terms of overall company strategy as well as particular shipping/logistics/SCM strategies. It was furthermore important that discussions could be had in Europe, China, as well as South Korea about how strategies can be coupled with business models encompassing key competencies, skills, and assets used in the derived SCM industry.

The goal of the individual interviews was to generate particular answers to prearranged questions organized in interview protocols based on an overall activity plan outlining the specific parties with whom interviews were required (Booth et al., 2008). The interview protocols were designed using seven different parts of which the fourth part was designed to be able to broadly cover as many aspects of the three propositions as possible (Yin, 2013). Posed not as specific questions, the interview protocols contained open ended keywords organized in sections to enable a smooth conversation where the interviewee could present as much information as possible. Sections of the interview protocol were designed to both enable steering of the conversation as well as efficient note taking. As knowledge of some of the topics was accumulated on the part of the author, the interview protocol was updated and further expanded upon in an iterative manner making the last version of the interview protocol more comprehensive and effective than the first ones.

Different organizational levels of personnel were interviewed in companies, learning institutions, as well as government organizations to obtain a blended point of view from both a strategic and tactical perspective. Organizational access to some extent dictated the level of organizational hierarchy obtainable. Due to the mainly strategic nature of the propositions, the highest possible organizational rank was sought where possible. When a point of data saturation was reached and the same findings were repeated, interviewing was ceased or redirected in line with the key principles of qualitative research (Yin, 2013). The interviews generally lasted between 45 minutes and 2 hours, whereas certain site visits included extensive transport time and thus enabled as much as up to a full-day conversation-type interview dialogue.

Due to the extensive exploratory study performed in advance of the specific analysis used for the questions posed in this paper, the author has been able to credibly contrast the responses obtained. In addition, the author has used his own industry experience as well as geographical knowledge from having lived and worked in eight countries around the globe to validate the reliability of the sources used, including cultural sensitivities. The sources are generally perceived by the author to be very good and the analysis cleansed in terms of any potential bias of individual interviewees. Due to travel budget restrictions

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of the research project, most of the interviews, site visits, and other interaction with the interviewees were, however, performed only by the author. And based on the nature of the encounters, transcripts were not signed by the interviewees.

The documents reviewed in addition to the interviews comprised publicly available industry reports, academic articles, books by leading researchers, and Internet documents/surveys from wind energy as well as shipping companies/organizations. Various internal organizational documents such as company presentations, reports, and business cases were also used. A total of more than 7,000 text pages have been reviewed since 2009, of which more than 1,000 pages were directly used for forming the analysis portion of this paper.

The Wind Market Compared to Other Industries

The research presented in this paper was organized along the dimensions of three original propositions. The propositions were defined *before* undertaking this research, as a result of findings from the previous exploratory study (Poulsen et al., 2013a).

First, the exploratory study indicated that the wind industry is different from other industries inasmuch as it seems fully dependent upon government subsidies within all markets around the world. In his first "diamond model" for how nations compete, Porter (1990) did not recognize that the state may have a strong influence on how one country may yield a competitive advantage over others. However, in his subsequently revised diamond model, Porter (1998) acknowledged that the state may play an important role in how nations compete. This argument has been taken forward in a particular clean technology (clean-tech) context by Mazzucato (2014) who argues that the nation state often makes significant investments with high risk in advance of private sector involvement.

Second, the exploratory study also indicated that different firms within the wind market set their overall strategies in a different manner depending on whether they have an exclusive focus on the wind market only or whether they are a conglomerate also serving other markets. Here, the exploratory study pointed to Asian conglomerates as seemingly having an approach of being able to make fast decisions and enter new markets quickly as discussed most notably by Whitley (1992).

Third, the exploratory study indicated that different constituencies within the wind market opted to handle the derived support industries in different ways. Particularly the conglomerates involved in many different lines of business seemed to aggressively expand using M&A methods into the derived SCM industry with their own assets, personnel, and skills. Such decisions could seem to go somewhat against the inside-out strategy of companies focusing on the resource based view (RBV) perspective originally argued by Wernerfelt (1984) and further improved using the VRIO framework by Barney (1991) to

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argue that companies should focus on their most valuable and rare core competencies, skills, as well as assets. In the analysis presented in this paper, shipping, logistics, and SCM services are used as the key exemplification of how the proposition of integration of support industries in general may successfully align a company's underlying strategy for such support services with the overall company strategy. Given that the example used in this research is that of the supply chain, Chopra and Meindl (2013) highlighted exactly this critical element of strategic alignment between the overall company direction and the supply chain as the key success criteria in terms of a company's or organization's successful supply chain design, planning, and subsequent execution. An example of the opportunities for how a country segment of the supply chain can win in the global shipping market for the wind energy market was provided by BTM Consult a part of Navigant (2014b) in their study for the Danish Shipowners' Association (DSA).

To summarize, the propositions forming the basis for the research presented in this paper may be outlined as follows:

- **Proposition 1: The entrepreneurial nation state—**The wind market seems to represent a good example of how nations have decided to propel an entire industry forward and successfully act in an entrepreneurial manner as a catalyst to innovation.
- **Proposition 2: Two wind market business models—**Two distinctively different business models seem to be evolving in the wind market. One group of wind market constituencies seems to compete exclusively within wind energy, and a second group of companies are conglomerates that seem to view wind as just one market opportunity out of many they are involved in.
- **Proposition 3: Conglomerates as winners—**The conglomerates seem likely to come out as winners in the wind market in the short term. This is because they are financially strong and thereby able to utilize a combined M&A and joint venture strategy to integrate critical support industries into their overall portfolio of products and services offered to their end clients as a seamless and integrated solution.

The Global Wind Energy Market

In the following, a high level analysis serving as the introduction to the wind energy market is necessary to set the scene and provide contextual understanding.

After the initial serial production of WTGs started around 1979 (Karnøe, 1991), WTGs were erected onshore in primarily Europe and the United States. The first WTGs were initially produced by the Denmark-based original equipment manufacturers (OEMs) such as Vestas, NEG Micon (today part of Vestas), Bonus (today Siemens Wind Power,

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SWP), and Nordex, as well as US-based OEMs like Zond Corporation (developed originally as Kenetech together with NASA, later Enron Wind, and today what is GE Wind). As operations and experience with WTGs expanded, WTG output was increased along with quality and durability. Simultaneously, WTGs were erected in larger clusters where more WTG positions were co-located to form onshore wind farms.

By the end of 2013, a total of 241,652 WTGs with an average yield of 1.33 MW had been erected on a global basis with a total capacity of 322 giga-Watt (GW) according to BTM Consult a part of Navigant (2014a). Table 5.1 shows the ten largest onshore wind markets in terms of installed wind power capacity up to and including 2012 installations.

Table 5.1 The Ten Largest Onshore Wind Markets, Cumulative Install Base in MW Up to and Including 2012 (Source: BTM Consult a part of Navigant, 2013 and own construction)

Ranking	Country	Cumulative 2012
1	China	75372
2	USA	60208
3	Germany	31467
4	Spain	22462
5	India	18602
6	UK	9113
7	Italy	7998
8	France	7593
9	Canada	6214
10	Portugal	4364
Rest of the world		42368
Grand total		285761

Denmark was the first country to install wind turbines in the ocean in 1991 (BTM Consult a part of Navigant and Poulsen, 2012). Referred to as offshore wind farms, the initial farms were limited in terms of number of individual WTG positions. Over time, they have increased in size, both in terms of the number of WTG positions within the wind farm site as well as the output of each WTG as measured in MW. As of the end of 2013, a total of 73 offshore wind farms were operational, with a total of 6.8 GW of capacity. In terms of WTG yield, the first offshore WTG installed in 1991 had a capacity of approx. 0.5 MW, whereas WTGs installed in 2013 generally yield some 3 to 6 MW (BTM Consult a part of Navigant, 2014a).

Due to the harsh conditions of the ocean and the unlimited scale when it comes to size of offshore wind turbines, wind market R&D technology efforts have now switched to

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offshore wind being the key innovation focus area. As of spring 2014, the average sized WTG installed in the North Sea is some 4 to 6 MW output per WTG compared to a global average of approximately 1.5 to 2 MW per WTG for onshore installations in 2013 (BTM Consult a part of Navigant, 2014a).

Although China has the largest individual country target for offshore wind in the world, a relatively small number of countries in Northern Europe still account for the largest install base so far. Denmark is home to the largest individual developer/operator of offshore wind farms, namely, the partly government owned DONG Energy. Based on the binding EU 20-20-20 targets for renewable energy, the largest producer of offshore wind energy was the United Kingdom (UK) as of the end of 2013. Figure 5.1 gives an overview of the number of installations of offshore wind farms and installed MW per year up to the end of 2013.

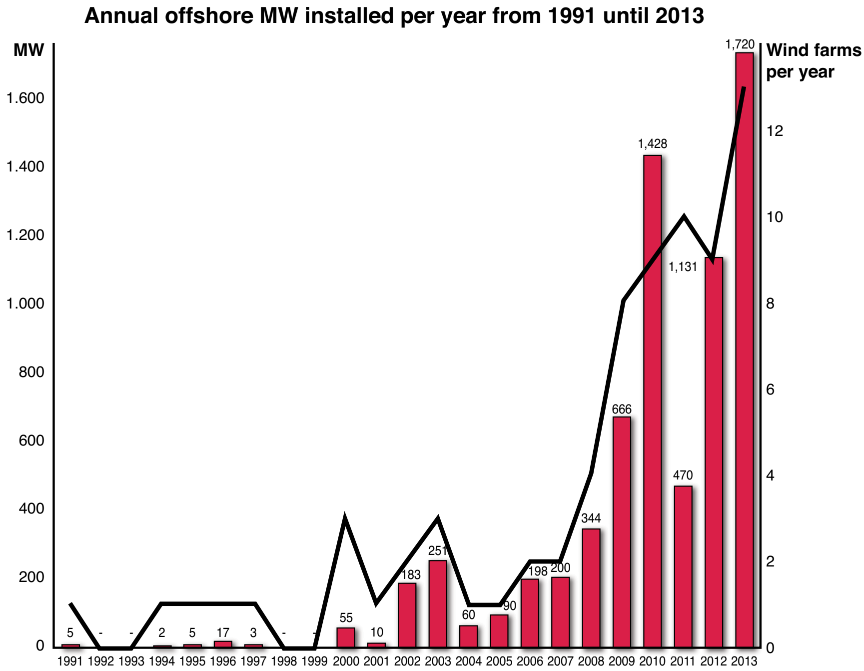

Figure 5.1 Number of offshore annual MW and wind farms installed through 2013 (Data Source: BTM Consult a part of Navigant, 2014a and own construction)

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Shipping, Logistics, and SCM as a Supporting Industry to the Wind Market

Supporting the market for wind energy is the derived SCM industry. To illustrate the life cycle of a wind farm mega project, Poulsen et al. (2013a) defined that four major phases exist after the concession for a wind farm has been awarded to a developer/operator of a wind farm. Table 5.2 describes the four life-cycle phases and the characteristics of the distinctively different supply chains related to the different life-cycle stages as discovered from the research performed for this paper.

Table 5.2 The Four Wind Farm Life-Cycle Phases and the Underlying Supply Chains (Source: Own construction)

Wind Farm Phase	Description	Characteristics
Development & Consent (D&C)	Site surveys, birds, wildlife, sea, seabed	Specialized vehicles (onshore) and vessels (offshore)
Installation & Commissioning (I&C)	Inbound assembly parts and components Outbound wind modules for wind farm site	Mainly a homogenous flow using ocean containers and air; some project cargo Project cargo/break-bulk
Operations & Maintenance (O&M)	Personnel parts, components, and modules	Service boats and helicopters, some larger vessels like MPV, tug and barge, WTIV
Decommissioning (De-comm)	Restoration of site for new wind farm or to original condition	Project cargo/break-bulk

Prior research on the outbound I&C market (BTM Consult a part of Navigant and Poulsen, 2012) revealed that the derived SCM market seems to have significant potential for cost savings, particularly among those paying for the shipping, logistics, and SCM services rendered. There is also significant cost savings potential for those supply chain constituencies who are considering becoming involved in supporting the growing global wind energy market.

Contracts between the governments granting wind farm concessions and those wind farm developers/operators responsible for producing the wind generated energy have generally been structured in such a way that incentive structures as well as fiscal penalties

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for each of the wind farm projects are extremely significant in case of a delayed construction process. The research findings indicate that the impact of the derived SCM market on the wind energy market appears to be significant: In cases where the derived SCM market has faced bottlenecks and capacity shortage in terms of supply chain facilities/assets/skills, this has led to various untraditional market constituencies getting directly involved in rendering shipping, logistics, and SCM services through M&A activities. Key capabilities and competencies have been absorbed to secure capacity and avoid construction delay situations and ensuing fines (Poulsen et al., 2013b).

Supply Chain Models Onshore

Onshore WTGs usually consist of three blades, a hub, a nacelle, and a tower. The WTG is mounted into a foundation in the ground, generally filled with a combination of steel and cement. The nacelle is the most complex individual WTG module, sometimes with a bill of materials (BOM) consisting of up to 65,000 individual parts and components (Lema et al., 2014) that need to be assembled. The blades are largely produced as a single piece and can vary in terms of length, weight, composition, and design. The towers may be assembled from two or more pieces to be transported.

Depending on the WTG output in MW, the weight and dimensions of the individual parts and components will vary greatly, having a significant impact on the supply chain in terms of strategy, composition, organization, facilities, economics, and operations/execution (Poulsen et al., 2013a). The larger the dimensions and the heavier the individual parts, components, and assembled wind turbine modules, the harder and more challenging it becomes to transport and install the WTG. A typical onshore outbound I&C supply chain setup is depicted in Figure 5.2.

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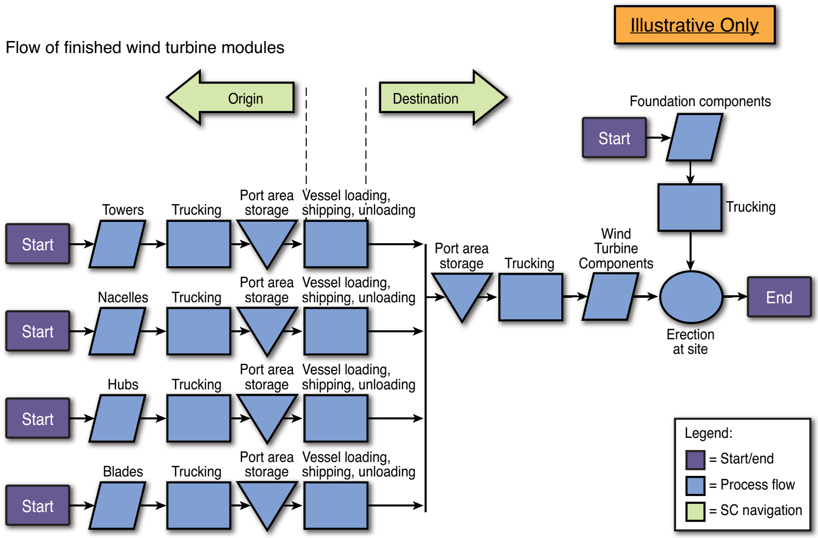

Figure 5.2 Outbound I&C onshore supply chain map (Source: Own construction using Chambers et al., 2010 framework)

Supply Chain Models for Offshore Wind in Europe

For offshore WTGs, a larger yield is produced (measured in MW) compared to onshore WTGs. Consequently, the WTG itself is generally much bigger, with a significant impact on the critical weight and dimension parameters of the individual WTG modules to be installed at the offshore sites.

Unlike an onshore wind farm, wind farms erected offshore need subsea cables, substations, and other specialized modules to function, jointly referred to as balance of plant (BOP). For example, when mounted offshore, the WTG itself has to be erected on top of a foundation protruding out of the water (usually a monopile/transition piece or jacket foundation). In addition, individual WTG positions need to be connected to the substation (transformer) through array cables. Sometimes, an accommodation platform is built as part of the substation construction to house service personnel on a continuous basis, and finally, the substation is connected to land via the subsea export cables. Given the much larger size of the WTGs as well as the need for additional BOP modules, offshore wind farms are generally much more complex than onshore wind farms.

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In Europe, offshore wind farms are distinguished mainly by two key factors: The water depth and the distance to shore. As such, it is possible to categorize European offshore wind farms and offshore wind concessions into three areas that impact both cost and operations:

1. Near shore/coastal
2. Offshore
3. Far offshore/far-shore

Some of the initial European wind farms were near shore, erected close to land in coastal areas. Over the past three to five years, a number of truly offshore wind farms have been erected under more complex conditions. In the later UK license rounds (often referred to as *round 2 ½* and *round 3*, especially the 12 GW Dogger Bank project) as well as for some German so-called far-shore projects, wind farm projects considered in the far offshore category have been awarded. With significant water depths and a distance of up to 150 kilometers to 200 kilometers to shore, various concepts for the I&C phase are being considered. One example is to possibly revitalize the floating port concepts used during World War II when the Allied Forces entered Normandy from the United Kingdom in 1944. Similarly, different O&M concepts are being considered in terms of shipping/logistics/SCM.

With SWP being the offshore WTG market leader at almost 80% market share in 2013 (GWEC, 2014), a large number of offshore WTGs are produced in Denmark and as such shipped out from a Danish port. In some cases, Danish ports like Esbjerg and Grenå (Poulsen et al., 2013b) have acted as the installation port and served the offshore wind farm in the different life-cycle phases directly. In other cases, the proximity of the port compared to the offshore wind farm site (for example the Danish port Esbjerg, compared to a wind farm in Scottish waters) might not be conducive to the slow steaming speed of some oceangoing vessels used in the I&C phase, such as wind turbine installation vessels (WTIV). In cases like this, a *double-port concept* might be used. As outlined in Figure 5.3, a double-port concept is often used where the port of Esbjerg serves as the export hub and a local port near to the offshore wind farm installation site is used as the installation or marshalling port (for example, Ramsgate in the case of London Array). In situations where the double-port concept is applied, the individual WTG and BOP modules are transported from the export hub(s) to the installation port where staging and preassembly tasks are performed to ease the job of installing the BOP modules and erecting the WTGs offshore.

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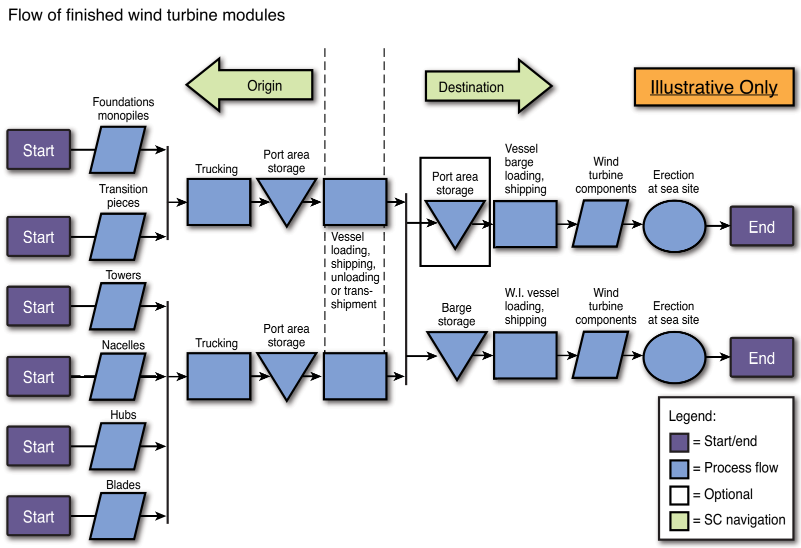

Figure 5.3 Outbound I&C offshore double-port supply chain setup using an operations management framework (Data Source: Own construction using Chambers et al., 2010 framework)

Offshore Wind Supply Chains in China Contrasted to Europe

Based on the research of this paper, it is estimated that approximately 200 GW of offshore wind farms can be installed along the coastal line of China with a maximum water depth of 20 meters (BTM Consult a part of Navigant and Poulsen, 2012). However, the pace of installation is proceeding slowly compared to the 12th Five Year Plan's target of having 30 GW of offshore wind installed in China by 2020.

The strategy of China as a nation has so far been to let a large number of OEMs develop WTGs and install them in test projects along the coastal line to do tests, improve quality, and increase overall O&M performance. In addition, a total of four leading state-owned enterprise (SOE) OEMs have been given government subsidy to speed up R&D efforts and come up with offshore WTGs that can yield an output of 10 MW to 12 MW. However, disagreements between the utilities/operators and city/regional governments have delayed the implementation of the many offshore wind farm concessions, granted as far back as 2010 for 1 GW, for example, by the Jiangsu Provence alone.

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In China, many of the early offshore wind farm concessions have been granted within river delta areas such as that of the Yellow River, Yangtze River, and Pearl River. The riverbed is often very porous in these areas due to layers of sediment carried by the river, and in addition, tidal water needs to be considered. In situations where tidal water is involved, Chinese offshore wind farm installations, such as the Jiangsu Dafeng offshore wind farm project, are located in an offshore area that—when the tidal water is low (ebb)—causes the riverbed of the Western part of the wind farm to be fully exposed while the Eastern part of the wind farm is covered by water at all times. Figure 5.4 illustrates this so-called intertidal offshore wind farm challenge, which is unique to China.

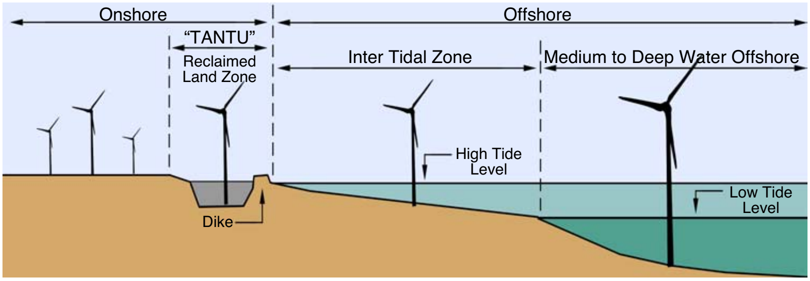

Figure 5.4 Example of unique China offshore inter-tidal wind farm outbound I&C challenges (Data Source: NEA and World Bank, 2010; BTM Consult a part of Navigant and Poulsen, 2012, and own research)

When performing I&C tasks installing foundations and erecting the WTGs, leading Chinese firms have developed specialized vessels suitable for these intertidal conditions, such as the Long Yuan Zhen Hua Number One WTIV, which can lay flat on the seabed and install WTGs when tidal water flows are ebb. For tidal water flow conditions and to cater for the Eastern part of the Jiangsu Dafeng offshore wind farm, the Long Yuan Zhen Hua Number Two vessel represents a modified version of a WTIV designed for the European market. As such, this particular custom constructed vessel, suitable for the Chinese intertidal wind farms, has four legs as known from Europe and is slightly smaller than some of the new vessels constructed for the European North Sea market. The smaller size could imply that it is less suitable for transport and more specialized for cranage type tasks.

Going forward, China's new 10-10-10 strategy will take offshore wind farms farther away from shore: The definition of 10-10-10 is that for a wind farm to be categorized as truly offshore in China, it must be located at least 10 kilometers from shore on at least 10 meters of water depth, and the width of the tidal flat must be more than 10 kilometers.

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High-Level Perspectives on the Offshore Wind Supply Chains of South Korea

South Korea has developed a number of test sites for onshore wind farms and from this, a series of OEMs have now ventured into the offshore wind market as well. South Korea has set a more modest target for future offshore wind power installations as compared to China, and by 2030, South Korea projects to have a total of 7.5 GW installed. A large portion of this will be near Jeju Island in the Southern part of South Korea. To get ready, a number of test WTGs have already been installed by South Korean OEMs both on land in South Korea and offshore in the United Kingdom as well as China (BTM Consult a part of Navigant, 2014a).

With large conglomerates structured in the special South Korean chaebol construction (South Korean structure of loosely connected firms with same name/logo/tight relations similar to that of the Japanese zaibatsu structure), it seems evident from the joint-venture (JV) strategy of South Korean firms that a big part of their strategy is to build up a competence in the home market first. This competence will then ultimately be utilized to compete globally in the offshore wind markets of, for example, China, Europe, and the United States. In this way, South Korea seems to want to emulate their export success experienced in other industries such as consumer electronics, automotive, and ship building.

Emerging Patterns of Winning Strategies and Business Models

Proposition 1—The entrepreneurial nation state

Both from the interviews, attendance of academic/industry conferences, and supporting industry reports, it seems clear that the wind energy market is presently recognized favorably by governments around the globe: Expansion of the use of renewable energy is high on the agenda of countries in all parts of the world, and at present, one of the more robust renewable energy sources appears to be wind. Therefore, a wide variety of different nations with different political and demographic structures can be seen as promoting the wind agenda using a great variety of support measures to subsidize the wind industry. The different approaches by nations to promote wind power can be generalized by simply stating that wind energy does not yet seem to be a viable energy source in its own right anywhere and that wind power thus seems to fully depend on government subsidies to survive. Most nations around the world furthermore seem to be more or less actively involved in trying to lower the cost of wind power generation so that LCoE becomes competitive with other energy sources.

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Ever since the birth of the industrialized wind energy market in the United States and Denmark during the 1970s and up to today's continued race for larger WTG output supported by, for example, the Chinese government, it seems evident that the wind energy market is a good example of how the state can essentially create, support, and continuously drive innovation. In the words of Mazzucato (2014, p. 142), also describing the government's role in, for example, nanotechnology, biotechnology, and Apple's iPad, "behind many wind and solar firms, and their core technologies, was the active visible hand of the State." Emphasizing the nation state's active role in many radical technologies including the creation of the Internet, Mazzucato continues by saying that "it was particularly state agencies that provided the initial push and the early stage high-risk funding, and that created an institutional environment that could establish these important technologies." Both in the cases of Denmark's partly government owned utility DONG Energy and the ambitious Chinese wind energy targets cemented in the five year plans with help from SOEs, nation states have been driving the wind industry forward toward market maturity and LCoE levels enabling direct competition with other energy types such as fossil fuels. Whether arising from political or environmental drivers on the part of a region like the EU or a deliberate green growth strategy of a country like South Korea, entrepreneurial involvement of nation states has spurred private sector investment in the wind market. These findings also seem to tally with the key frameworks provided by Porter (1998) where he revised his nation state diamond model from 1990 to also include the role of government. Porter's original framework had been criticized by other academics because it did not consider governments or nation states at all. However, exact key drivers such as nation entrepreneurship as well as considerations to develop critical industries including technology and energy were part of Porter's reasoning for expanding the framework for competition between nations to also include a nation state dimension.

Proposition 2—Two wind business models

In the previous analysis comparing onshore and offshore wind farm shipping, logistics, and SCM activities in Europe to that of, for example, the United States and Asian markets like China and South Korea, a difference in the overall composition of the various companies competing in the wind energy market can be noted. A number of select companies have been reviewed to analyze only one supporting industry, namely, that of the derived SCM industry. These companies have been included in the research because they currently play a significant role in the wind market or because they seem likely to do so in the future. Other supporting industries have not been reviewed such as sourcing, human resources management (HRM), finance, accounting, salary payment, and so on.

The market of wind energy does indeed seem to be characterized by two different business models at all levels: Some companies compete in the wind market alone, only being

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part of this single market, whereas other often larger conglomerates compete in many different industries with different characteristics, including the wind market. It follows that the conglomerates logically seem less vulnerable to fluctuations in the wind energy market. The key differences along two observed dimensions for the derived SCM industry are outlined in Table 5.3.

The first dimension analyzed is the overall business area of the wind energy constituency. Here, some companies are exclusively focused on the wind market, thus making them rather exposed to especially downward market trends. Conversely, other wind energy market constituencies are part of larger, more global conglomerate structures and as such, have a larger financial capability, and because they are not exclusively focusing on wind energy, they are also less subject to negative year-on-year market developments in the onshore and/or offshore wind market.

The second dimension analyzed is the integration of wind energy support industries and for this, the analysis is based on the derived market of SCM. At a high level, the analysis includes the financial resolve, supply chain strategy correlation with overall company strategy, and the actual way of strategy implementation. The findings indicate that those companies focusing exclusively on the wind energy business area have less financial opportunity to directly integrate support industries in their overall service offering. Conversely, a number of larger conglomerates seem to apply an aggressive M&A and JV strategy to integrate and absorb also the derived SCM industry service offerings, assets, and skills. It has not been possible to ascertain to what extent these strategies, on the part of the conglomerates, have been executed with risk aversion in mind or to achieve financial gains. The exact strategic drivers behind the partner selection strategies of the conglomerates are usually known to only a small group of senior executives and board members and as such not to the rest of the organization.

Table 5.3 Strategies and Business Models in Relation to the Derived SCM Industry Example (Source: Own construction)

Company Name	Origin Country	Company Type	Dimension 1: Business Focus	Dimension 2: Integration of Support Industries	Comments
DONG Energy	Denmark	Semigovernment owned	Conglomerate; utilities	Wind energy shipping JV with Siemens Wind Power	A2SEA

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Company Name	Origin Country	Company Type	Dimension 1: Business Focus	Dimension 2: Integration of Support Industries	Comments
Vattenfall	Sweden	Semigovernment owned	Conglomerate; utilities	No owned wind shipping activities	
RWE Innogy	Germany	Semigovernment owned	Conglomerate; utilities	Wind energy shipping subsidiary	Offshore Logistics Company GmbH
Siemens Wind Power	Germany	Publicly listed	Conglomerate	Wind energy shipping JV with DONG Energy	A2SEA
Vestas	Denmark	Publicly listed	Exclusive wind focus	No owned wind shipping activities	
Hyundai Heavy Industries	South Korea	Publicly listed	Conglomerate, chaebol	Own shipping activities like HMM	
Suzlon	India	Private	Exclusive wind focus	No owned wind shipping activities	
Goldwind	China	Publicly listed	Exclusive wind focus	No owned wind shipping activities	
Guodian	China	SOE	Conglomerate; utilities	Wind energy shipping JV with CCCC	Jiangsu Longyuan Zhenhua Marine Engineering

The findings indicate that the patterns are similar in both the regions of Europe and Asia where the same trends seem to be emerging: The large conglomerate players are integrating perceived bottlenecks and capacity shortages into their overall product and service portfolio to ensure that they are able to install and service the wind farms they are actively involved in. It also appears clear that these large conglomerates achieve both a capacity availability and/or cost advantage from doing so. Both the capacity availability to deliver the wind farm projects on time coupled with the cost advantage can be most advantageous for these conglomerates and help them distance themselves even further from the wind energy constituencies who have wind energy as their only focus area.

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The differences in today's wind market in China and India are highlighted by recent studies: The SOE model in China generates a different type of competitor, critical toward enabling the state to reach the often radical five year plan goals at a national level (Dai et al., 2014). This can then be compared to the Indian model, where private enterprises are left to compete in their own right, often with wind energy as the exclusive focus (Narain et al., 2014). In Europe and South Korea, business models exist that appear to be closely related to that of both China and India as described previously, both in terms of conglomerates versus focused wind companies and also with regards to direct involvement by the nation states. The effectiveness of an integrated business model operated by a partly government owned utilities conglomerate is illustrated in the fast and efficient process of constructing the Anholt offshore wind farm in Denmark (Poulsen et al., 2013b).

As a caveat, it should be mentioned that the fact that some of the research examples from China involve large SOEs is not very different from Europe where several of the examples used such as Danish DONG Energy also involve partly government owned companies. Like a Japanese zaibatsu structure, the South Korean chaebol conglomerate structure cannot be directly compared to the way a European/American conglomerate is structured. However, for purposes of this initial analysis, the correlation between the structure of a typical European conglomerate and a South Korean chaebol seems sufficiently strong to support the proposition.

Proposition 3—Conglomerates as winners

Upon examining especially company partner strategies as they relate to M&A and JV setups, the analysis reveals some patterns pointing in the direction that organizations competing exclusively within the wind market do not have the financial muscle nor resolve to effectively insource, for example, key bottleneck and scarcity factors. Conversely, the findings indicate that the larger conglomerates seem to be making use of a much more aggressive business model that incorporates an inclusive partner strategy where M&A and JV strategies seem to be utilized to secure capacity as well as gain competitive prices for rare assets and skills in the marketplace. When applied to the VRIO framework (value, rarity, imitability, and organization) established by Barney (1991), the key drivers behind the M&A and JV strategies of the conglomerates observed in this research are a complete match in terms of Barney's VRIO application of the RBV school of thought: A large part of the skills, assets, and people within the derived SCM industry has become

- Extremely *valuable* (day rates of, for example, WTIVs/CLVs, risk management in case of an overall project delay triggering fines)
- Very *rare* (greater demand than supply because of the exponential growth)
- Costly to *imitate* (WTIVs at EUR 250 million+ cost, long lead time to create necessary education/experience/knowledge)

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And these factors have driven the conglomerates to *organize* themselves by acquiring these skills/assets/people via M&A or JV to best capture the value and gain a sustained competitive advantage.

As the wind energy market matures and LCoE decreases to the levels of, for example, coal and oil, the market uptake will be considerable, and more of the traditional constituencies within the derived SCM industry such as shipowners, large logistics/SCM conglomerates, and the global freight forwarders seem poised to want to enter the derived SCM industry marketplace. Table 5.4 shows select M&A and JV activity in the derived SCM industry over recent years. This could be seen just as an overview of the competitive outlook in this derived market serving the wind business; however, it seems likely that these findings display a trend of what is going on in the wind market at large and that this trend will be accelerated in coming years.

Table 5.4 Competitive Outlook Changes in the Derived SCM Industry through M&A/JV Activity (Source: Own construction)

Acquiror/ JV Partner	Company Type	Target Company/ JV Partner	Company Type	Comments
DONG Energy	Conglomerate; utility	A2SEA	Private company, shipping.	49% of shares subsequently sold to SWP; CT Offshore later acquired as well.
GeoSea	Publicly listed	Beluga JV shares with Hochtief	Hochtief is an EPC company.	Beluga went bankrupt; new JV company name is HGO IntraSea Solutions.
Swire Pacific Offshore	Conglomerate	Blue Ocean	Private company, shipping.	New company name is Swire Blue Ocean.
Aarsleff	Private company, EPC	Bilfinger Berger	Private company, shipping.	JF company is called AB-JV.
DSV	Publicly listed	Baltship/ Seatainers	Private company, shipping.	Company now trading as DSV Baltship.
Mammoet	Private company, shipping	KR Wind	Private company, cranes.	Subsequently acquired Brande Maskintransport.
Maruberi	Conglomerate	Sea Jacks	Private company, shipping.	
Odendorff	Private company, shipping	Beluga	Private company; went bankrupt.	Took over some of the MPV fleet.
Peter Döhle	Private company, shipping	Beluga	Private company; went bankrupt.	Took over some of the MPV fleet.

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Acquiror/ JV Partner	Company Type	Target Company/ JV Partner	Company Type	Comments
Oaktree	Private equity company	Beluga	Private company; went bankrupt.	Restructured Beluga and renamed it Hansa Heavy Lift.

Continued Research and Invitation for Other Researchers

In conclusion, the findings of this research have largely supported the original propositions, as developed from the exploratory study. The wind market seems to be a good example that governments can be entrepreneurial at an industry level. It would seem that companies focusing more exclusively on wind energy may face financial challenges in the future, leading to industry consolidation, and early signs have already been detected with Danish-based Vestas being forced to enter into a JV with Japanese-based Mitsubishi Heavy industries to survive and Indian based Suzlon facing financial distress after the acquisition of German REpower (now Senvion). Finally, it would seem that conglomerates on a global basis use M&A and JV strategies to offer more encompassing solutions to their clients including the derived SCM industry as the example of this research.

Findings from this research effort have furthermore indicated that as capacity bottlenecks are evened out in a maturing market phase for the derived SCM industry, more traditional and financially strong native global constituencies of the derived SCM industry seem more poised to enter the market. Market entry by these more traditional shipping/logistics/SCM constituencies could pave the way for divestment by, for example, the utilities, engineering/procurement/construction (EPC) providers, and OEMs presently owning such types of assets/facilities/skills for purposes of capacity risk and cost mitigation. From an RBV perspective, this is a common approach when focusing on core competencies and competing in a more mature and saturated market.

It is the hope of the author that this initial research within this important area of the wind energy business has stimulated an appetite within other researchers to analyze both the derived SCM industry in general as well as the area of business models and strategy for the different parts of this important, emerging market. Further research efforts and collaboration within the topic itself are invited as it is the belief of the author that wind energy practitioners, policy makers, supply chain researchers, and economics academics will find future research results of vital importance and relevance. At the same time, this research project will further the coverage of these important topics as well.

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PAPER B: HOW EXPENSIVE IS EXPENSIVE ENOUGH? OPPORTUNITIES FOR COST REDUCTIONS IN OFFSHORE WIND ENERGY LOGISTICS

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Article

How Expensive Is Expensive Enough? Opportunities for Cost Reductions in Offshore Wind Energy Logistics

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Abstract: This paper reveals that logistics may conservatively amount to 18% of the levelized cost of energy for offshore wind farms. This is the key finding from an extensive case study carried out within the organization of the world's leading offshore wind farm developer and operator. The case study aimed to, and produced, a number of possible opportunities for offshore wind cost reductions through logistics innovation; however, within the case study company, no company-wide logistics organization existed to focus horizontally on reducing logistics costs in general. Logistics was not well defined within the case study company, and a logistics strategy did not exist. With full life-cycle costs of offshore wind farms still high enough to present a political challenge within the European Union in terms of legislation to ensure offshore wind diffusion beyond 2020, our research presents logistics as a next frontier for offshore wind constituencies. This important area of the supply chain is ripe to academically and professionally cultivate and harvest in terms of offshore wind energy cost reductions. Our paper suggests that a focused organizational approach for logistics both horizontally and vertically within the company organizations could be the way forward, coupled with a long-term legislative environment to enable the necessary investments in logistics assets and transport equipment.

Keywords: offshore wind; logistics; logistics innovation; organization; levelized cost of energy; LCoE (levelized cost of energy)

1. Introduction

According to the Global Wind Energy Council [1], wind energy can potentially cover as much as 25%–30% of the world's electricity demand by 2050. With more than 400 giga-Watts (GW) of cumulative nominal wind energy capacity installed as of the end of 2015 [2,3], offshore wind made up a small share of the total at 11.5 GW mainly installed in Europe according to the European Wind Energy Association [3,4]. Offshore wind will, however, be very important for the global wind energy diffusion targets up to 2050. In this paper, we present new research indicating that ***logistics makes up 18% of the levelized cost of energy (LCoE) for offshore wind*** energy power plants. Our case study findings, conservatively, point to this number of 18% of LCoE based on a definition of logistics throughout the offshore wind farm (OWF) life-cycle, from idea conceptualization and planning through construction, operations/service and, ultimately, de-commissioning/abandonment of the OWF site.

This is the major contribution of the authors' 14-month long case study conducted at the world-leading offshore wind developer and operator [4,5], DONG Energy Wind Power (WP). Whereas

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our findings are derived based on a single-company case study and we recognize that different findings could possibly be found for other companies, our results are useful and significant based on the leading market position of our case study company coupled with the size and depth of their offshore wind power organization. The WP case study was conducted from July 2014–September 2015 by a group of six key researchers, supported by company representatives. The case study was originally aimed at setting up a strategy for a new innovation initiative within the company covering the area of logistics. As part of the logistics innovation strategy crafting efforts, a key company output was for the case study to unveil at least five possible specific future innovation projects. Such innovation projects should be aimed at providing improvement opportunities within the area of logistics, which the company could subsequently incubate and work on in collaboration with suppliers, academia and/or governments: a WP hypothesis being that LCoE reductions are one of the potential improvement opportunities innovation can bring.

We opted to be part of the case study because WP is uniquely positioned in the market as the largest global OWF developer and operator. We also thought the case to be interesting because DONG Energy itself is a Denmark-based, government-owned utility company going through a major strategic development as a result of the ascension of a new minority shareholder in the form of the United States of America (U.S.) investment bank, Goldman Sachs [6]. Finally, WP owns and operates a public-private partnership (PPP) joint-venture (JV) for logistics in the form of the subsidiary company, A2Sea. The ownership of A2Sea is in JV with the largest offshore wind turbine generator (WTG) original equipment manufacturer (OEM), as measured in market share for offshore wind [3,4], Siemens Wind Power (SWP).

Our case study is timely and highly relevant from different perspectives:

- ***Policy***: Our case study indicates that a clear regulatory environment up to at least 2030 is critical for a conducive investment climate to exist. Such an investment climate is necessary in order to enable the needed logistics infrastructure, logistics assets and logistics personnel to be developed by government-owned and private organizations in order to support further offshore wind diffusion in an economical and safe/healthy manner.
- ***Governance***: Our case study shows that necessary research and development (R&D) funding will need to be allocated by governments to proactively ensure logistics innovation support to the technological development of even larger offshore WTGs, yielding a greater nominal output as measured in mega-Watts (MW). This need is further amplified, as the diffusion of offshore wind is about to expand from North Europe to become a globally-applied technology, while OWFs are at the same time moving further out to sea, away from shore and into deeper waters.
- ***Academic:*** It is only after the term 'logistics' is defined that we may adequately start assembling, qualifying and measuring data and knowledge about this phenomenon. Our case study depicts that the definition of logistics itself may vary greatly depending on many factors, e.g., organizational vantage point and specific life-cycle phase [7] involvement of the individual person involved in offshore wind. For offshore wind, an all-encompassing definition of logistics is challenging to achieve mainly due to the complexity deriving from the many and distinctively different supply chains comprising a complete OWF life-cycle. Each supply chain provides unique frameworks for the respective logistics-related tasks.
- ***Practitioner***: The strong empirical evidence from our case study suggests that logistics may be a somewhat overlooked frontier in the quest for lowering the LCoE of offshore wind. Our case study findings indicate that LCoE models and calculators do not separate out logistics as a stand-alone horizontal cost item throughout the entire OWF life-cycle, where clear levers can be used to impact LCoE in a simple and meaningful manner. Our case study also highlights how different offshore wind organizations do not seem yet to have dedicated logistics departments or competence centers, as in other industries. This prevents proper analysis horizontally across the life-cycle phases of an OWF, stopping synergies within a portfolio of many different OWFs within a single supply chain lead company to be realized. When we contrast this current state

of logistical affairs within offshore wind to the latest Council of Supply Chain Management Professionals' (CSCMP) review [8], it becomes clear that having an organization and singular focus are key contributing factors that have helped drive down U.S. logistics cost across industries as a percentage of gross domestic product ("GDP").

After this Introduction, Section 2 will present our research objective, the key academic terms of reference (LCoE, logistics and logistics innovation) and the background of our case study. Section 3 will present the case study in more detail and focus on the findings of the analysis. In Section 4, we discuss the findings along the dimensions of the aforementioned policy, governance, academia and practitioner perspectives. Finally, Section 5 contains the conclusion, including our suggestions for further research efforts.

2. Research Objectives, Key Academic Terms and Case Study Introduction

Compared to other more mature energy sources, such as nuclear power, coal as well as oil and gas, wind energy still depends on government subsidies for production, diffusion and consumption [9,10]. Shafiee and Dinmohammadi [11] point out that offshore wind presents a greater maintenance risk compared to onshore wind. LCoE for offshore wind still needs to be dramatically reduced in order to be competitive in its own right with other energy sources and without government support. With OWFs representing publicly-subsidized Weberian ideal-type megaprojects, as defined by Flyvbjerg *et al.* [12], the four distinctively different life-cycle phases of wind farm projects [13] make these projects very hard to manage.

2.1. Research Objectives

From a supply chain perspective, this research offers an in-depth perspective on the different supply chains comprised within offshore wind farm megaprojects through the project life-cycle phases [13]. As such, wind energy tends to be a government-created market globally with the underlying industry fueled by government subsidies [9,14,15]. With geopolitical drivers to have Europe depend less on oil- and gas-rich nations, such as Russia and several Middle Eastern countries [16], DONG Energy has played an important role in the execution of the aggressive climate change mitigation strategy of the government of Denmark. DONG Energy's role in the Danish mitigation strategy is particularly noticeable when it comes to the diffusion of wind energy in the form of a showcase within Europe.

Our WP case study about logistics innovation within offshore wind is both timely and relevant due to our three initial propositions:

1. Logistics is a significant cost driver for offshore wind, as it is for other industries. For logistics in the U.S., as defined by CSCMP across all industries, costs were cut in half over a 20-year period from 15.8% of GDP in 1981 to 8.4% in 2014 [8]. Logistics therefore holds the promise and allure of cost savings due to its sheer relative share of offshore wind LCoE.
2. Innovation is generally a path towards the maturing of industries, for example through platform leadership [17]. Furthermore, innovation provides an opportunity for cost reductions in general. Logistics innovation within offshore wind therefore seems relevant to pursue in order to obtain cost savings and to reduce LCoE.
3. With a market share of 15.6% of the operating European OWFs by the end of 2015 [3] and a construction/engineering, procurement, construction, and installation (EPCi) track record of 26% of all OWFs built globally [5] (p. 27), WP is the recognized market leader within offshore wind globally. WP seems to be the most interesting case study company to investigate in terms of logistics innovation within offshore wind, as they have the largest portfolio of planned OWFs, OWFs under construction and OWFs already in operation. Only a large market constituency like WP with a correspondingly significant organization and big portfolio of OWFs seems to be able to take advantage of synergies and benefit from economies of scale generating cost savings and

LCoE reductions from logistics innovation. A strong organization with strong focus on logistics seems relevant in terms of being able to execute logistics cost savings for offshore wind.

2.2. Levelized Cost of Energy

Diffusion of different energy types can be compared in different ways [18], and from a financial perspective, LCoE is the most commonly-used metric. LCoE is defined by The Crown Estate [19] (p. VII) as "the lifetime cost of the project, per unit of energy generated". The International Energy Agency ("IEA") defines LCoE as "the ratio of total lifetime expenses *versus* total expected outputs, expressed in terms of the present value equivalent" [20]. Prognos and Fichtner Group [21] (p. 12) define LCoE as "the average cost for generating electricity over an operational time of 20 years". Heptonstall *et al.* [22] further explain how to calculate LCoE and define it as "levelised costs seek to capture the full lifetime costs of an electricity generating installation, and allocate these costs over the lifetime electrical output, with both future costs and outputs discounted to present values". Liu *et al.* [23] evaluate different frameworks and finally utilize the 'E3' methodology in their setting of LCoE for China. Megavind [24] defines LCoE as lifetime discounted cost in EUR divided by lifetime discounted production in MW-hours (MW/h). As these different definitions indicate, the overarching concept for calculating offshore wind LCoE would seem similar; however, different countries within Europe have adopted different interpretations on how to perform these calculations, and many attempts have been made to use the calculations when planning OWFs [25].

When reviewing the state-of-the-art within academia, the topic of LCoE from a macro and policy perspective is addressed, e.g., by Gross *et al.* [26], as they explain how the government policy setting in the United Kingdom (U.K.) concerns itself mainly with the cost side of LCoE and why policy makers ought to focus on the revenue implications also for offshore wind. Based on mainly industry reports from 2006 to 2007, Blanco [27] breaks the wind farm cost components down into upfront capital expenditure and reoccurring variable costs for operations and maintenance (O&M) to arrive at an estimated LCoE number for onshore, as well as offshore wind, reflecting a downward cost trajectory over time. Heptonstall *et al.* [22] describe how LCoE for offshore wind has unexpectedly increased in the U.K. and break down the different cost drivers to justify how they expect LCoE to decrease also beyond 2020.

When it comes to cost drivers specifically related to logistics within offshore wind, the topics researched are generally very specific and seem to focus mainly on vertical "slivers" of the logistics chain as opposed to a holistic perspective with a horizontal view across the entire life-cycle phase, let alone the entire life-cycle of an OWF. This is illustrated by a state-of-the-art review of the offshore wind O&M logistics [28], where an overview of all logistics literature for the O&M life-cycle phase of an OWF is presented. The literature review reveals that whereas some logistics research deals with LCoE reductions, none of the academic works analyzed research logistics across all life-cycle phases of an OWF, nor do they consider logistics synergies across a portfolio of operating OWFs.

When we contrast individual academic works with more extensive efforts to unify academia, industry and government representatives in larger groupings to work towards bringing down LCoE across the entire offshore wind industry of a country in a systemic manner, the potential of logistics becomes gradually more pronounced:

Denmark study: In their report for the Danish Ministry of Climate and Energy, Deloitte [29] breaks down key cost drivers of OWFs. The report points out that a key cost driver for capital expenditure is installation vessels, and the Germanischer Lloyd Garrad Hassan underlying wind turbine installation vessel (WTIV) database is used to document the role of the WTIVs. The report points to a rise in installation costs in general because OWFs move further away from shore and into deeper waters.

U.K. study: In the final report from the U.K. industry-wide Department of Energy and Climate Change (DECC) Cost Reduction Taskforce [19], a target to reduce LCoE from Great Britain Pounds (GBP) 140 per MW/h in 2011 to GBP 100 per MW/h in 2020 is presented based on a six-month effort organized with five separate analysis tracks involving a total of 120 companies, organizations and individuals. Here, four different scenarios are presented based on four predefined OWF sites located in different offshore conditions. The offshore conditions vary by site in terms of average water depth, distance to shore and wind speed assumptions. The scenarios and different sites make the calculations and results more detailed and credible than the previous Danish study. Logistics cost drivers now start to feature more prominently and across several phases of the OWF life-cycle. Examples of LCoE reduction opportunities identified include more extensive site surveys, early involvement of suppliers, front-end engineering and design (FEED), better procurement, construction of new vessels, more competition in terms of installation, optimization of installation methods and evolution of the overall offshore wind supply chain. Applying an even broader implied definition considering overall offshore wind project financing, logistics plays an important role, as the key financing risks are seen as installation costs and O&M costs. Financing risks are crucial: the U.K. study explains that a change of 1% in the cost of financing for an offshore wind project in the form of weighted average cost of capital has a 6% impact of total project LCoE.

Germany study: In their analysis of how to decrease the LCoE of offshore wind in Germany over the coming 10 years, Prognos and Fichtner Group [21] base their research on the U.K. DECC Cost Reduction Taskforce results as published by The Crown Estate [19]. Prognos and Fichtner produce two different scenarios for three predefined OWF sites located in different offshore conditions [21]. The scenarios and sites contain more granular assumptions that make the calculations even more credible and accurate compared to the U.K. study. As Prognos and Fichtner Group are consultancies hired on behalf of The German Offshore Wind Energy Foundation to produce the analysis, they seem to have prepared a larger part of the findings by themselves than the U.K. study. However, approximately 50 external interviewees have been involved in the Germany study for dialogue and validation purposes. Logistics considerations feature much more prominently in the German study, which even has a detailed calculation involving day-rate hire costing ranges for eight different vessel types within the installation phase, as well as two vessel types and helicopter rates for O&M. A large part of the LCoE reduction initiatives identified have to do with logistics. The examples cited include improved logistics infrastructure for installing wind power plants, installation logistics innovation, improved logistics for offshore substations/wind turbine installation, new installation methods for substations/foundations, changing vessel requirements, larger vessels for foundation installation, more competition in the area of installation vessels for substations/turbines/foundations/cables, weather risk considerations for vessel bookings, O&M logistics costs and costs for loading, as well as transporting dismantled OWFs back to port at the end of the life-cycle. The German study considers different scenarios for O&M based on the distance to port and assumes a *land-based* maintenance set-up *versus* that of a *sea-based* concept for OWFs at deeper waters further from shore. In addition, unforeseen events, especially pertaining to the logistics components of the installation risk, are set at some 15% of the total OWF LCoE in the German study. Last, but not least, logistics plays an important role in OWF portfolio synergies and synergies between different farm operators, because the German study considers LCoE savings generated from joint fleets of vessel, helicopters, ports, warehouses, *etc.*

It is important to note that ***when comparing the different country LCoE studies*** outlined above, a key difference in calculation methods with profound impact is found within the area of offshore transmission assets and connection to the onshore grid. The Denmark study [29] reveals that offshore transmission assets and onshore grid connection investments for wind farms in Danish waters are planned, constructed and operated by a state-owned enterprise called Energinet.dk. In the German study [21] (p. 21), the OWF developer is responsible for building the wind farm, including an offshore substation; however, the developer is not responsible for connecting the OWF to the onshore grid. The U.K. study [19] (p. 34) reveals that the developer must construct the offshore transmission assets and ensure grid connection to the onshore grid only to subsequently transfer these assets to a third party offshore transmission owner via a tender process by the U.K. government, the Office of Gas and Electricity Markets. In the U.K., the operator of the OWF must then later pay for use and balancing use of these transmission assets, which is included in the LCoE calculations [19] (p. 6). The differences in calculation methods allow for a significant variation in LCoE cost reduction impact calculations, as offshore transmission assets and onshore grid connection costs could be as high as 20% of CapEx, as was the case for the Anholt OWF in Denmark [30].

2.3. Logistics

As indicated from our LCoE review, logistics for offshore wind may be rather broadly defined and, as such, comprise a very extensive scope ranging from more traditional definitions involving operation of assets, such as trucks, ports and vessels, to more complex implications, such as the logistics component of installation and O&M risks involving both "unforeseen events" and changes in the life-cycle project financing/weighted average cost of capital.

As a term and word, "logistics" originates from the Greek word "*logisitki*" deriving from the verb "*logizomai*", which means to think deeply about something and to calculate the consequence of actions. Logistics can be dated back to the Roman Empire, ancient Greece and Byzantium, where military officers, referred to as "*logistikas*", were responsible for finance, distribution and supply already back then [31]. Academically speaking, "logistics" was coined in several contexts through time including how it relates to the physical distribution of agricultural products by Crowell back in 1901 and from a marketing perspective by Clark in 1922 [32]. The first academic accounts of logistics as a more technical and managerial discipline, including the notion of a flow, inventory control and optimum lot sizes, were coined by Magee [33]. Other scholars like Heskett [34,35] and Shapiro [36] also discussed logistics in terms of definitions, structure, composition, operations, as well as strategic implications.

When it comes to strategy alignment of the company, logistics can be part of the competitive business advantage within the overall value chain [37], and alignment between the strategic goals of the company with the logistics system of the company is discussed by Shapiro and Heskett [38]. Fisher [39] discusses the same topic from a supply chain structure perspective, and Chopra and Meindl [40] devote the entire second chapter of their book to discuss the benefits of strategic fit between a company's competitive strategy and the supply chain strategy.

Other academic scholars attempt to group various lines of thought into different overall theory streams. Hesse and Rodrigue [41] present what they call "the evolution of logistical integration" from 1960 to 2000: They state that theory streams relating to many concepts, such as materials handling (MH), inventory management (IM), materials management (MM) and physical distribution (PD), are all antecedents to "logistics" as a theory stream. Additionally, they continue to state that by scholars adding information technology, marketing and strategic planning disciplines to the logistics theory stream during the 1990s, supply chain management (SCM) has succeeded logistics as a more encompassing theory stream. In a later study, Hou *et al.* argue [42] that PD, logistics and SCM can be considered to be "under the umbrella of a new theory", called the materials flow (MF) theory.

2.4. Logistics Innovation

Within the arena of logistics innovation, competing theory streams are also found along with a number of broader theoretical frameworks that impact either innovation in general or logistics innovation specifically. Some of this ambiguity within academic definitions is a result of the evolution of the core term itself, *i.e.*, whether we are discussing innovation for logistics or innovation for MH, IM, MM, PD, SCM or MF. Competing with logistics innovation, theory streams with some degree of weight attached to them could be supply chain learning management [43] or supply chain/SCM innovation [44]. Broader theoretical frameworks that are of relevance to logistics innovation according to Grawe [45] include the knowledge-based view, the dynamic capabilities framework, the Schumpeterian innovation framework, the exploration/exploitation framework, the theory of S-curves, network theory and resource advantage theory.

Regarding the term "innovation" itself, it is used by practitioners in a very broad sense from the action of invention to the discipline of R&D to innovation as an outcome of a process or effort.

The innovation definition and innovation framework of Schumpeter [46,47] generally seem to be recognized as the original academic thought processes defining and dealing with innovation.

Through an extensive literature review of logistics innovation, Grawe [45] also points out that logistics innovation is based on a number of factors that either relate to the organization of a company or the societal context/environment of a company. Grawe [45] furthermore argues that a company perspective may be either that of the company creating the innovation or that of the company(ies) adopting the innovation. Flint *et al.* [43] argue that logistics managers may be considered successful in terms of innovation if they innovate within the area of logistics to create a competitive advantage for the company or if they generate logistics innovation in order support the company's core product innovation process. To support a product innovation, logistics managers need to be involved upfront in the product innovation process [43]. A good example of this is FEED for offshore wind [19]. Arlbjørn *et al.* [44] have performed a broad literature search and argue that logistics could equal SCM and in the presentation of their results, SCM innovation (SCMI) seems to equal supply chain innovation (SCI), prompting them to label the field of study "SCI". Whereas the convergence and evolution of the terms logistics and SCM have been covered above, some academic scholars and practitioners alike would disagree with Arlbjørn *et al.* [44] and argue that the supply chain is, however, not equal to the discipline of SCM.

2.5. DONG Energy Wind Power Case Study Introduction

The key topic of this case study is the role and relative importance logistics plays within offshore wind when it comes to LCoE reductions, as well as how logistics innovation may specifically be applied within the WP setting, also organizationally. Flint *et al.* [43], Grawe [45] and Arlbjørn *et al.* [44] agree that the theoretical frameworks of logistics innovation, respectively SCI, described need empirical testing in an empirical setting along several dimensions for the benefit of both academia and practitioners alike. It is with this goal of empirical dimensional testing that the following company case study was developed.

With an exclusive focus on offshore wind, WP presently counts in excess of 1600 full-time-equivalent (FTE) people in a matrix organization organized in a hierarchical tiered structure and along the OWF life-cycle phases (see Table 1). WP is a complex organization to navigate for people working inside the company, let alone for outside researchers. Within offshore wind logistics, WP has a fairly unique position inasmuch as it owns shipping and logistics subsidiary A2Sea in a 51% PPP partnership with conglomerate SWP [13]. In addition to being the minority owner of A2Sea in the PPP set-up with WP, SWP is also a "preferred supplier" of WP, as SWP holds large frame agreements with WP for WTG supply and related services, such as WTG installation, commissioning, servicing and warranty. The WP business model is unique in the market place because the company believes that it is the world leader at constructing and operating offshore wind farms. Unlike many other industries, shipping/logistics/SCM did, however, not seem to play a significant role within the company, and the goal of our project with WP was to develop an offshore wind logistics R&D strategy for the company going forward towards 2020, 2030 and 2050.

From an academic perspective, the key assumption at the start of the project was that WP would most likely not have a commonly-agreed definition of what "logistics" is. A secondary assumption was that WP would perhaps also not have a commonly-agreed definition of what R&D efforts are comprised of. It was known that WP did not have a logistics department or logistics competence center, and another assumption was therefore that the company could be faced with organizational challenges within the field of logistics skills and competencies. In order to explore this setting, to understand logistics innovation within WP and to gather information needed to craft the R&D strategy for logistics, the investigation method applied was the case study [48].

Table 1. Case study company organization in 2015: multidimensional employee count.

Organizational Layers	Management and Finance	Development & Consent (D&C) Life-Cycle Phase	Installation & Commissioning (D&C) Life-Cycle Phase	Operations & Maintenance (O&M) Life-Cycle Phase	De-Commissioning (De-Comms) and Site Abandonment Life-Cycle Phase	Full-Time Equivalent (FTE) Employee Count	% of Total
Management Board	4	2	4	2	0	12	0.76%
Top management	6	3	27	11	0	47	2.96%
Middle management	27	18	38	45	0	128	8.06%
Operations/execution/analytical	103	60	762	202	0	1127	70.93%
Site	0	0	0	275	0	275	17.31%
FTE count	140	83	831	535	0	1589	-
% of total	8.81%	5.22%	52.30%	33.67%	0%	-	100%

To explore the topic, a largely WP-driven selection process yielded a total of 15 company interviews comprising a total of 18 company interviewees. The interviewees were chosen in order to represent the entire WP business unit in the interview process. An extensive interview protocol was simultaneously designed by the research team in order to be able to cater to all of the different organizational constituencies selected for interview within WP. The interviewees were chosen along several different dimensions, as illustrated in Table 1: they had to represent different organizational layers of management within the company; they had to represent the different offshore wind farm life-cycle phases; and lastly, the interviewees had to have representative expertise within the key parts making up an offshore wind farm (for example, the WTG, the foundations, the underwater cables and the substations). It was also important that the interviewees had some knowledge of both logistics and R&D within the company or at least within the industry in general (see Figure 1).

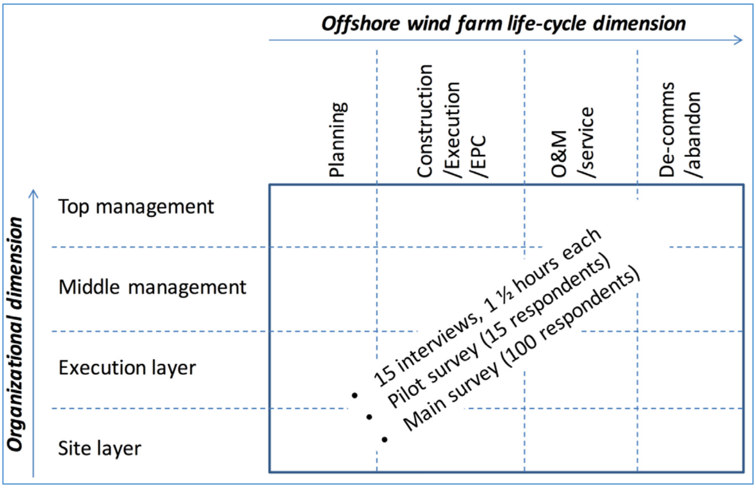

Figure 1. Interview and survey selection matrix.

The selection process for the interviewees and the interview protocol design efforts took from July–October 2014 to organize, and the 15 interviews were conducted from November 2014 through the middle of February 2015. Each interview lasted between 60 and 90 min, depending on availability. Two interviewers in the form of a company representative and an academic interviewer were present in all interviews, and in one of the interviews, a third interviewer participated as an observer. The company representative started off all interviews to set the scene and subsequently handed over the interview process to the academic interviewer.

The first phase of empirical data-gathering efforts in the form of the interviews was conducted in person, face-to-face, except two, which were conducted via video conference. Fourteen of the 15 interviews were, with due consent from the interviewees, audio taped for later transcription purposes, and 14 of the 15 interviews were conducted in English to enhance the scientific value to be derived from the subsequent academic team processing and interpretation. Each interview had an introductory section, which was aided by a hard-copy presentation for visualization purposes, and this was the same for all interviews in order to ensure that the background and purpose of the interview process was framed in the same way for all interviewees. The transcription was organized with the research team splitting and transcribing a number of interviews. Each transcript was subsequently reviewed and edited/completed by another research team member with an ultimate joint review conducted by the transcriber, the reviewer and the academic representative who was present within the interview itself. In nine cases, the transcribed interviews were sent back to the interviewee for validation/comments.

The second phase of the empirical data-gathering efforts reviewed the evidence gathered through the 15 interviews and used these findings to craft/issue a survey within the case study company. The survey was crafted in order for the research team to understand the topic of R&D within logistics as seen by a larger and randomly-selected, non-biased employee population. The survey was initially issued to 15 people in a pilot version. Subsequently, the survey was modified based on the pilot population input before being issued to a population of 100 employees within the case study company. A total of 38 useable survey responses were obtained from the survey effort. The objective of the survey was to test the overall understanding of logistics innovation topics within the company organization using general industry vocabulary as opposed to WP-specific vocabulary.

3. Results

According to the empirical findings of our case study, an important finding is that DONG Energy entered the market of offshore wind farms as a pioneer when no "traditional" EPCi companies had yet developed skills and competencies to move land-based WTGs offshore and build wind farms offshore. The senior manager responsible for the strategy of WP explained that " . . . the philosophy of course stems from the fact that we have been in the market when there had not been anybody available who could readily do what was needed. I mean, had it been started within the industry with a clear technique or something in order to be able to buy a full park fully installed, we probably would have taken that". Therefore, a strong set of in-house skills and competencies was developed by WP in what is portrayed as a vacuum of the market and where the company was an early mover. Still today, most competitors of WP in the offshore wind sector in Europe employ 5–50 employees to develop a wind farm where WP, in turn, now employs in excess of 1600 people: The case study company acts as both utility, offshore wind farm developer/EPCi and offshore wind farm operator with a multi-contracting governance structure "slicing" up the work tasks into small contract pieces. From a logistics perspective, this makes WP a very strong supply chain lead company with vast human resources available to plan, develop, monitor and manage many of the different sub-supply chains within each of the wind farm life-cycles. For almost all other wind farm developers and operators, the very low number of in-house employees results in single contracting set-ups, where typically 4–6 larger contracts are awarded to, for example large (and now capable) EPCi providers and WTG OEMs in the construction phase and, e.g., a WTG OEM and a service company in the operations phase.

Regarding the topic of logistics within WP, the interviewees were subjected to questions about the case study company's ownership of the major shipping and logistics company A2Sea. This PPP subsidiary company was first acquired directly by the Scandinavian state-owned utility case study company in the open market place, and subsequently, 49 percent of the shares were sold off to the dominant WTG OEM. The PPP subsidiary has increased its financial standing considerably and is now active both in the offshore wind farm construction and operations life-cycle phases with a much enhanced asset set-up and human resources infrastructure. The WP interviewees generally downplayed the importance of having such logistics, shipping and SCM skills available in-house and explained that it was operated at arm's length: the interviewees generally stated that at the time of the acquisition by the state-owned case study utility company, the market situation was such that a bottleneck surrounded key assets and competencies possessed by the subsidiary company, but that the situation has now changed to a supply/demand equilibrium. The interviewees generally did not seem to find the ownership of the PPP subsidiary to provide the case study utility company with an unfair advantage over both direct OWF developer/operator competitors nor shipping/logistics/SCM companies trying to serve the global wind energy sector. The interviewees generally stated that they also did not find the WTG OEM JV partner to be put in a more advantageous market position than its direct WTG OEM competitors, or its indirect EPCi competitors, or the shipping/logistics/SCM companies serving the global wind energy sector.

3.1. Definition of Logistics

It was clear from the interview process that WP does not have a logistics strategy as such. A member of the WP management board explained that " . . . from the strategic perspective, we don't have a strategy on logistics, or what logistics is. Then I want to mention this because you ask 'What is the definition?' and there is none. There is none . . . " This view was supported by other interviewees and another member of the WP management board said that " . . . ok, when we now talk about logistics we have, either we have a definition, [or...] We don't have that! . . . ".

As a leading practitioner association, CSCMP [8] defines logistics across multiple industries as: "*The part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements*". Within our case study, the logistics definition varied both across WP team member work scope within the OWF life-cycle phases, organizational layers of WP and depending on our methodology of obtaining the empirical data. In addition, we found that to a certain extent, WP has their own logistics terminology, which varies somewhat from the non-WP industry definitions. During the 15 ***interviews***, the interview guide was designed in such a way that the interviewees were given an opportunity to freely discuss logistics issues, including how they would define logistics. Here, it became clear that their vantage point, definition and perspective were very much based on where in the OWF life-cycle they worked, as well as where they had prior experience from. The ***surveys*** were more structured in advance by the research team inasmuch as the logistics definition section gave a number of options for the respondents to tick, as well as a free text field option in terms of how they felt that logistics should be defined. The logistics definition options in the survey were based on industry definitions not specifically designed around the WP terminology (see Figure 2).

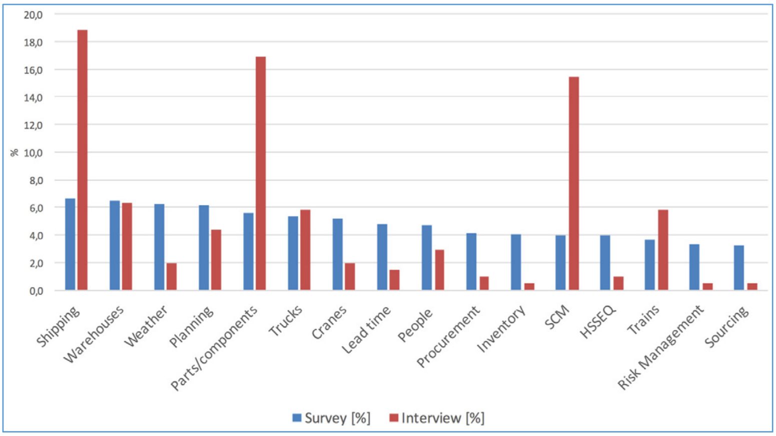

Figure 2. Frequency of terminology used (in %) during interviews and in the survey definition section.

The people interviewed at WP spoke much more about three of the keywords from the survey, *i.e.*, "shipping", "parts/components" and "SCM". When we disentangled these and other WP key terms during the interviews, we got into an underlying set of additional words associated with each of these keywords (see Table 2). These words we could further categorize along several dimensions, each forming part of the definition of offshore wind logistics:

- The term "shipping" could mean transportation by both vessel and helicopter (***mode of transport*** being sea or air); different types of trucks/ships/boats/vessels/helicopters could be involved (***means of transport***); and different tasks could be performed (***activities*** such as transporting personnel, performing surveys, preparation, loading, unloading).
- In terms of ***what we ship***, different "parts and components" mentioned by the interviewees included both main WTG and BOP components, but also technicians including their tools, personal protection equipment (PPE), equipment, parts, as well as power to the grid.
- Just like we saw within academia, the definition of "supply chain management" was much wider during the interviews with the WP personnel. Here, the discussions ranged across a wide spectrum: from skills/knowledge (***competencies***), who is being served within which supply chains (who is the customer of either a ***single or multiple supply chains***), the scale, scope and extent of the different supply chains (***beginning and ending points***) and the use of key performance indicators and computers (***IT and data management***).

Table 2. Words included in the interview dialogue about key survey terms.

Shipping	Parts/Components	Supply Chain Management (SCM)
Transport	Foundations	Delivery
Vessel	Turbine	Reduce delivery time
Crew transfer vessel (CTV)	Cable	Set-up around transportation
Helicopters	Goods/components	Preparation prior to execution
Transportation as part of installation	Towers	Coordinate logistics activities
Accommodation vessels	Building materials	Aligned flow of components
Survey vessels	Spare parts	Installation
Other vessels	Equipment	Logistics in operations & maintenance (O&M)
Offshore	Suppliers	Transport
Transportation with installation vessel	Survey equipment	Starts at production
Personnel logistics	Fixed platform	End-to-end (E2E)
Execution	Life vests	Between different countries
Installation vessel	Tools	Tier one customer
Unloading	Onshore activity	Idea to project hand-over
Prepare for shipping	Transition assets	Quay side
Sailing	Return of faulty component	Build an offshore wind farm (OWF)
-	Distribution	Supply
-	Technicians	Onshore projects
-	Logistics concepts	Knowledge regarding transportation process quality
-	Traffic	-

Both the discussions and survey reflected that ***weather*** considerations and health, safety, security, environmental and quality (***HSSEQ***) considerations play a very significant part in both OWF installation and O&M. Similarly, it was also clear that the context of logistics is very different if the ***logistical focus*** (unit of analysis) is that of an individual WTG (for example, break-down maintenance), an entire OWF (for example, during installation or in the event of a cable disruption during operations) or across a portfolio of OWFs (for example, survey vessel operations across more OWFs or synergies in terms of spare part storage for several OWFs). The risks and costs are much smaller for an individual WTG compared to an entire OWF or the synergies from portfolio asset management economies of scale.

When grouped along the definition category dimensions, the individual words used in the interviews and survey responses could be further sorted and contrasted, as seen in Figure 3, showing a difference in how the WP survey personnel responded differently from those interviewed because the surveys prompted industry terms rather than commonly-used WP in-house terminology. Our research resulted in a suggested and all-encompassing ***definition for offshore wind logistics*** as follows: "*Parts, modules, components, people and tools are responsibly stored and moved safely, weather permitting, onshore, as well as offshore by air/ocean/land using various transportation assets and transport equipment with a focus on an individual wind turbine generator, an offshore wind farm asset project or across a portfolio of projects by means of different in-house and outsourced logistics skills/capabilities/IT systems used across multiple supply chains spanning different starting and ending points*". This definition was a very important cornerstone in the efforts of the research team to come up with a tangible R&D strategy for logistics within WP.

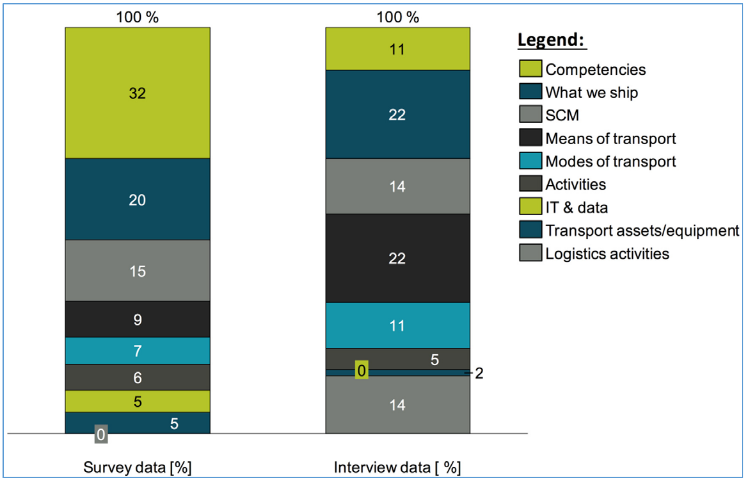

Figure 3. Logistics words frequency (in %) categorized along dimensions from surveys *vs.* interviews.

3.2. The cost of Logistics

Part of the interviews and a section of the surveys were dedicated to understanding the cost of logistics. Of 28 useful answers obtained regarding logistics costs from the interviews and surveys, eight answers had some degree of ambiguity in terms of whether the logistics costs portrayed could be directly associated with different life-cycle phases, for example installation and commissioning (CapEx), operations and maintenance (OpEx) or LCoE as measured in end-to-end (E2E) logistics costs. To resolve these ambiguity conflicts, the research team had to either review the overall context of the interview or the survey response submission in its entirety in order to determine the exact context for the logistics cost answer. The rest of the answers could be clearly categorized within CapEx, OpEx or E2E with one example being a senior DONG Energy Group finance manager who clearly had a full LCoE and E2E logistics scope in mind: " ... I think that there is logistics all through the value chain from [when] you acquire the, the right to build wind turbines in a specific area until you take it down. But of course it's, it's different kind of logistic capabilities you need ... ".

None of the respondents had a good sense of the size of the de-commissioning costs as a stand-alone cost component of LCoE, but many were discussing it. A member of the WP management board responsible for key component design and manufacturing: " . . . if you have to remove a gravity foundation, what to do with that excess concrete afterwards? If you asked 10 years ago, we would say it could be used for pavements, *etc.* Looking into the future [now], perhaps it's going to be reused into a different form somewhere in a different way . . . ". Furthermore, a WP manager with a leading role in the design and manufacturing process for WTGs said " . . . and if at one point we do see a major failure in one of our turbines, we have to think about whether it is time for de-commissioning or how the business case is the best . . . ". As can be derived from Figure 4, logistics costs form a relatively significant part of the overall costs irrespective of the vantage point within WP.

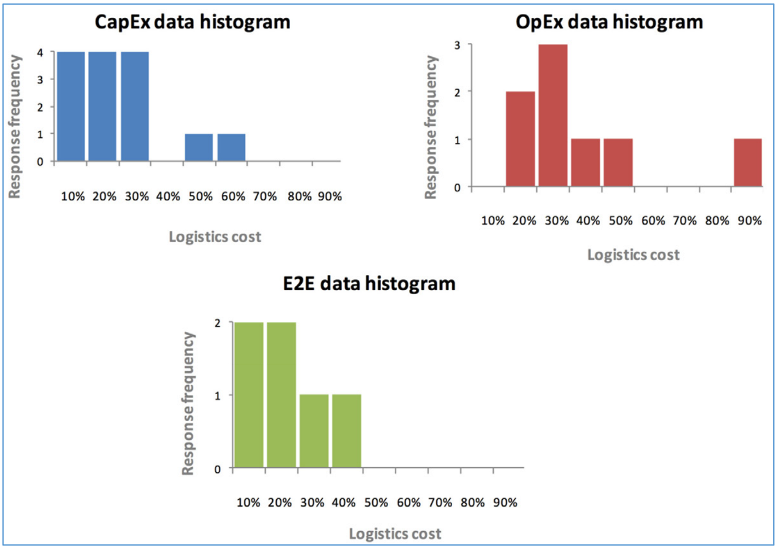

Figure 4. The 28 useful responses about logistics costs (in %) of CapEx, OpEx or LCoE (E2E).

Another LCoE initiative [24] practically substantiates that it is not possible to simply add CapEx and OpEx costs to get to the total costs within the LCoE calculation, because both the development and consent (project development expenditure, DevEx) costs prior to the OWF project final investment decision and the de-commissioning (site abandonment expenditure, AbEx) costs need to be included, as well. It was therefore only possible to review the useful WP logistics cost responses separately within their respective categories as depicted in Figure 5. In doing so, we can conclude that whereas 23% and 36% of CapEx and OpEx costs, respectively, are attributable to logistics, 18% of the E2E OWF project costs across life-cycles and equal to the cost equation of the LCoE can be attributed to logistics. Based on the ambiguity within both the country LCoE definitions themselves and the definition of logistics in its widest application (including the project risk from the U.K. [19] and German [21] LCoE studies), ***logistics costs of 18% of LCoE*** must be deemed to be a 'very conservative minimum level' according to our research.

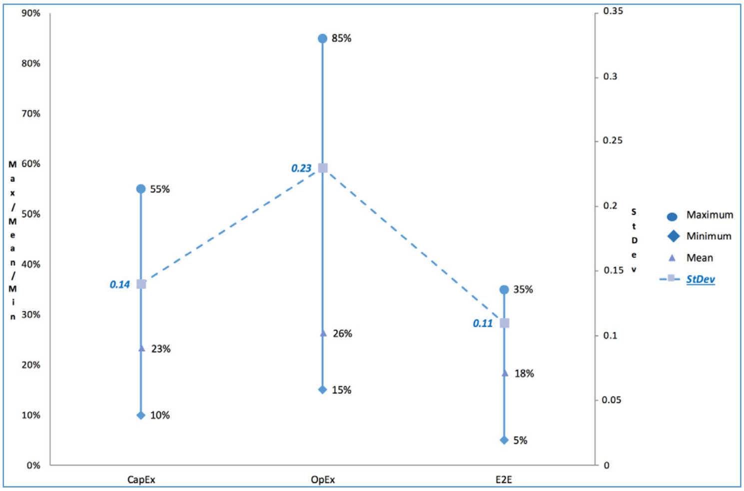

Figure 5. Distribution of responses about logistics costs as a share of total costs.

3.3. Logistics Innovation

The interpretation of logistics innovation within WP was clearly framed by a member of the WP management board, who said that " ... logical next step business issues ... " and " ... execution of the normal business strategy ... " should not be confused with logistics innovation. Another member of the management board said that logistics innovation within WP can be classified as " ... ideas that are known solutions but new to wind power in general, ideas that are known solutions but new to DONG Energy Wind Power, or new solutions ... ". A WP top manager within the area of procurement and LCoE defined the critical success factors ("CSFs") for logistics innovation as " ... sustainable improvements in cost of energy, health/safety/environment, or quality".

On this basis, the research team reviewed the interview transcripts and survey responses in order to come up with a gross list of potential logistics innovation ideas. A total of 159 quotes were identified and processed during three workshops involving the research team and case study company representatives. Several interviewees and survey respondents talked about the same or similar ideas, and some of the quotes from the interviews/survey responses needed further interpretation. This resulted in a gross list of 61 useful ideas generated from the case study process, and of these, eight were not related to logistics. Of the 53 remaining ideas in the catalogue, 38 could be considered a resourceful expansion of the daily work scope for different parts of the organization. When reviewing the remaining 19 idea catalogue items together with company representatives, these could be further consolidated into 12 innovative project ideas for WP to focus on. To focus on 12 projects is, however, not efficient, and a prioritization therefore took place both focusing on the aforementioned CSFs. The level of complexity, whether WP has the necessary personnel in-house to complete the task, and the estimated time required to implement the changes were factors also considered. Accordingly, the top five "must-win battles" were identified as depicted in Table 3. The goal to identify at least five tangible R&D projects for the new logistics R&D project organization to work on was achieved, which is in line with the original project charter to craft a logistics R&D strategy of the company.

Table 3. Top 5 "must-win battles 2016" for the WP R&D logistics project organization.

ID	2016 "Must-Win Battles"	CSF
1.	Establish preventive maintenance process for balance of plant (BOP) components including foundations/cables/offshore substation	LCoE
2.	Market analysis of future offshore accommodation options as offshore wind farms (OWF) move further from shore into deeper waters	LCoE
3.	Improve present and future crew transfer process to/from any offshore structure to reduce risk of accidents	HSSEQ
4.	Proactively support wind turbine generator (WTG) mega-Watt (MW) yield step-change in terms of logistics to cater for heavier and larger WTG and BOP components	LCoE
5.	Determine if present and future vessels can be used for multiple purposes (e.g., wind turbine installation vessels (WTIVs) for foundations, WTGs, cables, and OSS; crew transfer vessels (CTVs) for surveys)	LCoE

3.4. Organizational Implications

According to our research, expansion into the U.S. and Asian offshore wind markets is being contemplated at all levels of management of WP beyond 2020. Logistically, this means replicating the largely Scandinavian company culture, skills and competencies much further away from home than hitherto. This is recognized at the DONG Energy group level according to a manager in the Group finance organization: " . . . the supplier relations and the culture change and I think today we are a very Scandinavian company . . . " Now people, competencies, cultural integration, legislative understanding, WTG parts, wind components, ports, vessels and other transport assets/equipment will be needed in far-away markets where the rest of the case study company experiences little synergy. Within the WP finance team, a manager expressed it as " . . . it's going to be a big challenge for DONG [WP] going really far abroad. I think culture wise it's going to be a massive change . . . ". Today, logistics is not organized horizontally across the company in a centralized department, competence center or center of excellence. One member of the WP management board said a centralized function for logistics is needed in the future: " . . . To be able to actually to build competence, to build culture, to build method, and build also the future... All that intelligence should be here. And, and why should it be in one department is, of course, that to be able to have that central expertise you need to gather these people who are working with this daily, to get the knowledge into, say, this center, so you can gather it . . . ". With the rapid globalization of the WP offshore wind business model, the need for a centralized focus and attention to logistics becomes even more relevant.

Our findings indicate that an organizational shortcoming within logistics was confirmed through the interviews with both the interviewees and the survey respondents. A senior WP manager within the area of construction and EPCi explained that in terms of replicating a European offshore wind project in, for example, an Asian geography like China, Taiwan, South Korea or Japan, " . . . there would be maybe a handful of those profiles where I would have that kind of trust that they would be able to develop this on, on their own . . . " and he continued that " . . . some of them are no longer in my organization and elsewhere in DONG [Energy] em, but still accessible . . . ". He concluded that " . . . it would generally be some of the quite senior, em, installation managers that I have". It is also a question of having the right skills and competencies available, both in the future as well as right now, as the portfolio of OWFs continues to expand. A member of the WP management board explained that tenure with the firm and industry experience is lacking within offshore wind, as the industry is still rather young: " . . . if you look at the people working here, we have very experienced people that are on the ships and out in the projects. We don't have people . . . with the 25 years in the business . . . these guys are fact people . . . [people who learned by doing]". In addition, the logisticians employed are considering mainly their own vertical area of responsibility and not horizontally across the project life-cycle or across multiple offshore wind projects. One WP middle management representative from the construction and execution arena explained that " . . . there are very, very few that are, are good generalists. It is specialists that we have employed and I think that is the challenge. That many of these, they are so hardcore in their own discipline that they, they sometimes are difficult to lift up in a helicopter to give you the full perspective. So they would attempt to sub-optimize their own silo and that's some of the barriers that we would need to break down . . . ".

From a knowledge management point of view, it is difficult for the company to perform a hand-over of the experience gained by multiple people from multiple sources within an individual OWF project to future projects [49]. One WP management board member with R&D responsibilities said " . . . in the ideal world you would do the R&D work upfront before you have a problem. Or when you identify the problem on one wind farm then you would start an R&D project and once you have a solution, you could implement it on the next one. But with the timeframe we have [laughing] on our projects, often we have to develop almost as we built. . . . ". The challenge is great during individual life-cycle phases, such as the installation and commissioning process as, e.g., voiced by the senior manager in the construction and EPCi part of the WP organization, who said " . . . I think one of the challenges we have in DONG [WP] is that we are working in those [logistics] silos. We don't talk together, we have a lot of guys sitting over here, doing a lot of work—they don't talk with the end users out here. And we have seen it on a lot of our projects now that we have someone going that direction but we should have been in this direction and it costs us a lot of money because we didn't meet upfront to align this . . . ". Furthermore, between life-cycle phases, hand-overs present a logistical challenge, said a WP manager with full visibility of the WTG manufacturing process: " . . . one of the important things for us is to understand what abnormalities they [suppliers] see during construction. And that is actually logistics. When they are moving it on the harbor to do some tests, and then moving it into the sea and erecting them, that logistics part is also important for us to understand, because that is basically the baseline for the integrity. So if they have had some [damages] during this part of the logistics, which is important for us to know. Because when we do start to see some problems in the O&M phase that can be due to transportation or mishandling of the product during that erection period . . . ".

To conclude our case study findings, three macro factors were identified that seem to be going to make the offshore wind business more complex beyond 2020:

1. ***OWFs will move further away from shore***. The near shore sites are becoming rarer, which means that OWFs are moving further offshore and into deeper waters. The individual OWFs will be GW-sized, which means that risk management efforts and focused contingency plans will be increased. Each WTG position must produce a greater yield in terms of MW/h, and this, in turn, requires more shore-based personnel to stay offshore for longer periods of time.
2. ***WTG output yield will go through another step-change size increase***. The present WTGs yielding 4–8 MW will be replaced by WTGs yielding 10–15 MW by the early 2020s. Towards the end of the 2020s, WTGs yielding 20 MW will be introduced to the market along with floating WTG concepts.
3. ***Offshore wind is rapidly going global***. The WTG supply chain is largely global already; however, the BOP supply chain is predominantly European. This means that new key markets, such as China, Japan, South Korea, Taiwan, India and the U.S., will largely depend on a European supply chain for BOP and a largely European experience base in terms of the process of moving land-based WTGs into the ocean.

4. Discussion

Our case study identified that these macro-level findings do have a profound impact on especially our overall case study policy and governance perspectives:

- ***Policy-wise***, our work with WP shows that offshore wind is still a fairly young and immature industry with a large dependency on government subsidies to survive and expand diffusion. Up to 2020, the legislative environment is firm in key EU countries and especially the emerging Chinese offshore wind market. A stabile and long-term legislative environment also beyond 2020 is needed to ensure that the necessary investments can be made by shipping/logistics/SCM companies. This is needed to ensure that transportation assets and transport equipment of the necessary size, caliber and the right lifting abilities are in place for the expected advances in technology size and shape. Although downplayed in the interviews, the role of the case study firm's JV-owned PPP shipping/logistics/SCM subsidiary originally alleviated a significant supply bottleneck at the time of acquisition. Now, the PPP logistics subsidiary has, at a minimum, strengthened the relations between the case study company and the dominant WTG OEM, SWP, with whom the JV subsidiary is jointly owned. In addition, critical shipping/logistics/SCM skills and competencies are now available "in-house" via the JV PPP logistics subsidiary company. Although supposedly run at arm's length, the availability of both assets, people, competencies, skills and knowledge within the field of logistics seem to go hand-in-hand with the case study company's ambition to remain in the market leadership role for global offshore wind farm construction and operations. Additional players from the market are, however, needed in order for the industry sector of offshore wind to create the diffusion necessary to reach global renewable energy targets.

- ***Governance-wise***, it is important that necessary government funding is allocated to the area of logistics innovation in order to support the core technological innovation of the WTG products. Only by ensuring proper alignment and due FEED several years in advance can new WTGs and supporting BOP structures be transported and installed to their offshore sites.

When it comes to the applicability to both practitioners and academicians alike, our case study findings are very useful:

- From an ***academic perspective***, strategy alignment is necessary, as well as critical. The task of defining an R&D strategy for logistics within the case study company became more complex when the lack of a common logistics definition along with the inexistent logistics strategy became apparent early in the interviewing process. The strategy hierarchy seemed to be clear with company strategy placed squarely at the top and supported by business unit strategy; in this case, strategy within the offshore wind business unit. WP business unit strategy would ideally be comprised of different supporting pillars of which a logistics or supply chain strategy could expectedly be one such pillar. As defined by Chopra and Meindl [40], alignment of a company's supply chain strategy to the company strategy is critical to success and company survival. It follows from this argument that the strategy for R&D within the area of logistics should therefore be closely aligned with the overall strategy for logistics. The logistics strategy would be dependent on how logistics itself is defined. Our case study definition category shows that a proposed definition of offshore wind logistics across multiple dimensions should be a step in the right direction for the case study company and also for the offshore wind industry at large. With almost all other offshore wind farm developers and operators applying a single contracting business model, where large contracts are given to, e.g., EPCi companies and/or WTG OEMs, the market is not very transparent to the shipping/logistics/SCM companies trying to serve the global wind energy market. Who is actually the customer demanding the services to be rendered? When is the customer a competitor? Additionally, what alliances and allegiances exist between seemingly straight-forward companies with not so apparent links to sovereign nation states and their national agendas? These questions and the fact that the mere future existence of the wind energy market depends on continued government-sponsored subsidies are factors that may keep some shipping/logistics/SCM companies away from competing in the muddy waters of the global offshore wind industry; or perhaps causes some of the metaphorical blindness referred to by Mintzberg and Lampel [50] in their description of how both practitioners and scientists view this particular "elephant" in the safari of strategy. If the right companies do not enter the offshore wind logistics market place, the much needed professionalization of the supply chain may not happen. This lack of professionalization will be the beginning of a vicious circle that may lead to a lack of industrialization of the wind industry itself and inability to practically lower LCoE, a parameter that in itself is vital for offshore wind industry survival in the long-term without government subsidies; and an important factor for the OWFs already in operation as they start to move closer to their end of life service time [51].

- From a ***practitioner perspective***, our case study findings indicating that logistics is at least 18% of LCoE should point towards the area of logistics being ripe to explore in terms of possible cost reduction exercises. Findings from the U.S. over an extensive period of time reveal that by making logistics a recognized and admirable focus area for a cross-section of all industries with support from academia had brought down logistics costs as a percentage of GDP from 15.8% in 1981 to 8.4% in 2014 [8]. Realizing a 50% reduction in cost is not easy and has taken in excess of 20 years in the U.S. Therefore, the offshore wind industry needs to get organized not only within project life-cycle phases, but also horizontally across the different OWF life-cycle phases and across a portfolio of more OWFs. As the LCoE calculations of respectively Denmark, the U.K. and Germany showed [19,21,29], it is always hard to determine exactly how to measure costs within offshore wind, as it needs to be made very clear from the context or questions asked what, for example, a percentage is related to. Here, the LCoE initiative [24] should be highlighted because it developed a LCoE calculator tool based on the company-specific LCoE calculation models of key offshore wind developers (DONG Energy Wind Power, E.On and Vattenfall), key offshore wind OEMs (Siemens Wind Power and MHI Vestas Offshore Wind) and with input to the initiative from an additional 15 organizations, including several academic institutions, such as Aalborg University and DTU Wind Energy. This LCoE calculator tool [24] takes all wind farm life-cycle stages into consideration, from project idea through site restoration at the end of service life, as it is organized along four main cost dimensions, DevEx, CapEx, OpEx and AbEx. The cost items to be included in the LCoE calculator tool are generic in nature and as such do not allow for a significant further itemized breakdown. However, this model offers a full scope regarding the different supply chains where logistics costs may be incurred throughout the entire OWF project life-cycle. The LCoE calculator tool also considers, for example, production in the construction phase, and as part of production, a large inbound logistics flow is required. None of the country studies accounted or allowed for such an inbound flow. As such, the LCoE calculator tool [24] comes closest to being able to establish a platform able to address the end-to-end logistics costs in a horizontal manner across an OWF project and, thus, also the opportunity to start optimizing across a portfolio or several portfolios of OWFs. The LCoE calculator [24] furthermore addresses the offshore grid connection challenges described earlier by establishing a "point of common coupling" between the onshore grid and the offshore transmission owner, which may be supported by the model. Finally, the terminology used within the Megavind LCoE calculator tool [24] matches almost identically the company-specific terminology we found within our case study company.

5. Conclusions

Our case study was comprised of 15 interviews and 38 usable survey responses out of a total of 115 possible responses within DONG Energy. This largely government-owned market share leader of the offshore wind market segment has positioned itself strongly within the field of logistics before a contemplated listing of the company on the stock market in Denmark [52]. When seen in conjunction with the large workforce employed in order to position the company as an offshore wind farm construction company and operator, the multi-contracting business model and on-going global market scaling efforts make the case study company a very serious player to be reckoned with in the market.

When analyzing the 28 useful qualitative responses about ***logistics costs***, we conservatively identified that end-to-end offshore wind logistics across the four offshore wind farm life-cycle phases make up at least 18% of the offshore wind levelized cost of energy. Based on the fact that it took the United States in excess of 20 years to reduce logistics costs across all industries as a percentage of gross domestic product from 15.8% to 8.4% [8], our findings show that the offshore wind industry should focus on reducing logistics costs: It will take time; however, cost savings can be reaped.

From the list of 12 specific ***logistics innovation*** ideas yielded by our case study for the case study company to focus on during 2016 and beyond, several of the "must-win battles" identified hold a lot of promise and potential, also for the offshore wind industry at large, in terms of cost reductions within the area of logistics. Efforts to create logistics innovation within the area of preventive maintenance for the balance of plant parts of offshore wind farms must be highlighted. Efforts should also be put into the idea to logistically innovate in terms of vessel types to be used for multiple purposes. Logistics innovation in the early stages of the technological product design process for larger wind turbines is critical for the industry in general due to the additional issues of them being placed further from shore in deeper waters.

Focus on the ***organizational*** set-up within offshore wind is of paramount importance, and our case study highlighted that economies of scale are required by optimizing across all assets across all wind farm life-cycles. These include logistics activities across a portfolio of offshore wind farms under development, under construction, as well as offshore wind farms already in operation. Being the market leader in terms of construction and operations of offshore wind farms, our case study company is a good example of the state of the industry. Our case study showed that the case study company is not yet ideally positioned organizationally to focus beyond vertical organizational silos, let alone replicate offshore wind logistics skills to markets outside Northern Europe. This implies that for the offshore wind industry in general, infusion of additional skilled logistics personnel trained from other industries with the required vertical specialist skills and strategic horizontal skills is a must to realize logistics cost savings.

We recommend that ***further research*** efforts be undertaken by other academic scholars and practitioners alike in order to ensure that the exact logistics cost components of offshore wind are unveiled and fully defined. We recommend that specific studies be completed regarding how the levelized cost of energy can be reduced and executed within logistics cost component groupings through specific cost-out initiatives. We also recommend that logistics be included as a vertical life-cycle phase cost component and that a horizontal logistics view be adopted and defined. This definition should be at a national level, a company-specific level and for use within academic levelized cost of energy models, calculators and initiatives. Finally, we recommend that our study be followed up by additional quantitative studies on what planned "ideal state" logistics costs are expected to attribute in terms of levelized cost of energy share compared to actual "realized" logistics costs for real offshore wind projects across the entire offshore wind farm project life-cycle, as well as across a portfolio of offshore wind farms.

Our research shows that at a level of at least 18% of the total life-time costs of offshore wind farms, logistics costs are considerable. Therefore, our overall conclusion is that logistics is an area that is expensive enough to be a major focus for innovation and that further work is essential in order to reduce cost for the offshore wind sector.

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Abbreviations

The following abbreviations are used in this manuscript:

AAU	Aalborg University
AbEx	Abandonment expenditure
BOP	Balance of plant (cables, substations, wind turbine foundations)
CapEx	Capital expenditure
CSCMP	Council of Supply Chain Management Practitioners
CSF	Critical success factors
CTV	Crew transfer vessel
DECC	UK Department of Energy and Climate Change
De-comms	Decommissioning, site abandonment at the end of service life
DevEx	Development expenditure
DTU	Technical University of Denmark
E2E	End-to-end
EU	European Union
EPCi	Engineering, procurement, construction and installation companies
EWEA	European Wind Energy Association, now WindEurope
FEED	Front-end engineering and design
GBP	Great Britain Pounds
GW	Giga-Watt
GWEC	Global Wind Energy Organization
HSSEQ	Health, safety, security, environment and quality
I&C	The installation and commissioning life-cycle phase of an offshore wind farm
IEA	International Energy Agency
IM	Inventory management theory stream
IT	Information technology
JV	Joint-venture
LCoE	Levelized cost of energy
MF	Materials flow theory stream
MH	Materials handling theory stream
MM	Materials management theory stream
MW	Mega-Watt
MW/h	Mega-Watt hours
O&M	Operations and maintenance
OEM	Original equipment manufacturer
OpEx	Operational expenditure
OSS	Offshore (and onshore) sub-station
OWF	Offshore wind farm
PD	Physical distribution theory stream
PPP	Public-private partnership
R&D	Research and development
SCM	Supply chain management
SCI	Supply chain (management) innovation
SWP	Siemens Wind Power
U.K.	United Kingdom
U.S.	United States of America
WP	DONG Energy Wind Power
WTIV	Wind turbine installation vessel
WTG	Wind turbine generator

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PAPER C: THE ROLE OF LOGISTICS IN PRACTICAL LEVELIZED COST OF ENERGY REDUCTION IMPLEMENTATION AND GOVERNMENT SPONSORED COST REDUCTION STUDIES: DAY AND NIGHT IN OFFSHORE WIND OPERATIONS AND MAINTENANCE LOGISTICS

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The Role of Logistics in Practical Levelized Cost of Energy Reduction Implementation and Government Sponsored Cost Reduction Studies: Day and Night in Offshore Wind Operations and Maintenance Logistics

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Abstract: This paper reveals that logistics make up at least 17% of annual operational expenditure costs for offshore wind farms. Annual operational expenditure is found to vary by a factor of 9.5, making its share of levelized cost of energy for offshore wind range from 13% to 57%. These are key findings of a 20-month research project targeting cost reduction initiatives for offshore wind systems. The findings reveal that cost-out measures are difficult to implement due to cultural differences. Implementation efforts are rendered by personnel located offshore in a harsh sea environment which is in stark contrast to the shore-based office personnel who develop studies directing cost reduction efforts. This paper details the company motivation to join industry-wide cost reduction initiatives. A business case for offshore wind operations and maintenance logistics yielding 1% savings in levelized cost of energy is included on how to expand working hours from daytime to also work at night.

Keywords: operational expenditure (OpEx); operations and maintenance (O&M); levelized cost of energy (LCoE); offshore wind; cost reductions; logistics; shipping; supply chain management (SCM)

1. Introduction

In this paper, new research is presented which indicates that the often government sponsored levelized cost of energy (LCoE) policy studies for offshore wind cost reductions [1–3] are hard for industry practitioners to understand, let alone implement. The research indicates that operational expenditure (OpEx) is the cost component within wind farm LCoE calculations that represents the single most significant variance in different studies and reports. This OpEx variance has a big impact on the overall project LCoE as OpEx is a recurring cost item during the 20–25 year operational phase of an offshore wind farm (OWF). Operations and maintenance (O&M) costs make up approx. 50% of offshore wind OpEx and the research findings presented in this paper show that logistics makes up at least 34% of O&M costs and consequently at least 17% of OpEx costs. Logistics is therefore a key cost factor which deserves more focus at a policy level, in academia, and from practitioners.

The research findings include an analysis of eleven LCoE cost-related studies and reports which are made, often at the request of, and with funding from, governments, in order to help the subsidized offshore wind energy industry focus on reducing costs to make wind competitive compared to other energy forms [4–6]. Although extensive experience has been amassed since the first wind turbines were erected offshore in the early 1990s in Europe, installing and operating wind power plants in the ocean is no easy task and the pivotal role of shipping and logistics is exacerbated offshore compared to similar operations when performed on land [6]. The analysis of the eleven LCoE cost-related studies and reports examined in combination with the actual learnings from the parallel case study efforts make this research unique and novel. This research provides the most in-depth analysis of LCoE cost-related studies and reports hitherto, the research couples the analysis of the LCoE related studies and reports with a practical cost-out case study angle for the first time, and through a detailed logistics analysis the research presented in this paper illuminates some of the challenges which make offshore wind cost calculations very difficult to compare as well as contrast.

The research design is based on the findings from active participation in a 20-month industry practitioner focused offshore wind LCoE cost reduction initiative in Denmark [7] which serves as the practitioner case study part of this research. The offshore wind industry LCoE cost reduction initiative case study is being facilitated by a Danish not-for-profit and non-government offshore industry member association, Offshoreenergy.dk (OE). OE is a national cluster organization and innovation network for the offshore industry in Denmark [8]. As part of the research project, and the case study developed within the actual cost reduction initiative, a group of offshore wind energy related companies voluntarily got together during 2014–2017 via OE. The companies met from August 2014 to jointly work on implementable cost-out initiatives for the offshore wind industry and it was felt that it was justified to join the initiative as the learning institution representative. By December of 2014, a total of five work streams for potential cost reductions had been selected by the industry practitioners, using the Danish 400 mega-Watt (MW) Anholt OWF as a baseline case [9]. Logistics emerged as a significant theme from practitioners to wish to focus on and as such, 3 of the five work streams had to do with logistics.

In the following, one of the business cases actually developed from the practitioner case study will be presented in detail in order to demonstrate a tangible roadmap from desktop and shore-based government sponsored LCoE studies to practical offshore implementation at a company level. As part of the analysis of the business case, the case study research findings are presented in terms of the reasoning and motivation on the part of the companies for joining this cross-industry initiative. Inherently built-in cultural difficulties will be presented because the research unveiled that such differences exist between shore-based offshore wind personnel and personnel operating offshore or at operational sites in ports to actually execute and implement the cost savings. Findings from the case study will be presented regarding benefits and disadvantages caused by assets and skilled personnel moving from the offshore oil and gas (O&G) industry, often referred to as the petroleum industry in academic contexts, see e.g., [10], to the offshore wind logistics industry.

Throughout the case study efforts, LCoE savings were encountered for offshore wind expressed as a percentage by different company representatives. As company representatives were questioned in more detail and the topic researched further from a perspective of what the cost savings share was indeed measured as a percentage of, significant ambiguity was found in the unit of analysis applied by practitioners, consultancies, government studies, and organizations alike. Challenges existed with the assumptions, calculation process, and methodology behind the different studies and reports providing the basis for the calculations. Consensus did not exist on how to calculate savings due to many different methodologies being used which individually seemed to make sense but do not leave room for comparison. Findings are therefore presented on what causes the annual OpEx component of LCoE cost calculations for offshore wind to vary by up to a factor 9.5 in government funded LCoE studies. Being only one of four cost components in the LCoE calculation [11], the research indicates that the relative OpEx share of total LCoE may vary from 13% to 57% over the life-cycle of an OWF project as a result of the variance within OpEx itself. Finally, research findings are presented which indicate that logistics makes up at least 17% of OpEx costs but could make up as much as 32% depending on how individual cost items are measured and described.

The geopolitical case study context is that of the oil price dropping to a level of United States Dollars (USD) 22.48 per barrel in January 2016 compared to its June 2014 high of USD 110.48 [12].

This has caused distortion in the O&G industry [13]. Because of the fuel component of LCoE calculations [14], oil-generated energy has therefore become relatively cheaper making the journey for offshore wind to reach parity with fossil fuels even steeper [5]. Significant job creation is expected within the offshore wind industry over the coming years [15] and some of the world's largest fossil fuel companies are now seen to be implementing strategies to actively "diversify into low-carbon energy" [16–18] with wind as a strong contender based on e.g., resource efficiency [19]. Idle O&G assets and personnel are seeking deployment in the offshore wind logistics arena which may lead to lower costs and increased industry maturity within wind O&M logistics [20]. Irrespective of the possible contribution from the O&G context (e.g., learnings from O&G in the Gulf of Mexico described by Kaiser and Snyder [21] which could be applied to offshore wind in the North Sea), it is critical for further diffusion of offshore wind as an important renewable energy technology that it becomes cost competitive with other energy forms in terms of comparable LCoE [22]. This ought primarily to be done through cost reductions made by the offshore wind industry itself and with logistics accounting for at least 18% of LCoE within offshore wind [22] according to the definition of offshore wind logistics [22], the area of logistics as researched for the offshore wind O&M life-cycle phase in this paper represents a major cost reduction opportunity. The real-life industry-wide OE project in Denmark is an interesting academic research project and several key reasons served as the motivation to get involved:

- Going it, it was estimated that this particular industry practitioner initiative had a good chance to succeed in producing tangible cost-out initiatives due to the relatively narrow scope of O&M logistics.
- It was important to craft a research design which could actively contribute to the steering of the government sponsored and policy level cost-out studies/reports towards a practical trajectory which may actually be implemented by companies in real life, onshore as well as offshore.
- A strong desire existed academically to obtain information about O&M logistics from the participating companies and in return contribute with a scholarly perspective to the industry practitioner dialogue and process.

Geopolitically, the journey towards a wind energy electricity source being competitive in its' own right, compared to other energy sources [5], has been made more challenging as a result of the drop in the oil prices. At the time when the practitioner case study opportunity emerged, the need for cost reductions within offshore wind had therefore become even more pronounced which was the final academic justification to get actively involved.

In the next section, the research questions, the key academic terms, and an introduction to the case study will be presented. In Section 3, the results of the case study will be presented followed by Section 4 with the discussion. To conclude, Section 5 sums up the findings and provides input for further research within the area of O&M logistics and LCoE reductions for offshore wind.

2. Research Objectives, Academic Definitions, and Case Study Introduction

Measured in comparable LCoE, offshore wind is not competitive with other energy sources [5], with other renewable energy forms [23], nor can offshore wind projects survive without government subsidies [5–7,24]. Proponents of offshore wind argue that other factors should be considered when evaluating whether to continue offshore wind diffusion. Such factors include job creation [15], CO_2 emission cost avoidance [25], low offshore wind subsidy levels compared to subsidies for dark energy technologies such as coal [5], [26] (p. 7), and the issue of avoiding to take up scarce land areas onshore [27]. Conversely, opponents of offshore wind diffusion argue that animal life is disturbed, that near-shore offshore wind turbines distort the view of humans, that wind power production cannot be stored, that the grid cannot handle an energy form which is intermittently on/off, and that the subsidy levels are too costly for tax payers.

When comparing LCoE across different energy sources [5], renewable energy forms do not depend on a particular type of fuel to generate electricity and heat [28]. Traditional fossil fuel based energy sources such as coal, oil, and gas do depend on fuel. For fossil fuels, the fuel itself therefore makes up a large portion of the LCoE life-time calculation for these energy forms. Within the European Union (EU), most energy research and development funding is by far directed into nuclear fission while offshore wind receives the least attention and funding [5]. Within the EU, fossil fuels such as coal enjoy far more government subsidies than renewables such as offshore wind [5]. Globally, fossil fuel subsidy levels stood at USD 490 billion against renewables of USD 135 billion in 2014 [26] (p. 7), [29]. Wind power was furthermore found to be the only power source not presenting a security risk to the EU [30] which is important from a geopolitical perspective.

Government studies of LCoE for offshore wind in Denmark [31], the United Kingdom [1], Germany [2], and across industry coupled with academia [3] provide definitions of LCoE for offshore wind and create break-downs of the end-to-end life-cycle cost composition of an OWF [22]. Consultancies [16,32–34] and different wind energy associations [15,35–37] provide historical data on actual offshore wind diffusion along with scenarios for deployment and costs going forward as forecasts until 2020, 2025, 2030, and 2050. Especially the government LCoE studies for offshore wind also point to possible areas of potential cost reduction opportunities. The government LCoE studies are often made with extensive input from industry practitioner representatives [1,2].

2.1. Research Objectives

From a supply chain perspective, an OWF can be divided into four distinctively different life-cycle phases, i.e., Development & Consent, Installation & Commissioning, Operations & Maintenance, and Decommissioning [7,38]. Logistics makes up a significant portion of the cost of each of these four life-cycle phases and is often embedded or hidden in other cost items not captured by current LCoE models [22], let alone the O&M life-cycle phase with downstream implications (e.g., to failure mode and effects analysis [39]). This paper presents an in-depth review of logistics aspects of the O&M life-cycle phase. The O&M phase starts [40] (p. 4) when the construction of the OWF has been completed including full commissioning of the different wind turbines and offshore sub-station as well as grid connection [7,38]. Typically, the OWF can operate for 20–25 years before it needs to be decommissioned including site abandonment/restoration [1,2,41]. The annual OpEx costs to manage, administer, insure, operate, inspect, maintain, repair, and make replacements within the OWF are included in the LCoE calculations. Within the OpEx calculations, the logistics cost component had qualitatively been estimated at 26% by the world's leading OWF operator [22]. From this point of departure, this research project was conducted with the following upfront propositions and motivations:

(a) Major LCoE models and cost reduction initiatives for offshore wind [31] (pp. 1–3) are crafted by a certain type of people, organizations, and companies. These more conceptual studies have a certain audience and are generally characterized by a high degree of complexity, rigor, and financial backing. Is it indeed feasible for the industry practitioners to implement the identified LCoE savings opportunities from these government LCoE studies?

(b) The harsh sea environment within offshore wind is not native for offshore wind inasmuch as wind turbines were first put up on land and subsequently moved into the sea. Do cultural differences exist between shore-based personnel creating the government LCoE studies and the offshore personnel of the industry practitioners required to implement many of the actual cost-out savings needed for LCoE to factually decrease?

(c) The major government sponsored LCoE and cost reduction studies are very broad and cover the entire life-cycle of an OWF. These LCoE studies often involve a vast range of consultancies as well as management level industry practitioners and maintain a somewhat high-level perspective [31] (pp. 1–3). Could a specific life-cycle phase, such as O&M, be examined in detail and generate practically implementable cost-out opportunities that can realistically be implemented by industry practitioners to reduce the cost of offshore wind?

2.2. Offshore Wind Operational Expenditure

A good definition of OpEx within offshore wind has been provided in a study for the UK Renewables Advisory Board [40] (p. 4): OpEx "... includes all expenditure occurring from immediately after point of takeover, whether one-time or recurring, related to the wind farm, measured on an annual basis. Excluded are expenses inherent to the operation of the operators business but not directly related to the operation and management of the wind farm". OpEx is sometimes referred to as variable costs [35] (p. 45), [42], operating & maintenance costs [43], operating costs [1], operations cost [2], or operation, maintenance, and service costs [44]. OpEx may be broken further down to separate costs between "physical maintenance" and "non-physical services such as insurance" [14]. Some studies include added dimensions such as grid transmission charges and seabed rent [1] whereas others point out that present calculation regimes do not include key parameters such as lost revenues due to downtime caused by ineffective operations [45] (p. 365) or logistical factors such as weather windows and vessel availability [46] (p. 5).

From an accounting point of view, the recurring operating costs (OpEx) of a project are deducted from the income in the profit/loss statement of the project on an annual basis. Conversely, the initial capital costs (CapEx) of a project are put on the balance sheet of the project when incurred and subsequently depreciated. Cash flows and profitability are therefore treated very differently accounting wise [47] (p. 119). To be able to understand the value of any project at the time of making the investment decision, the corporate finance perspective prescribes that net of the future revenues less the future costs is discounted back to the time of making the investment decision using a discount factor often referred to as the weighted average cost of capital (WACC). CapEx and OpEx are therefore important terms to fully understand when making investment decisions [47] (p. 121).

As a phenomenon, LCoE focuses on the cost aspect of some of these same accounting and corporate finance terms [1] (p. vii) and as also described by Poulsen and Hasager [22]. The goal of the LCoE measure is to be able to compare the lifetime costs by electricity output unit of different energy producing plant types (for a good example of how to compare costs, see for example Namovicz [48]). According to the Megavind [3] LCoE calculator, development expenditure (DevEx), CapEx, OpEx, and site abandonment expenditure (AbEx)/decommissioning costs make up the cost factors used in LCoE calculations for offshore wind. From the research presented in this paper, OpEx is the LCoE cost component with the single most variance between different studies, reports, and calculations. This variance has a big impact on the overall project LCoE as OpEx will incur during each year of operations over the entire O&M life-cycle phase of the project which is usually 20–25 years for offshore wind.

2.3. Offshore Wind Operations and Maintenance

Originally, maintenance as a concept can be traced back to work performed by craftsmen before the Industrial Revolution. Later in history, Admiral Nelson's flagship, HMS Victory, was carefully maintained to an extent where almost all of her parts were replaced more than one time. The HMS Victory used timber corresponding to some 40 hectares of wood meaning that the effort to fell this wood, ready the timber, and ultimately replace it made the vessel a very valuable asset worthy of the expansive maintenance [49]. A review of maintenance history and maintenance management literature based on a number of books published and extensive consulting efforts on the topic was presented in London and cited by many [50]. Another study concluded that the concept of maintenance has evolved through four phases from being "a necessary evil", to internal company focused "technical specialization", through to being a "profit contributor", to finally becoming partnership driven with "positive cooperation" [51].

An early O&M example from the military context was the need for having US airplanes operational at all times for air combat during World War II which required intensive maintenance and repair (M&R) after completed missions in order to get the planes airborne again as soon as possible. The detailed need for such M&R efforts had to be balanced by researchers considering that the war time life-cycle of the airplanes was short and that "major parts" would therefore not need maintenance [52].

M&R understood as "maintenance & repair" is often used as a separate academic theory stream in different fields such as construction [53] and the electric industry [54]. Competing theory streams use the same abbreviation of "M&R" differently, e.g., maintenance & renewal [55], maintenance & replacement, maintenance & rehabilitation [56].

Within the O&G industry, O&M is often referred to as inspection, maintenance, and repairs (IMR) thus including the inspection function as a means to diagnose the problem at hand [34]. Another commonly used abbreviation [10,57,58] within sub-sea O&G is inspection, repair, and maintenance (IRM). Different theory streams include a wider array of functions such as inspection, repair, maintenance, and replacement (IRMR) in their definition [59]. The different groupings of several lines of thought into different theory streams make literature searches and comparisons of academic literature difficult across industries and one recent literature review found a total of 10 different maintenance management techniques within the many groupings of tasks [60]. Each maintenance management technique is either quantitative or qualitative in nature and each technique such as Total Productive Maintenance (TPM) is described extensively in literature and across different industries (for TPM as an example, please refer to e.g., Nakajima [61] and McKone, Schroeder, and Cua [62]).

O&M for OWFs can be split into four distinctively different generations of evolution according to Petersen [63]: "Run to failure", "systematic maintenance", "condition based", and "failure elimination". An offshore wind O&M taxonomy built on several sources has been crafted by May [46].

2.4. The Logistics Share of Offshore Wind Operations and Maintenance Costs

The logistics share of OpEx or O&M costs in offshore wind is not clearly defined in literature, nor in various cost reduction/LCoE studies Whereas the offshore wind industry is a young and somewhat immature industry [22,45,64], the topic of logistics within offshore wind O&M academic literature has been covered at operational, tactical, and strategic levels as summarized by Shafiee [65] and operations reviewed from a perspective of the wind turbine generator (WTG) and impact on the grid [66,67]. As determined in a separate study [22], logistics itself was previously not defined for offshore wind nor had a share of LCoE been attributed to logistics. The offshore wind logistics definition of that study [22] (p. 13) encompasses the O&M logistics chain and when prior academic work on OpEx cost shares of LCoE is reviewed as a starting point, it was concluded that several recent and very extensive studies [46] (p. 5), [63] (p. 3) were based on relatively few and quite similar sources. Upon reviewing these sources, it was found that one source [42] based its estimate that OpEx equals 30% of LCoE on a single study on offshore wind from 2007 but was very rich on onshore examples. Another source [68] was rather specific on OpEx cost items but contained a variance between the referenced minimum and maximum monetary values equal to a factor 2.3. Therefore, it was found to be necessary to scope and define what O&M logistics is for OWFs and perform a more detailed study of this phenomenon. This tallied with a prior recommendation for researchers to perform further research in the form of specific quantitative studies of the logistics costs for OWFs [22] (p. 20). In performing such a quantitative study as part of this research, with focus on logistics for the O&M life-cycle phase in particular, a total of eleven studies were analyzed in detail. These particular studies were selected because they had previously been included in related work scopes [1,2], [31] (pp. 1–2), [34] (p. 3), [44], because they were cited by major recent academically related O&M research efforts (such as May [46], Petersen [63], and Brink, Madsen, and Lutz [69]), or because they have been broadly recognized by academicians and/or practitioners to be of major relevance to the offshore wind industry [35,40,68,70,71]. These eleven different studies were performed by and on behalf of different—often government—constituencies from 2007 through 2015 (see Table 1 below for a high-level presentation of the eleven studies). Similar to earlier conclusions by e.g., Blanco [42] (p. 1374) and Dinwoodie et al. [72] (p. 8), it was determined as part of this research that the studies are very different in their fundamental assumptions and methodology including key parameters such as OWF capacity in MW and WTGrating. It was also concluded that none of the studies have a clear logistics definition nor does any single study break down logistics as a separate OpEx/O&M cost item.

Table 1. Analysis of inclusion of O&M logistics in eleven major LCoE related studies.

Year	Study	Cost Itemization
2015	Megavind 2015 LCoE calculator [3]	Built-in template data based on 400 MW OWF modeled after Danish Anholt OWF. Contains up to 15 OpEx/O&M cost line items with 7 pre-suggested types of which none can be attributed to logistics
2015	Douglas-Westwood offshore wind global forecast 2025 [34]	Forecast up to 2025 of global OWFs. Defines OpEx as a percentage range of CapEx costs. Breaks OpEx down into 6 cost items of which 3 can be directly attributed to logistics
2014	BVG Associates UK Supply Chain Assessment [44]	500 MW OWF using 6 MW WTGs. Operation, maintenance, and service costs defined as 39% of lifetime costs. Operation, maintenance, and service costs split between minor service and major service with cost items defined but not further broken down
2013	Prognos and Fichtner Group Germany cost reduction [2]	Extensive study with 3 different sites ranging from 320 to 450 MW OWFs modeled with 4, 6, and 8 MW WTGs based on distance to shore and water depth. O&M costs modeled for different scenarios and costs provided per MW per year. Insurance costs are separated
2013	GL Garrad Hassan offshore wind O&M spend guide for Scottish Enterprise and The Crown Estate [68]	500 MW OWF using 6 MW WTGs. OpEx cost items broken down into 18 line items of which 5 can be fully attributed to logistics. OpEx provided per line item
2012	The Crown Estate UK cost reduction pathways study including sub-studies in work streams [1,73]	Extensive study with 4 different 500 MW sites modeled based on distance to shore, water depth, and wind speeds. Operating costs estimated at 33% of total LCoE [1] (p. 15)
2011	Deloitte study on offshore wind competitiveness for Denmark [31]	Study considers O&M to be out of scope [31] (p. 4)
2010	BVG Associates for UK Renewables Advisory Board offshore wind sector value break-down report [40]	500 MW OWF using 5 MW WTGs. 5 O&M cost items discussed including operation, maintenance, and license fees. One cost item is port activities. Costs also segmented into labor, materials, and other where "other" includes vessels and cranes.
2009	European Wind Energy Association report on the economics of wind energy [35]	The report is largely built based on onshore wind technology and findings except one section on offshore wind based on 2 MW WTGs and a park capacity of 160–200 MW. The onshore wind O&M break-down has 5 line items of which none can be attributed to logistics. Offshore wind O&M defined as a cost per MW hour (MWh).
2009	Vattenfall VindKraft third annual technical report for Kentish Flats OWF [71]	30 WTG OWF with 3 MW capacities. 6 OpEx cost items including administration, insurance, lease & rent. O&M under warranty from OEM. Estimated OpEx costs broken down per line item.
2007	Offshore Design Engineering OW cost study for UK Department of Trade and Investment [70]	Early study based on 30 WTGs each with 3.6 MW capacities, near shore. 5 OpEx cost items of which 4 were WTG related and 1 related to vessels. OpEx costs set as a percentage of CapEx.

The most detailed OpEx cost itemization was found in the study made for Scottish Enterprise and The Crown Estate [68]. In this particular study, OpEx costs have been broken down into 18 different cost items which have been separately described in the study (see Table 5). Following overall logic of other studies for The Crown Estate at that time [1,44,73], costs for a 500 MW OWF with a WTG rating of 6 MW has been modeled by GL Garrad Hassan [68]. Of the 18 cost items, it was possible to attribute five fully to O&M logistics.

2.5. Case study Introduction

Leading OWF developer and operator DONG Energy Wind Power set out to reduce LCoE for offshore wind by 40% in 2020 compared to 2012 costs [22]. This was supported by a number of EU governments [1,2] as well as the EU Commission. In addition, many different initiatives were started by academia [64], practitioners (for example the Cost Reduction Forum of OE which is the practitioner related topic of this paper), and academia in collaboration with practitioners [69] in order to support this goal to reduce cost. DONG Energy Wind Power has committed to delivering the cost reduction targets for two Dutch OWF projects with a rated capacity of 700 MW [74] as construction of these OWFs will be completed by early July 2020 with an option to extend the completion up to no later than

July 2021 [75]. Similarly, Swedish utility Vattenfall has committed to delivering the Danish Vesterhav Syd, Vesterhav Nord, and Kriegers Flak OWFs by winning even lower auction bids in Denmark [76].

As an organization, OE is a non-profit cluster organization with members primarily from the small- to medium sized enterprise (SME) segment. OE focuses on offshore and separates between O&G and renewables. Offshore wind is the main activity within renewables for OE. OE is based in Esbjerg, Denmark which is the major European hub port for wind energy. Some of the key goals of OE are to facilitate strategic collaboration to create innovative solutions to promote the Danish offshore industry, to foster internationalization, and to act as an enabler when it comes to funding applications for industry, government, and/learning institution collaboration. To support the offshore wind industry's attempt to cut costs by 40% in 2020, OE launched the Cost Reduction Forum (CRF) in August, 2014. This was done after extensive consultation with the offshore wind industry based in Denmark and internationally. Whereas each organization consulted felt that they were doing what they could in their own right regarding cost reductions for offshore wind, especially the SME members of OE felt that a lot more tangible results could be achieved if an industry-wide effort spanning all parts of the offshore wind market could be put together. OE set out to do so and in designing the set-up with the companies, it was important for the CRF initiative to have a learning institution representative actively join up and participate in the work process. This was done in the form of a case study [77] with the detailed methodology applied being a combination of student learning project supervision, participant observation, interviews, focus groups, and action research [78–80].

From January, 2015 the academic involvement was increased along with the active participation in the leadership of one of the five specific work stream working groups tasked to review potential cost reductions within the area of O&M logistics. Following two series of intensive meetings in the practitioner working group, five specific O&M logistics cost-out initiatives were in different stages of completion by the time academic case study participation was terminated in April 2016 (see Table 2 for an overview of the five cost-out initiatives).

In total, 30 organizations comprised the main CRF member organizations (see Table 3).

Table 2. The five cost-out initiatives for O&M logistics.

Initiative Name	Cost-Out Initiative Description	Idea Agreed
Lean in O&M logistics	Eliminate waste from quay side up to in within the offshore wind farm site	First series of meetings
Working 24/7	Adding a night shift to present daytime operations (12/7) during maintenance campaigns	First series of meetings (and the focus of this research)
Asset sharing	The sharing of vessels and helicopters between different offshore wind projects	Second series of meetings
Parts, tools, and consumables pre-planning	Optimization of advance packing of parts and tools including location of tools	Second series of meetings
O&M logistics vision 2025	Vision for the future of O&M logistics in both near shore and far shore context	Second series of meetings

Table 3. Main Cost Reduction Forum member organizations.

Utilities	OEMs	EPCi	Engineering and Design	Shipping and Trucking	Logistics and Forwarding	Ports	Suppliers of Manpower	Learning Institutions
DONG Energy	MHI Vestas	MT Højgaard	Rambøll Offshore Wind	A2sea	Blue Water Shipping	Port of Esbjerg	Apro Wind	Aalborg University
Vattenfall	Siemens Wind Power	Per Aarsleff	Blaaholm	Torben Rafn	Deugro	Port of Grenaa	Alpha Offshore	
E.On	Envision		Granly Engineering		Nils Winther		Total Wind	
	Bladt Industries		Thomas as				Global Wind Service	
	Semco Maritime		AH Industries Solutions				VB Enterprise	
			R&D					

From the time the case study coverage was initiated in August 2014 until coverage was terminated in April 2016, a total of 3 CRF meetings had been conducted as follows:

- 25 August 2014: Inaugural meeting and kick-off. Through a focus group set-up, rules of engagement established and the Anholt OWF chosen as a "base case" scenario to work from and ensure focus on tangible results [9].
- 2 December 2014: Brainstorm meeting. The 30 participating organizations could attend an OE facilitated focus group session. The focus group session led to the establishment of five different working groups, each dealing with a single focus area on behalf of the CRF (see Figure 1).
- 8 October 2015: Progress review meeting. Progress from the working groups engaged with the five different focus areas was reported back to the CRF forum. Only working group 4 on O&M logistics (the group included in this paper) had made real progress. Other work groups were kicked off including Group 3 which had obtained separate public funding to progress in a more comprehensive manner to review installation and commissioning (I&C) logistics. Figure 1 below outlines the structure of the Cost Reduction Forum compared to the work groups working on the individual areas of possible cost reduction.

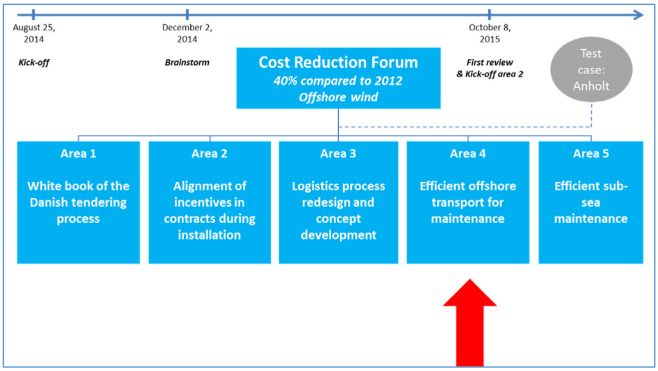


Figure 1. Offshoreenergy.dk Cost Reduction Forum structure including work groups.

The detailed research on potential cost reductions for offshore wind O&M logistics as reported in this paper is a direct result of the decision to actively join the work of CRF Group 4. The research team consisted of two researchers, both members of the CRF group 4 O&M logistics initiative. The Group 4 research design for the first series of meetings to generate cost reduction ideas and business cases was carried out in January and February of 2015 where an initial interview protocol was designed for open-ended semi-structured interviews [79]. During March 2015, coinciding with the European Wind Energy Association (now WindEurope) Offshore Wind 2015 conference in Copenhagen, a total of 18 interviews were carried out. The interview guide was specific in terms of focus on the logistics processes involved in the O&M phase of the OWF life-cycle and ideas for cost reductions. Fourteen of the interviews were carried out face-to-face and four additional interviews carried out by phone. The interviews were summarized in writing with a focus on cost reduction ideas which were highlighted. The initial interview summary interview process yielded a total of 36 cost reduction ideas within the area of O&M logistics which were reviewed by the researchers and further grouped during a workshop focus group.

Effectively, Group 4 had a very narrow O&M logistics focus and as such, it made sense that some of the main CRF member forum organizations took part in the Group 4 work and that particularly knowledgeable subject matter experts were invited to join as well (see Table 4). At the inaugural Group 4 O&M logistics meeting on 13 April 2015, a focus group setting was facilitated by OE to jointly review and qualify the 36 cost reduction ideas and the total number of ideas was increased to 44. The ideas were grouped into five categories and a delimitation session performed where only cost savings ideas from quay side up to and within the OWF site were deemed to be included for the group going forward. The findings from the focus group session were summarized in writing and shared with all participants for comments and edits.

Table 4. Specialized CRF Group 4 O&M logistics member composition.

Main CRF Forum Members Also Participating in Group 4	Specialist Firms in Group 4 (Rounds 1 and 2)
DONG Energy	Hvide Sande Skibs og Både Byggeri
Vattenfall	Dansk Offshore Transport
E.On	Valling Ship Management
Siemens Wind Power	Esvagt
A2Sea	Danish Yacht
DBB Jackup/Ziton	World Marine Offshore
Thomas as	Uni-Fly
Niels Winther Shipping	K2 Management
Port of Esbjerg	Maersk Broker
Aalborg University	Waypoint North/SeaState Aviation
	Siemens Service
	Oddfjell Windservice AS
	FairWind

Shortly after the Group 4 kick-off meeting, a follow-up meeting was conducted on 4 May 2015. At this meeting, two more ideas were generated and all ideas prioritized using a funnel technique with several criteria: Impact on LCoE, investment required, time need to implement the idea, alignment with the participating companies' own strategies, and probability of successful implementation. Three projects were chosen at the meeting for sub-work groups to focus on in detail: How to make the O&M logistics process more lean (the lean sub-group), how to work daytime and at night for preventive maintenance and repair campaigns (the 24/7 sub-group), and how to more objectively evaluate safety. The work performed was again summarized in writing and shared with all focus group participants. The lean and 24/7 sub-groups subsequently gained the most traction and were chosen as the projects to move forward with.

During August 2015, the lean and 24/7 sub-groups each met twice to perform more detailed work on how to practically realize the selected projects, selection of elements to be focused on in a business case, and detailed discussions about business case calculations. These meetings were smaller sub-working group meetings facilitated by OE and were more hands-on and practical in nature. Each meeting was summarized in writing and the results were shared with the participants for comments/edits. The business case documents were also included as they started to take shape from the discussions (mainly Microsoft Excel spreadsheet models). A subsequent online focus group meeting was facilitated by OE and supported by emails in order to jointly review and actively evaluate the results of the work crafted by the two sub-work groups working separately on the lean and 24/7 business cases. Additional focus was put on implementation planning, risk analysis, and an evaluation of the likeliness of the success of each of the projects. The business case documents were updated further and the overall discussions summarized and shared along with the business case documents to all participants.

Three extensive face-to-face business case review meetings were conducted as semi-structured open-ended interviews with selected key players in terms of actual operational knowledge. The three interview participants were carefully hand-picked from the team members of working group 4 based on their perceived ability to evaluate the process of generating the business cases, answer questions to fill in the last remaining assumptions for calculations, and also review the business case calculations themselves. A single interview protocol had been developed for this purpose of final validation and the questions were split between the interviewees.

The final versions of the business cases for lean and 24/7 were presented at the 8 October 2015 CRF meeting where the key CRF member organizations were represented. The progress of Group 4 including the lean and 24/7 business cases caused the main CRF member organizations to express satisfaction with the work efforts rendered thus far. An extended focus group session itself, the CRF forum entered into a review of the work results generated by Group 4 including detailed feed-back and comments to the working group members. A further brainstorming focus session about subsequent and "second series" of group 4 O&M logistics cost reduction ideas took place as part of the 8 October 2015 CRF meeting itself. Already on 26 November 2015, the second series of cost reduction business case working group meetings was kicked off with a focus group meeting to prioritize this new set of O&M logistics cost reduction ideas. More participating organizations had now joined and the meeting was facilitated by OE by splitting the meeting participants in 3 groups working on different methods to prioritize the cost reduction ideas. At this session, three ideas were selected for further focus thus taking the total number of business cases being worked on by Group 4 to a total of five (see Table 2).

Three of the organizations participating in the work efforts of Group 4 never really became actively involved in the detailed work efforts associated with building the business cases. Of the remaining 22 organizations, a total of 26 people were actively engaged and the organizational split was 38% top management, 38% middle management, 19% execution layer, and 4% site layer. In this paper, the 24/7 business case of extending working hours from day to night will be used as the representative example of the work efforts rendered within this practitioner case study.

3. Results

The results from this research are divided into two parts. One part is the empirical findings from the practitioner case study and the other part is the quantitative analysis of eleven LCoE related cost studies. To present ***the case study findings***, a detailed review of one out of a total five business cases has been included in this paper. This approach has been developed with an aim towards exemplifying work done in order to create practically implementable business cases useful for taking costs out of the logistics chain. The selected business case is that of working daytime and at night 24/7 instead of only during daytime. In the work to quantify the savings generated from the different business cases, ***eleven different LCoE related cost studies*** for offshore wind were analyzed with the goal to be able to quantify the savings as a percentage of either O&M costs, OpEx, or LCoE in an accurate manner. In doing this quantitative work, the first realization was that the unit of analysis utilized in the various studies differed greatly, e.g., OpEx measured as a percentage of CapEx [34,65], OpEx as a percentage of LCoE measured as a sum of the discounted lifetime electricity output (in MWh) [1], annual OpEx per kWh [35], total OpEx costs as a percentage of total lifetime costs [44], OpEx per MW per year [2], total OpEx costs per year for the OWF [3], or outright costs per OpEx line item [68,71]. One study on behalf of Scottish Enterprise and The Crown Estate concludes in terms of unit of analysis that O&M " . . . is best considered on a per turbine basis as costs tend to scale most strongly with turbine numbers, rather than per MW of installed capacity" [66]. However, other and more elaborate cross-industry studies on potential cost reductions in the UK [1] and Germany [2] used very complex scenario modeling with different WTG ratings, foundations, distances to shore, water depths, and wind speeds. Both of these studies [1,2] make use of OpEx costs measured by MW per year and on the basis of the complex scenario models providing a more representative view of the reality within offshore wind, it was decided to also utilize the OpEx/MW/year unit of analysis in the following.

3.1. Differences in the Dimensions Used for Calculations

Besides the differences noted in terms of the unit of analysis, it would seem that the different studies have evolved dramatically over time. This learning curve built into the study logic applied can be demonstrated by the different dimensions that have gone into the calculation of LCoE in the different studies. Apart from the macro level country LCoE differences such as whether the offshore sub-station is part of the national country level scope or that of the developer, as reviewed in earlier work [22] (pp. 4–6), a number of other differences in terms of dimensions applied for OpEx became clear from the detailed analysis performed of the eleven studies. Examples of differences in dimensions include:

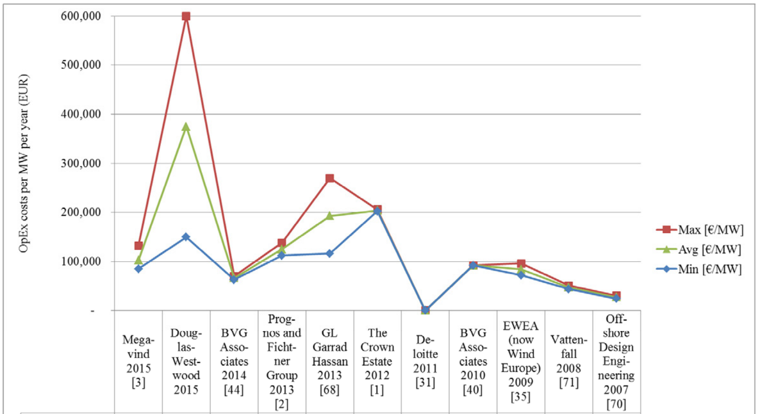
- WTG rating determines the number of WTG positions to be operated and maintained. The bigger MW rating of each WTG, the fewer positions to maintain in some scenarios where the OWF concession is based on over OWF MW rating [1]. In other scenarios, the OWF concession is based on an award of a certain number of WTG positions [2] which means that the annual energy production will be higher if the WTG rating is increased. A higher WTG rating means lower LCoE in both studies, however, as new technology is introduced, insurance premiums and the cost of capital (WACC) will increase due to increased project risks.
- Higher project risks will increase WACC and 1% increase in WACC equals a 6% increase in overall LCoE costs for an OWF [1] (p. ix). The same study cites logistics topics " . . . installation costs and timings, turbine availability and operating and maintenance costs . . . " to be the key project risks and WACC influencers.
- Distance from the OWF to shore significantly affects the overall O&M logistics strategy for the individual OWF. Only later studies [1,2] with different site scenarios are able to distinguish whether the O&M strategy should be land-based (using crew transfer vessels (CTVs) operating daily from a shore base) or sea-based (with fixed platform/floating hotel vessel [floatel]/service operation vessel (SOV) enabling personnel to stay offshore for longer periods of time). The sea-based scenarios are more expensive in both studies.
- Water depth determines the kind of foundation type to be used [44] and this again determines O&M efforts needed subsea. OWFs further from shore in deeper waters use more expensive foundations [1] that are less proven in terms of technology and therefore more expensive to insure due to increased technological risk which again negatively impacts WACC [2].
- The initial O&M warranty period for WTGs is contractually paid for as part of the CapEx costs as the WTGs are sold including warranty [40] (p. 5). This creates " . . . invisible costs covered in the supply chain during warranty periods" [40] (p. 17) which effectively means that OpEx costs are frequently artificially deflated.
- OpEx costs are not constant over the life-cycle of the OWF. One study for the UK Department of Trade and Investment highlights that " . . . final costs being higher as the farm comes to its life end and maintainability and reliability issues increase" [70]. Other studies consider that early OWFs need to have their operating life extended as they were designed for a 20-year operational life only. Costs for "repowering" or "end of service life extension" for WTGs [34] or prolonging operating life of WTGs [2] are considerable and have undergone some study also by academia [81]. Some operators consider costs for repowering or prolonging operating life to be outside of the normal realm of O&M costs and one operator treats these types of actions to be refurbishments which are accounted for financially as maintenance projects or maintenance investments [63] (p. 27).
- One of the studies quantifies that a learning curve will produce cost savings for an operator of an OWF over time [70].
- LCoE definitions are specific about OpEx and AbEx costs being used in a discounted manner in order to be able to compute the comparable numbers [1–3]. Some studies do, however, make use of undiscounted OpEx numbers [44] (p. 11).

Last but not least, the studies use the terminologies O&M and OpEx intermittently and interchangeably. Early academic work on LCoE concluded that their definition of O&M could explain

50% of OpEx, mainly for onshore wind [42] (p. 1377). Early practitioner work for the UK government stipulates O&M as a share of OpEx for offshore wind to be between 60% and 75% [70]. A paper recommending strategies to be applied for O&M in the UK offshore wind sector in 2015 and 2016 points to their definition of O&M making up some 52%–54% of OpEx [82] (p. 3) with costs for lease, transmission, and insurance considered to be excluded. This latter paper [82] bases its calculations on interpretations of the UK cost reduction study [1] including comparisons with key conclusions from one of the sub-work streams [73] of this extensive UK cost reduction study.

3.2. Comparison of Operations and Maintenance Calculations

Having selected a unit of analysis and with due attention paid to the different dimensions applied in the eleven studies subjected to the analysis, any studies with O&M numbers were first converted to OpEx numbers to ensure that an adequate comparison could be made of the annual OpEx figures per MW. Figure 2 shows the annual minimum (min), average (avg), and maximum (max) OpEx costs per MW per year converted to Euro (EUR). Due to the learning curve observed within the LCoE related studies pertaining to the calculation of OpEx costs and the different OpEx dimensions described earlier, the minimum and maximum ranges for OpEx costs in absolute terms per MW per year vary from EUR 24,363.- to EUR 600,000.-.



	Mega-vind 2015 [3]	Doug-las-West-wood 2015	BVG Asso-ciates 2014 [44]	Prog-nos and Ficht-ner Group 2013 [2]	GL Garrad Hassan 2013 [68]	The Crown Estate 2012 [1]	De-loitte 2011 [31]	BVG Asso-ciates 2010 [40]	EWEA (now Wind Europe) 2009 [35]	Vatten-fall 2008 [71]	Off-shore Design Engi-neering 2007 [70]
Max [€/MW]	132,000	600,000	70,150	138,000	269,942	205,955	-	92,093	96,000	50,819	30,454
Avg [€/MW]	102,840	375,000	66,521	125,000	193,068	204,105	-	92,093	84,000	47,324	27,408
Min [€/MW]	85,250	150,000	62,893	112,000	116,194	202,255	-	92,093	72,000	43,829	24,363

Figure 2. Calculated annual OpEx cost ranges per mega-Watt for the eleven studies.

If the very early studies from before 2010 are excluded, where WTG rating and the total OWF capacity were smaller and mainly based on exclusively near shore locations which make these studies hard to compare to later studies, a minimum/average/maximum OpEx cost of EUR 62,893.-/166,895.-/600,000.- may be obtained respectively (a variance factor of 9.54 between minimum and maximum values). If these minimum and maximum OpEx cost numbers per MW per year are applied to a simplified LCoE calculation following the principles of Megavind [3] where it is possible to simultaneously apply the corresponding minimum and maximum ranges for CapEx in the respective study scenarios, the relative proportion of the discounted total life-cycle OpEx costs as a percentage of LCoE fluctuates from 13.1% to 56.5% as illustrated in Figure 3.

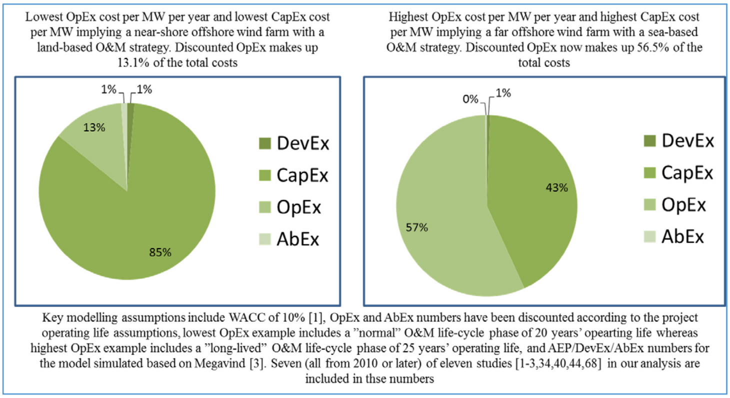


Figure 3. Scenarios displaying fluctuations in Operating Expenditure share of total costs.

These findings highlight the importance that applying the right O&M strategy whilst carefully monitoring OpEx costs can have a very significant impact on whether to enter into an OWF project at all from a financial perspective. The right O&M strategy with OpEx cost balancing greatly impacts the overall profitability of the OWF project over its life-time. The different dimensions used and settings for OpEx cost models seem to be somewhat subjective and the actual application for each OWF project therefore becomes critical.

3.3. Ascertaining the Logistics Share of Operational Expenditure for Offshore Wind

One of the eleven studies analyzed included a very detailed cost itemization of OpEx costs [68] and this was selected as the "logistics base case" for determining the logistics share of OpEx. When the 18 cost items (outlined in Table 5) are compared to the definitions of OpEx in the other studies analyzed and academic literature, it was found that although itemized in the greatest level of detail, several line items were still missing (see Table 6). Each line item contained in the base case cost model (Table 5) contained both a minimum and maximum amount provided by the source.

Individual OpEx line items that are similar in their descriptions across different studies analyzed were found to vary in size and this is also the case for logistics. Using "Port Operations" as an example, this line item ranges from approx. 1.2% of O&M [68] to 5% of OpEx [34] to 31% of OpEx [40]. Another example is the "Vessel costs" line item (including helicopters) which ranges from 9% of OpEx [34] to 30% of O&M [68] to 38% of O&M [70]. It was possible to ascertain that the different results vary based on the data itself (actual costs vs. simulations), the data collection method (quantitative modeling vs. qualitative interviews), and the actual OWF projects modeled (the LCoE dimensions applied). The research efforts indicate that the individual OpEx cost line items were furthermore aggregated and described at a somewhat high level due to the immaturity of the O&M part of the offshore wind industry [40,42,70]. This should be contrasted and compared to other industries where more detailed and advanced phenomena can be analyzed [83,84].

Table 5. Cost line items in the logistics base case study (table developed based on [68]).

Contract Package	Additional Explanation	Minimum (GBP)	Maximum (GBP)	Logistics Factor
Onshore logistics	Shore base	400,000	700,000	100%
Workboats	Crew transfer vessels (CTVs)	2,000,000	3,000,000	100%
Aviation	Helicopters	1,500,000	3,000,000	100%
Crane barge services	Wind turbine installation vessels (WTIVs)	4,000,000	12,000,000	100%
Senior authorized person and marine co-ordination	On-site senior authorized person, monitoring of vessels/personnel 24/7	400,000	800,000	100%
Export cable surveys and repairs	Surveys, repairs, remotely operated vehicle (ROV), cable laying vessels (CLVs)	50,000	200,000	80%
Array cable surveys and repairs	Surveys, repairs, ROV, CLVs	200,000	500,000	80%
Scour and structural surveys	Divers, ROVs, surveys, inspections, repairs, survey vessels	200,000	600,000	80%
Foundation repairs	Paint, cleaning, grout, scour, repairs, lighting, vessels	100,000	600,000	80%
Offshore accommodation/base	Fixed platform or floating (floatel, service operation vessel [SOV])	10,000,000	20,000,000	70%
Lifting, climbing & safety equipment inspections	Inspections, drills, certified personnel, vessels	100,000	200,000	60%
Offshore substation maintenance	Inspections, services, repairs, paint, WTIVs, CTVs	50,000	200,000	40%
Administration	Financial reporting, public relations, procurement, inventory/HSSEQ/permits management, administration	200,000	500,000	20%
Onshore electrical	Skilled personnel, some logistics	20,000	100,000	10%
Turbine maintenance	Skilled personnel	2,000,000	8,000,000	0%
Turbine spare parts, components, consumables	Excl. storage and sourcing	3,000,000	6,000,000	0%
SCADA and condition monitoring	Data monitoring, analysis	400,000	800,000	0%
Daily weather forecasting	Wind, wave, atm pressure, precipitation, temperature, visibility	40,000	90,000	0%
		24,660,000.-	**57,290,000.-**	

Table 6. Missing line items in most detailed levelized cost of energy related cost study.

Line Item	Source	Included in This Study
Seabed rental	The Crown Estate 2012 [1]	No
Insurance	Prognos and Fichtner Group 2013 [2]	No, found to be able to explain about 25% of the delta from O&M to OpEx
Transmission charges	The Crown Estate 2012 [1]	No
Weather windows	May 2016 [46]	No
Lost revenue	Dinwoodie and McMillan 2013 [45]	No
Vessel availability	May 2016 [46]	No

In the eleven studies, each line item had been applied with a more or less thorough description within its source. From this description, a calculated proportion of the line item contents ("the logistics factor") was applied in a manner within which it was possible to attribute to the definition of offshore wind logistics [22]. For several line items of the base case (Table 5), the logistics factor is 100% as the descriptions of the line items can be fully correlated with logistics beyond any reasonable doubt. An example could be the line item "Senior authorized person and marine coordination". In other cases, the logistics factor attributed had to be less than 100% if the description of the line item was ambiguous or only partly inclusive of logistics tasks. "Administration" was one example of a somewhat ambiguous line item which—in most descriptions reviewed—contained logistics related costs such as "Inventory management for parts and consumables" as well as "Procurement activities". In the analysis using the logistics base case [68], a logistics factor of 20% has—as an example—been attributed to "Administration" and the logistics base case has both a minimum and a maximum cost range. Table 7 shows that if logistics is conservatively attributed only to those line items that can be classified with 100% accuracy as being logistics costs, logistics makes up a minimum of 17% of offshore wind OpEx costs if the lower cost ranges are applied. Conversely, if the logistics factor is applied to all line items at the higher cost ranges, logistics could make up as much as 31% of OpEx. These numbers happen to tally with previous qualitative research findings of Poulsen and Hasager [22] (p. 15) on this topic in the world's leading offshore wind operator.

Table 7. The logistics costs share range of operational expenditure.

Logistics Costs	Minimum Cost Levels	Maximum Cost Levels
Cost line items with a logistics factor of 100%	17%	17%
All cost line items with logistics factor applied	32%	31%

Even at the lowest share of close to 17% of OpEx costs excluding many cost line items (detailed in Table 6), logistics ought to be a focus area for any operator of OWFs. This should be the case when evaluating the overall project viability before the investment decision as well as later on when the OWF becomes operational and the warranty period ends.

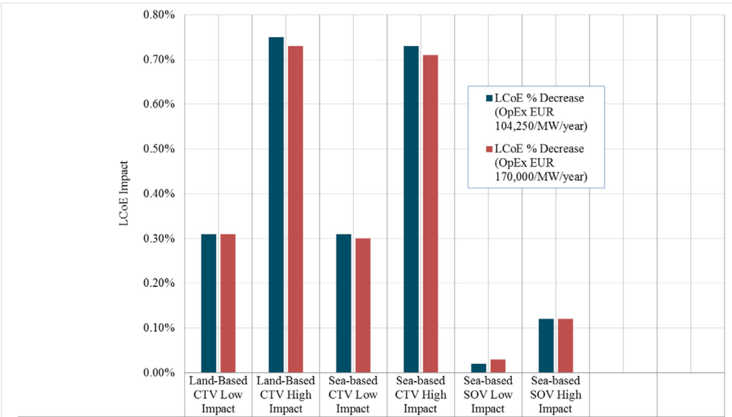
3.4. Calculated Savings from the Business Case on Working 24/7

Only one of the eleven studies related to LCoE mentioned working 24/7 as an area where costs may potentially be reduced [1] (p. 62). The results from producing the 24/7 business case indicate that by extending working hours to also include night time operations, a savings of approx. EUR 1.8 million per year can be realized. For a 400 MW near shore OWF with a land-based O&M set-up as modeled in the business case, this equals a reduction of just above 1% of LCoE.

The practitioner business case is based on a number of assumptions and the savings generated are based on using CTVs in a land-based or sea-based far offshore O&M set-up. The business case logic applied follows other studies that also utilize several sites with multiple dimensions applied [1,2]. No significant savings were found working 24/7 in the scenario modeled for a sea-based O&M set-up operating exclusively using SOVs. Therefore, the sea-based scenario was based on either a fixed accommodation platform set-up and/or stationary floatel set-up. Several assumptions were considered and subsequently ruled out in the business case as these criteria were deemed to be similar whether working daytime only or daytime and at night. These excluded criteria with a zero-sum impact on the business case comprised the overall OWF output yield measured in MW rating, the individual WTG yield rating in MW, number of WTG positions within the OWF, number of trips to WTGs during the summer season, and fuel consumption. Other assumptions have been entered as criteria in the 24/7 business case which effectively act as "levers" which—if altered—may impact the overall results of the business case:

- Number of vessels needed if working daytime (12/7) vs. also at night (24/7)
- Night-shift add-on salary payment for technicians
- Night shift add-on to cover on-shore support for monitoring purposes
- Months per year working 24/7
- OWF capacity factor
- Time for production stop per WTG as a result of faults/repair time
- Number of errors/faults/stoppages per wind turbine per month
- Price of electricity during and after subsidy period

A good example of a lever in the business case model is the OpEx costs per MW/year. The business case is built based on the Danish Anholt OWF and to some extent also the Danish Horns Reef I OWF. This has resulted in a near shore OWF modeling assumption with a land-based O&M strategy estimated at EUR 104,250.-/MW/year based on the focus group practitioner interviews and a linear view on OpEx costs included in the Megavind [3] 400 MW Anholt reference case. In the case study work forming part of this research, this number had been applied throughout the life-cycle of the OWF (the OWF life-cycle has in this case been set to be 25 years). However, following the analysis of the eleven government sponsored LCoE cost-related studies, a more realistic number for OpEx seems to be EUR 170,000.-/MW/year. In the land-based 24/7 CTV scenario, applying this higher and more realistic annual OpEx cost level affects the overall LCoE savings from 0.75% impact to 0.73% (see Figure 4). This can be explained as follows: When the annual OpEx lever is increased, the overall share of OpEx as a part of LCoE increases. Kept at a constant level in terms of savings impact in actual monetary values, the relative savings impact as a percentage of LCoE decreases. The business case model utilizes the Megavind [3] LCoE calculator tool methodology to compute the savings impact on LCoE. The Megavind [3] (p. 7) calculator tool offers four different LCoE calculation perspectives (developer costs pre-tax and post-tax, society costs pre-tax and post-tax) and a choice was made to work with the developer costs including tax, i.e., the Megavind "developer post-tax" scenario [3]. This scenario most accurately reflects the true project LCoE to be compared across OWF projects in different countries.

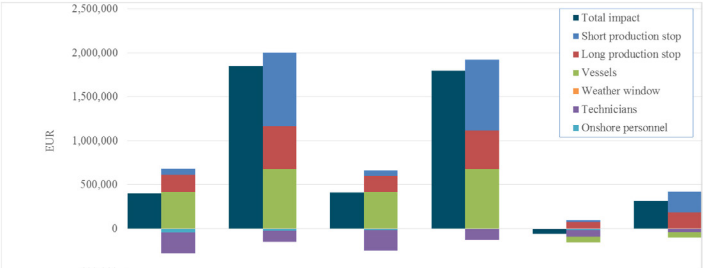


	Land-Based CTV Low Impact	Land-Based CTV High Impact	Sea-based CTV Low Impact	Sea-based CTV High Impact	Sea-based SOV Low Impact	Sea-based SOV High Impact
LCoE % Decrease (OpEx EUR 104,250/MW/year)	0.31%	0.75%	0.31%	0.73%	0.02%	0.12%
LCoE % Decrease (OpEx EUR 170,000/MW/year)	0.31%	0.73%	0.30%	0.71%	0.03%	0.12%

Figure 4. Selected business case impact on offshore wind farm levelized cost of energy.

Another example of a lever is the weather window which determines offshore WTG accessibility. The focus group work yielded a result of 15 days per month with no OWF accessibility for a land-based set-up using CTVs. The focus group work furthermore yielded a perception among the subject matter experts that the weather is less adverse during night time. This hypothesis was tested based on wave data from Fino-1 and Sylt, courtesy BSH and the MARNET network, respectively. The significant wave height data was subjected to a statistical test (*t*-test) and it was concluded that there is no significant difference between daytime and night wave heights. As this is very OWF site specific, the business case was left with this lever open to adjustment based on a site-specific analysis of weather data observations. In this respect, it is worth noting that it is possible to better exploit WTG accessibility weather windows if the work continues 24/7.

The business case model for 24/7 operates with three scenarios that each have a low and high impact sensitivity analysis which provide output ranges per scenario respectively. Figure 5 outlines the key outcomes of the business case cost savings components where the high impact ranges are primarily a result of lower costs for technicians and higher subsidy prices per MWh used for early OWFs (in this case Burbo Bank Extension based on www.4coffshore.com [85] contrasted against recent DONG Energy Wind Power [75] Dutch award subsidy price including a higher number of errors per WTG per month and long production stops).



	Land-Based CTV Low Impact		Land-Based CTV High Impact		Sea-Based CTV Low Impact		Sea-Based CTV High Impact		Sea-Based SOV Low Impact		Sea-Based SOV High Impact	
Total impact	399431		1850510		409631		1794961		-61571		315873	
Short production stop		68917		838948		66626		811056		19376		235865
Long production stop		200104		487186		180538		439550		75253		183215
Vessels		415188		674520		415188		674520		-61160		-61160
Weather window		0		0		0		0		0		0
Technicians		-236520		-126144		-236520		-126144		-78840		-42048
Onshore personnel		-48257		-24000		-16200		-4020		-16200		0

Figure 5. Business case outcome for working 12/7 (left columns, daytime only) and 24/7 (right columns, daytime and at night) for three cases (land-based CTV, sea-based CTV and sea-based SOV) for low and high impact estimates.

The scenarios and low/high impact sensitivities do not change in terms of absolute cost savings values as the lever with annual OpEx/MW cost is altered as the analysis is moved from near shore to far offshore. However, OpEx as such becomes higher within the Megavind [3] calculator tool as DevEx, CapEx, and AbEx are kept constant. With a higher annual OpEx for the far offshore output, this results in OpEx growing as a share of LCoE compared to the land-based O&M example for near shore Danish OWFs like Anholt and Horns Reef III. Conversely, the production as well as number of errors per WTG per month are parameters which could be expected to be higher for a far offshore OWF because of higher wind speeds and the cost savings impact of working 24/7 would therefore be further amplified.

3.5. Why Companies Chose to Join the Industry-Wide Cost Reduction Initiative

A particular area of interest for this research design was to determine why companies are interested in joining these industry wide cost reduction initiatives. The empirical evidence collected centered around 3 major areas:

- The larger companies attended with senior managers from staff functions working exclusively to reduce LCoE. These larger companies were interested in working with other large companies to steer cost saving initiatives. Simultaneously, the larger companies wished to work with SMEs to benefit from a more agile, lean, and innovative approach to the market. The larger companies felt that the combination of other large companies with SMEs generated a mix of companies useful for the quest towards lowering the costs for offshore wind.

- The SMEs attended with top managers who at times brought practitioners with hands-on experience to the focus group meetings and subject matter expert interviews. In addition, the SME top managers often had hands-on subject matter expert experience themselves. The SMEs used the cost reduction initiative to try to impact the industry overall because the offshore wind industry is very immature and therefore driven by different operators on a project-by-project basis. The SMEs were individually not significant enough to impact a large group of operators and hoped to be able to get close to decision makers from larger companies in a more informal setting.
- Common to large companies and SMEs was the wish to be able to work together as a larger group across the offshore wind industry to create truly useful cost-out opportunities which no individual company would have otherwise been able to develop or implement on their own. A sense of unity and urgency existed in the different working group meetings which resulted in passionate discussions and innovative dialogue. No single company had this much O&M logistics experience amongst their ranks of employees and the diversity in the working group composition yielded a very unique foundation to create useful business cases to be applied by all in an open access manner.

The sheer opportunity to meet new customers and suppliers respectively was a clear undeclared driver for some participants. As work progressed and the OE CRF became more widely known, more participants voiced interest in becoming part of the work which provided for better opportunities academically to triangulate data points used in the business cases and thereby strengthen the validity of the results presented.

4. Discussion

The key finding of the part of the research efforts focused on the eleven LCoE cost-related studies is that what constitutes the OpEx part of LCoE is not very clearly defined or agreed. Because of the inconsistencies in both unit of analysis and key assumptions making up the different LCoE calculation methods, the variance of the OpEx share of LCoE is significant. When the O&M portion of OpEx was subsequently analyzed, it was again found that definitions and assumptions varied extensively in terms of how each of the eleven cost studies was put together. As the area of logistics as a cost element within the annual O&M expenditure was further understood, a significant variance was again encountered in terms of the individual line items that make up the total logistics costs as part of O&M. For the logistics portion, supposedly easy-to-compare areas like costs of vessels, helicopters, and ports displayed great variance within the eleven reports reviewed.

These findings correspond to the separate case study performed within the organization of the world's largest offshore wind operator [22] and that research study indicates the root cause being that logistics is an area which is not yet subjected to proper organizational focus within offshore wind. The detailed line-item cost breakdowns of the government sponsored LCoE cost-related studies are immaturely applied and uncoordinated across different studies which ultimately make the studies impossible to compare.

4.1. Government Sponsored Studies—Not Useful for Practitioner Implementation

The first research question set out to understand whether practitioners can understand and implement the government sponsored LCoE cost-related studies. When the case study findings are combined with the analysis of the eleven LCoE cost-related studies and reports, the emerging pattern is that the government sponsored LCoE studies are used at policy level to drive strategic thinking and work with industry to lower the future costs for offshore wind energy. This work is contrasted within the case study part of this research where industry practitioners working ashore devised specific LCoE cost-out measures for their site colleagues working offshore to realize and implement immediately.

From the analysis, the largely government sponsored LCoE cost-related studies and reports are primarily driven by a strong desire at policy level to avoid subsidies for wind energy and to ensure that offshore wind is competitive with other energy forms. In the case study, the large OWF operators ultimately in control of the offshore wind projects took part as well as the SMEs serving the individual OWF projects and it was observed how their respective involvement and motivations varied considerably. At the policy level, the ability to utilize the government sponsored LCoE cost-related studies to generate ideas for cost savings opportunities supported by the proper research and analysis are the key success factors utilized to determine forward trajectories of offshore wind diffusion. At the execution level, the OWF operators attended the practitioner case study to ensure that they could benefit from any possible cost savings ideas generated whereas the SMEs attended mainly to be able to speak to the operators in a more united manner, with a stronger voice.

It was not easy to produce a clear path from the largely government sponsored LCoE cost-related studies and reports at policy level to the case study work with industry practitioners to create practical cost-out initiatives. This was mainly because the industry practitioners ultimately focused on the cost models of the operators involved in the case study, not government policy/industry strategy matters, as being the driving force behind the need for LCoE reductions. As such, the largely government sponsored LCoE cost-related studies were not directly tied to the work performed by practitioners in the cost reduction case study.

As a final caveat, it is worth mentioning that if applying the most extreme OpEx estimate of EUR 600,000.- year in the higher range applied of the study [34], it would, according to the calculations forming part of this research, not be possible for the OWF to be profitable even under the highest subsidy schemes seen hitherto.

4.2. Cultural Barriers between Cost-Out Initiative Planning and Implementation

The second research question pertained to the interest in understanding whether cultural differences exist between the players involved in devising the paths for cost reduction and those responsible for the actual cost-out implementation. Here, the first major finding had to do with the different types of stake-holders. A pattern of several distinctively different levels of cost reduction efforts therefore emerged from the research in terms of stake-holders and objectives:

- Government (policy/industry strategy level);
- Operator (OWF portfolio and operator specific cost model/experience);
- Shore based execution personnel (defining the cost reduction initiatives);
- Site personnel located either in offices ashore or offshore in the harsh marine environment and whether their background, as well as experience, were onshore or offshore based (responsible to implement and execute the cost-out initiatives such as working at night).

In the largely government sponsored LCoE cost-related studies forming part of the research, the involvement of major consulting firms to lead the analysis portion, perform the research, and engage with the industry practitioners was integral to the contents produced. In the case study, 77% of the participants were from the top management and middle management layers of the companies whereas only 23% were from the office execution/offshore site layers tasked to actually implement the cost-out business cases. In the government sponsored LCoE cost-related studies, the consultancies with government backing gained access to a broad base of industry stake-holders representing the entire offshore wind market in a very adequate, balanced, and justifiable manner. Conversely, the case study participant roster contained four participants from three operator organizations and three participants from a major OEM meaning that 74% of the case study participants were from SME organizations. Within the operators and OEM segment, the case study participants were comprised exclusively of shore based personnel with an onshore background. Within the SME participant segment, 80% of the case study participants had an offshore background.

In the government sponsored LCoE cost-related studies, it was determined that most of the directly involved participants appear to be office based and this was similar in the practitioner case study forming part of this research. The execution layer of the organizations as well as the responsible parties at e.g., port sites and offshore maritime operations are not well represented in the analytical phase of planning the cost-out measures to be implemented.

In the case study, a significant cultural barrier was experienced as the difference between being shore based working from a secure desk location in an office with theoretical concepts and ideas is very different from being deployed into an offshore site. When working offshore with harsh weather conditions and health/safety considerations to be taken into account as part of the daily operations, the background as well as experience from having worked offshore in the past was very important and could be directly contrasted to that of onshore personnel such as technicians working offshore.

4.3. Offshore Wind Logistics Operations and Maintenance Savings Are Achievable

The third and last research question pertained to whether it would be possible to create practically implementable cost-out initiatives by analyzing a particular life-cycle phase in much more detail and by joining a practitioner work effort as a case study. This research substantiates that cost reductions in the offshore wind O&M life-cycle phase are indeed possible through cost-out initiatives. This is evidenced by the work with business cases in the case study described in detail in this paper. The lean initiative, the asset sharing business case, the pre-planning of parts/tools/consumables, as well as the 24/7 business case presented in more depth are all examples of practical and short-term cost-out initiatives that can be applied by the operators and/or OEMs together with the SME suppliers serving them.

Separately, cost reductions may also be achieved through innovation as evidenced by the separate case study about offshore wind logistics innovation with DONG Energy Wind Power [22]. It is, however, critical that the organization driving the innovation has a certain size and mass to be able to accommodate and also test the innovation cases being worked with. And here, the offshore wind innovation conundrum exists in terms of wanting innovation on the one hand versus wishing to reduce risk by only using fully tested and proven concepts on the other hand [22]. Significant differences exist in terms of supply chain composition, readiness, and set-up between Europe and Asia [86].

To get offshore wind to be competitive with other energy forms, the paths of practically implementable cost-out initiatives and innovation need to be combined and logistics would be an ideal demonstration ground.

4.4. Application of the Studies Was Possible for Several of the Business Cases

Individually, each LCoE cost-related study can be very useful. In the practitioner case study, the selected business case pertaining to extending the operational working hours offshore at sea to 24/7, the Megavind [3] LCoE calculator tool was successfully applied and it was found to be appropriate.

However, for one of the more conceptual business cases forming part of the case study such as creating a vision for the future of O&M logistics in 2025, the Megavind LCoE calculator tool [3] would not be similarly appropriate.

Most of the case study business cases were fairly sophisticated in nature and based on a learning curve in Europe of offshore wind dating back to 1991. Many of the findings should also be applicable in Asia where especially the fastest growing market of China has cited O&M and logistics as significant gaps that need to be filled [86]. However, O&M logistics for floating wind turbines have not been considered within the case study performed [87].

4.5. Case Study Findings about Operations and Maintenance Logistics Strategies

One of the three goals identified as a justification for joining the practitioner cost reduction case study was to learn about offshore wind O&M logistics. Several dimensions emerged from the analysis of the eleven studies and the case study efforts as ***structural considerations*** for O&M logistics strategy going forward.

The ***distance from shore*** to the OWF would determine if a shore-based or sea-based O&M set-up would be required. These decisions would again have significant implications on the shipping and logistics strategy and thereby the costs involved.

The degree to which OWF operators are able to ***obtain data*** from the OWF in general and each WTG position in particular to use for preventive maintenance efforts would also have an impact on the shipping and logistics strategy. Advanced utilization of condition monitoring and structural health monitoring software and kits [46] would create an environment of more precisely pre-planned O&M activities. If done correctly, preventive maintenance of main components such as the generator or gearbox could avoid significant costs for jack-up vessels with cranes to have to be deployed on short notice for major repairs. The operators, who were part of the practitioner case study, expressed that whereas they were generally aware of the existence of these softwares and kits, their access was via the WTG OEMs which means that in practice, several different systems and kits operate in parallel because operators generally utilize WTGs from more OEMs. Each OEM would continuously upgrade their solutions with a strong focus on protecting intellectual property rights and the operators would constantly try to gain full access to already purchased software, especially towards the end of the warranty period. Reviews of new technology and kits were cited as constantly being performed by the operators and for existing and future OWFs, a clear business case proof had to exist in order to justify investments on the part of the operators. For such business case proofs, logistics was cited to play a key role for work performed subsea, below water, as well as topside, above the waterline, due to the high overall cost share attributed to offshore wind logistics.

Different supply chains exist for O&M activities which can be planned long in advance compared to scenarios where an offshore asset ceases to operate and needs to be diagnozed and subsequently repaired in an ad-hoc and unplanned manner. In the pre-planned scenario, efficiencies can be built in through efforts such as lean. When an asset breaks down and diagnostics as well as subsequent repairs need to happen quickly, the supply chain is mobilized swiftly and in an ad-hoc manner. This causes the supply chain to be more expensive to deploy as the deployment is often bespoke and without economies of scale.

Whether the preventive maintenance or the needed repairs take place ***topside or subsea*** also greatly affect the shipping and logistics strategy. Implications, in terms of deployment of vessels carrying divers and remotely operated submarines with cameras and repair capabilities, need to be considered for subsea operations on foundations and cables. This is contrasted to bringing technicians, parts, tools, and consumables to wind turbines and/or offshore sub-stations for preventive maintenance and/or repair work above water where the technicians and equipment are transferred from vessels to the OWF asset.

Finally, the implications of a break-down or damages incurred to an export cable and/or a sub-station were in the research efforts found to be comparatively more severe and thus warrant a different shipping/logistics response. In such break-down cases, damages could cause an ***entire OWF asset to be unavailable*** which could often be very costly for the operator if the downtime is over an extensive period of time due to e.g., a cable damage which needs to be located. Situations where the entire OWF asset is down may be contrasted and compared to a break-down of an individual WTG unit within an OWF which is also critical but with very different cost implications for the operator.

5. Conclusions

This research has provided new knowledge about the learning curve involved in order to produce the largely government sponsored LCoE cost-related studies within the offshore wind industry. It was found that this learning curve has been steep over the last ten years as evidenced by the analysis of eleven extensive studies. As part of the research presented in this paper, OpEx as a single component of the LCoE calculation was found to be able to vary by a factor of 9.5×. When applied to a commonly accepted LCoE calculator tool for offshore wind [3], this high variance resulted in creating a range of 13%–57% for the OpEx portion of LCoE in the low/high scenarios presented in this paper. It would therefore seem prudent for a standardized methodology for cost modeling to now be implemented, for example in line with the work done by Strategic Energy Technologies Information System [88]. Alternatively, the use of LCoE as a way to evaluate progress of offshore wind compared to other industries would seem to be futile.

As a phenomenon, LCoE is already being subjected to harsh criticism for not being an accurate measure to compare energy forms. For wind, this is argued to be of particular relevance as wind is intermittent in nature and therefore non-dispatchable from a grid perspective [89]. Dispatchable energy forms are more valuable to the overall grid balancing and this is argued to be a critical flaw of the LCoE measure itself. Other ways to compare energy forms have been proposed e.g., by Evans et al. [27], Ueckerdt et al. [28] and Dale [90]. LCoE in combination with Levelized Avoided Cost of Energy is being proposed by the United States (US) Energy Information Agency [91] as a new methodology to make evaluations more holistically for an area, region, or country [92].

For now, the analysis of OpEx and O&M costs within offshore wind presented in this paper reveals that different assumptions have been applied to the different LCoE studies by different countries and that these assumptions have changed as the wind energy technology has evolved over time. If the main objective at policy level of producing LCoE cost-related studies is to create an opportunity to benchmark costs at a certain point in time compared to the future, as well as, compare the costs of offshore wind to other energy forms, the findings presented in this paper call for further research efforts which are critically needed in order to devise solutions on how to apply the assumptions of the cost studies down to a line-item cost level. This was evidenced by the work efforts rendered as part of this research to exemplify our findings within the specific areas of shipping, logistics, and port line item costs as analyzed in this research.

The work presented in this paper from the case study with industry practitioners on practically feasibly and immediately implementable cost-out initiatives in the form of business cases has been very useful in terms of actively being part of the process of understanding how to contrast the often very policy level macro studies of LCoE cost-related issues sponsored by governments to real-life practitioner cost reduction pressures. Working intensively at the practitioner level with action research, it became apparent that further research should be undertaken to further study the impact of the key structural dimensions identified in this paper (Section 4.5) to have a major influence on O&M logistics strategy going forward.

It became evident from this research that the cultural gap between shore-based personnel and the maritime personnel, often working offshore at sea and being ultimately responsible for the majority of the actual, practical cost-out implementation work, is a critical area in need of further research (Section 4.2). This cultural gap could in fact be an important barrier to the actual realization of cost savings as opposed to desktop efforts to identify, simulate, and track more theoretical initiatives organized without a true ability on the part of the operators and supporting companies to determine the true bookkeeping impact.

Finally, the work with the very specific 24/7 cost-out business case example yielded an opportunity to compare this not only to the LCoE cost studies and reports but also to the separate, prior case study on offshore wind logistics and logistics innovation [22]. Whereas the goals and objectives of logistics cost-out (the topic of this paper) and logistics innovation (the topic of the former paper [22]) are somewhat similar in terms of the wish to bring forward tangible cost reductions, the methodology and processes would need further research as well. The two paths to cost reductions for offshore wind are metaphorically as different as night and day. And working both night and day is exactly what is required from the offshore personnel having to work 24/7 should the key business case of this paper be implemented by OWF operators going forward.

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Abbreviations

The following abbreviations are used in this manuscript:

AbEx	Abandonment expenditure, decommissioning cost
AEP	Annual energy production
Avg	Average
CapEx	Capital expenditure
CRF	Cost reduction forum
CLV	Cable laying vessel
CTV	Crew transfer vessel
DevEx	Development Expenditure
EU	European Union
EUR	Euro
EPCi	Engineering, procurement, construction, and installation companies
Floatel	Floating hotel vessel
GW	Giga-Watt
HSSEQ	Health, safety, security, environmental, and quality
I&C	The installation and commissioning life-cycle phase of an offshore wind farm
IEA	International Energy Agency
IMR	Inspection, maintenance, and repairs
IRM	Inspection, repair, and maintenance
IRMR	Inspection, repair, maintenance, and replacement
LCoE	Levelized cost of energy
M&R	Maintenance and repair, maintenance and renewal, maintenance and replacement, maintenance and rehabilitation
Max	Maximum
Min	Minimum
MW	mega-Watt
MWh	Mega-Watt hours
O&G	Oil and gas
O&M	Operations and maintenance
OE	Offshoreenergy.dk
OEM	Original equipment manufacturer
OpEx	Operational expenditure
OWF	Offshore wind farm
ROV	Remotely operated vehicle
SME	Small to medium sized enterprise
SOV	Service operations vessel
TPM	Total productive maintenance

UK	United Kingdom
US	United States of America
USD	United States Dollars
WACC	Weighted average cost of capital
WTIV	Wind turbine installation vessel
WTG	Wind turbine generator

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PAPER D: THE (R)EVOLUTION OF CHINA: OFFSHORE WIND DIFFUSION

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The (R)evolution of China: Offshore Wind Diffusion

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Abstract: This research presents an industry level gap analysis for Chinese offshore wind, which serves as a way to illuminate how China may fast track industry evolution. The research findings provide insight into how the Chinese government strongly and systematically decrees state-owned Chinese firms to expand into overseas markets to speed up learning efforts. Insights are offered regarding the nation-level strategic plans and institutional support policies mobilized by China in order to be able to conquer market shares internationally by building a strong home market and then facilitating an end-to-end and fully financed export solution. This is interesting in itself and in particular so because it now also includes complex billion-dollar megaprojects such as turnkey offshore wind farm assets with an expected lifespan of 30+ years. Research findings are provided on how European and Chinese firms may successfully forge long-term alliances also for future Chinese wind energy export projects. Examples of past efforts of collaboration not yielding desired results have been included as well. At policy level, recommendations are provided on how the evolution of the Chinese offshore wind power industry can be fast-tracked to mirror the revolutionary pace, volume, and velocity which the Chinese onshore wind power industry has mustered.

Keywords: China; offshore wind; gap analysis; industry maturity; mergers & acquisitions; central state-owned enterprises; turnkey project export; industry evolution; industry life-cycles

1. Introduction

From an industry evolution and maturity perspective, the Chinese ***onshore wind*** market had developed with revolutionary pace based on policy stimulus from the Chinese government [1]. However, challenges in terms of the operations of the onshore assets had started to emerge [2]. By the end of 2015, this phenomenon of operational challenges deriving from the onshore wind turbine generator (WTG) technological trajectory of Chinese wind turbine original equipment manufacturers (OEMs), as well as a different operations and maintenance (O&M) philosophy, was being debated openly at conferences and industry events [3] as onshore asset performance negatively impacted profitability of large wind farm operators. This open debate seemed to be somewhat at odds with the general culture of trying to avoid admitting to mistakes and 'losing face' which indicates how significant the operational and ensuing financial challenges are.

Similarly, ***offshore wind*** in China was originally slated to move forward with an equally revolutionary pace. The question as to whether this was indeed realistic was raised by very few scholars [4,5]. General wind energy policy settings aimed mainly at the onshore industry were organized both centrally [1,6] and subsequently for offshore wind also with opportunities to top up the central subsidy schemes regionally at a provincial level [3]. However, the offshore wind industry did not evolve as quickly as expected and not in line with targets outlined in the official Five

Year Plans. As of the end of 2016, a total of 1.6 giga-Watt (GW) capacity had been grid connected in China [7] compared to original targets of 5 GW by 2015 and 30 GW by 2020 [4,5].

In Europe, both the onshore and offshore wind industries have developed technologically over a longer time trajectory than what has been the case in China. For onshore wind, the Danish government decided to support the emergence of the industry in 1979 [8,9] and as of the end of 2016, Europe enjoyed 148.7 GW of grid connected onshore wind capacity. Conversely for offshore wind, ministerial reports from 1983 and 1988 on renewable energy in a Danish context ultimately led to the erection of the world's first offshore wind farm (OWF) in 1991, Vindeby [10]. The experiences with offshore wind from the Vindeby OWF and its early successors such as Tunø Knob and Horns Reef 1 have displayed significant differences in the technological trajectory of WTGs erected onshore compared to those erected offshore [3,10] as well as 'learning the hard way' differences in cost composition [11–13]. From an industry evolution perspective, it is important to note that by now, Europe has witnessed a full cradle-to-grave evolutionary path cycle within offshore wind as evidenced by the Vindeby OWF as this has just been decommissioned during 2017 [14]. The Vindeby OWF was comprised of 11 WTGs each with a capacity of 0.45 mega-Watt (MW) and the OWF was located between 1.5 and 3 km from shore in Lolland, Denmark. Over the 25-year period since the grid connection of the Vindeby OWF in 1991, a total of 12.6 GW of offshore wind had been erected and grid connected in Europe [15] with OWFs becoming GW-sized in terms of capacity while moving further from shore into deeper waters [12,13,16]. By 2024 and 2025, the first OWFs free of government subsidies will have been constructed and grid connected in Germany [17,18]. This is a result of the cost reduction path started in 2012 by the United Kingdom government and the world's leading offshore wind farm operator, Ørsted, formerly DONG Energy Wind Power [12,19].

In order to pick up speed in terms of offshore wind diffusion and mirror the revolutionary pace of Chinese onshore wind energy diffusion, it could be relevant for China to look towards European offshore wind constituencies in terms of experiences, knowledge, and skills needed to fast-track the industrial evolution. However, memories of the introduction of local content rules [1] to the Chinese onshore wind market are—as presented in this research—still on the forefront of the historical context viewed by some European firms participating in the early part of the onshore wind industrial revolution in China.

The next section will present our research design, the key academic terms of reference (industry maturity, state-owned enterprises, and mergers and acquisitions), and the background for our case study. Section 3 will present the method applied in more detail. Section 4 will detail the findings of the analysis and in Section 5 we will present the results of the research. In Section 6, we discuss the results of our findings. Section 7 concludes and provides suggestions to guide the work efforts rendered by other researchers.

2. Research Objectives, Key Academic Terms, and Case Study Introduction

The specific contextual setting used as the inroads to empirical data collection in our case study is based on the prior knowledge and experience of the research team which is comprised of the areas of shipping, logistics, and supply chain management (SCM), hereinafter jointly referred to as 'logistics' or jointly 'shipping and logistics', depending on the context.

2.1. Research Objectives

With this as a backdrop, our China offshore wind case study was initiated in 2013 and originally set out to analyze the following three research questions regarding the offshore wind industry in China:

(1) Are the 12th Five Year Plan offshore wind targets of 5 GW and 30 GW of offshore wind power in operation realistically implementable by the prescribed plan deadlines of 2015 and 2020 respectively?
(2) With the onshore (r)evolution of wind energy in China, why has the evolution of offshore wind been seemingly a lot slower?

(3) What role, if any, does logistics, as defined by Poulsen and Hasager [12], play in this slower offshore wind diffusion in China?

A number of ***key academic terms*** are important to define in order to set the scene for the research. These academic terms will be presented in Sections 2.2–2.4 while an introduction to our case study will follow immediately thereafter in Section 2.5.

2.2. Industry Maturity

According to several extensive reviews of available academic literature, the metaphor of life cycles was born in the 1950s within the marketing field of study at a product and services level and was referred to in general as the product life cycle (PLC) theory stream [20,21]. The notion of PLC was that a product or service generally experiences four phases of development which evolve over time as the product matures and these four phases were [20–22]:

(1) embryonic
(2) growth
(3) mature, and ultimately
(4) decline.

The PLC theory is generally understood within management literature to be the antecedent of what is now commonly referred to as the industry life cycle (ILC) theory stream [20,23,24] which uses the same four phases as PLC theory to describe the trajectory of evolution of an industry, the business ecosystem lifecycle, or the trajectory of ***industry maturity***. Although described by scholars much earlier according to Andersen et al. [22], the seminal work of innovation scholars Abernathy and Utterback [23] is for the most part considered the foundation of the ILC theory stream.

Interestingly, the prior work of the same authors [25] identified that process innovation by a firm's suppliers signifies product maturity, which means that product innovation precedes process innovation. The underlying industry maturity related taxonomy is that products and services are usually sold to customers in a market place where the market and customers signify demand and the supply is provided by an industry which again is comprised of different firms [21,22]. Whereas the relation between the market and industry is well described in literature in terms of market mechanics, the co-evolution of industry and firms has long been discussed at both a regional/national macro level, at an industry meso level, and at a firm micro level [22]. Essentially a discussion of whether the industry shapes firms or firms shape the industry, the ILC literature works at several levels:

- First, the ILC theory stream deals with several attributes and groupings of characteristics of the industry or firms therein which can be observed to change over time as the industry evolves through the life cycle phases. Findings from literature have been grouped in several literature reviews [20,21,24] with the general objective that observations may then determine where in the ILC trajectory an industry is. As an example, Jensen and Thoms [21] define five groupings of characteristics with a total of 17 different sub-attributes that evolve and change over the life cycle of an industry based on a literature review that also includes a detailed review of the two prior literature reviews [20,24].
- Second, the ILC theory stream is also concerned with how one ILC phase ends to give way to the next phase in order for firms to understand when for example the growth phase ends and the maturity phase commences for example based on the emergence of a dominant design [26]. General opinions on the behaviour of different industries have been formed on this topic by reviewing literature [20] with the result that certain industry growth rates imply the shift from e.g., the entrepreneurial regime/embryonic ILC phase to the growth ILC phase. As the ILC theory stream is in itself still in the process of maturing [20,24], terminology pertaining to the different ILC phases is somewhat ambiguous and the timing of some critical ILC events like 'the shake-out' is sometimes noted to be taking place in different ILC phases [21].

- Third, ILC literature is concerned with how firms can be successful in an industry and how an industry survives or declines and ultimately dies out. Several events in the ILC phases are of interest such as entry timing of firms/first mover advantage, survival of the shake-out, and the emergence of a dominant design [21]. In addition, other factors such as the technological trajectory, prior experience, and prior industry affiliation [22] are also understood to be of importance. From the ILC literature it is clear that not all events happen across all industries. For example, a shake-out may not occur because of situations, such as spin-offs or new niches emerging [21] or the formation of sub-markets [27]. Similarly, the industry may stay in the mature ILC phase and never enter the decline phase by virtue of events such as dematurity, renewal, and re-cycles which counter-act the standard ILC trajectory pattern [21,22].

Based on the three levels at which the ILC body of literature works, industry evolution, industry maturity, and the movement of an industry and the firms within the industry along the ILC trajectory are important frameworks to consider when wind energy is the topic of discussion. The wind industry is generally considered to be less industrialized compared to e.g., the automotive industry, truck assembly, or airplane assembly [28,29], the construction industry [30–32], the oil and gas industry [33], similar turn-key project industries [34,35], and one-of-a-kind construction projects [34,36].

Furthermore, differences in industry maturity between the onshore and offshore wind markets exist with the offshore wind industry generally understood to be less evolved than onshore wind [3,11]. As such, the strategic focus of the wind industry and its constituencies is likely to switch from product innovation among the key firm constituencies to process optimization by suppliers [25,37], such as the shipping and logistics firms serving the wind industry, in the coming years. To drive this change and trajectory of industry maturity, platform leadership is required [38,39] along with the emergence of a dominant design [26].

2.3. Chinese State-Owned Enterprises

In China, ***state-owned enterprises*** (SOEs) make up a significant part of the economy. These types of Chinese firms have been subject to much research such as the overall government reform of the SOEs [40,41], public reporting/disclosures [42], and corporate governance [43].

Usually owned by the local governments [44] in the different provinces/municipalities and referred to as local SOEs (LSOEs), many comparisons have been made between SOEs and non-communist owned firms in OECD countries on topics as diverse as initial public offering (IPO) stock performance [45], due diligence and accounting challenges [46], executive compensation [47], and corporate social responsibility reporting [42].

A number of approx. 100 very large and/or nationally important SOEs are managed/overseen centrally by the State-owned Assets Supervision and Administration Commission of the State Council (SASAC) at a central government level and these firms are referred to as the Central SOEs (CSOEs). SASAC and CSOEs are defined as well as discussed in a number of papers as these papers review topics, such as firm ownership structure [43], stock market listing [45], financial performance [48], audit quality [49], and social as well as environmental reporting [42].

Many papers dealing with SASAC and CSOEs cite that SASAC policies are first implemented by CSOEs and in many cases subsequently adopted by the stock exchanges and LSOEs to a varying degree depending on provincial adaptation and individual firm situations [42,43,49]. As we proceed to review the Chinese wind industry, understanding the SOE set-up in China is an important prerequisite both at a national and province/local level.

2.4. Mergers and Acqusitions

Within the strategic management literature [50–52], growth and value creation within firms are examples of strategies that may be planned and implemented either organically or through ***mergers and acquisitions*** (M&A).

In terms of a definition of M&A, many exist and it is generally understood that a 'merger' commonly implies a combination of two firms that are relatively equal whereas an 'acquisition' is a type of merger where one firm buys a controlling interest in another [53]. Different transaction types exist including joint-ventures (JVs), Public-Private Partnership (PPP) JV types, leveraged buyouts, spin-offs, and different kinds of partial or full acquisitions such as asset purchase transactions or share purchase agreements [54].

In terms of key terminology and language of the M&A field, a bidder firm is interested in a target firm and a deal between the two firms is the event that marks that M&A transaction is successfully consummated [55]. Both bidders and targets may be privately held, including family owned firms, or publicly traded and the transacting party could be the firm itself or subsidiaries [55]. The acquirer may choose to pay an acquisition premium for different reasons and here, revenue and cost related synergies may play an important role in terms of target firm valuation [56]. Payment methods include payments in cash, stock, and various kinds of bank related financing [55].

The M&A process is complex and can generally be segmented into what happens before and after the M&A transaction itself [57]. Phenomena such as deal antecedents (why acquire?), drivers behind the transaction (what is the strategy?), and the decision making process leading to the deal (how did the deal come about?) are generally viewed by academia on the one hand. On the other hand, the consequences of the deal, as a result of the integration, are generally seen by academic scholars as the outcome post deal transaction, including performance and value distribution [55,58]. It is, however, generally understood by scholars and practitioners alike that the M&A process can advantageously be sub-divided into several phases.

The M&A process is complex because it starts at the level of a firm's strategic goals, both from the perspective of the acquirer and the to-be-acquired firm [50,51]. The subsequent M&A process steps include identifying and selecting the target(s) on the part of the bidder as well as deciding to sell on the part of the target, the negotiation process, due diligence, deal announcement, deal completion, post-merger integration (PMI), performance measurement, and hopefully value creation [53]. M&A process complexity is generally understood within academia to intensify in cross-border M&A deals, where the target is located in a different country than the country of the acquirer's head office, compared to 'within-country' or domestic M&A transactions [53,55]. Much academic literature has traditionally been quantitative in nature and has to a large extent concentrated on M&A activity of publicly traded firms in the United States (US) mainly because M&A activity has historically been more intense in the US and also because of data availability [55].

In the US, the size of the country and characteristics of the different M&A waves [55,59] has meant that much M&A activity has traditionally been focused on domestic deals within the country and here, the M&A process has been broadly accepted based on Reed and Lajoux [54], i.e.,:

(1) planning and finding,
(2) valuation and pricing,
(3) financing and refinancing,
(4) structuring M&A/buyout transactions,
(5) the due diligence inquiry,
(6) pension, labour, and compensation concerns,
(7) negotiation of the letter of intent and the acquisition agreement,
(8) deal closing, and
(9) PMI.

Conversely, this seminal work of Reed and Lajoux [54], in a US setting, attributed only a small focus to M&A transactions with an international aspect, i.e., cross-border M&A deals.

According to Zhu and Zhu [53], motivations behind M&A deals can be to integrate the two firms to create value and increase performance of the combined entity going forward (strategic M&A deals) or for a financial investor to acquire a target and subsequently sell the acquired firm at a higher price (financial M&A deals). From a value perspective, most M&A transactions create an uneven distribution of the value generated where target firms obtain the largest share of the value and it is largely understood within academia that the acquirers rarely create value from M&A transactions [55]. On the part of target firms, strategic management options for value creation often include the choice of a stock market listing or going through the process of finding a strategic buyer or financial investor. Whereas separate bodies of literature exist on IPOs and M&A respectively within academia, the two literature streams unfortunately seldom merge or cross-reference [55]. On the part of acquirers, performance is generally measured using defined terms such as cumulative abnormal returns as measured by increases seen over time in the stock prices of the acquiring firm after the deal announcement event or by calculating the acquisition premium paid [55,58]. In their seminal work, Haspeslagh and Jemison [57] suggested that it is often decisions in the pre-acquisition stage that cause the many negative post-merger outcomes. According to the extensive reviews of Haleblian et al. [55] and Zhu and Zhu [53], scientists increasingly focus on researching the value creating conditions that make up the minor portion of deals where value is created for acquirers.

Due to the strategic importance put on different kinds of M&A initiatives orchestrated by the Chinese government at an industry level especially using the CSOEs as the execution instruments, having a general understanding of M&A is therefore important as we review how China is approaching the wind energy industry in the offshore segment. This is contrasted and correlated with the approach China took at an earlier stage for onshore wind.

2.5. China Offshore Wind Case Study Introduction

This research is very timely and coincides with two other major studies of the Chinese wind market, namely those of Kirkegaard [2] for onshore wind and Korsnes [5] for offshore wind. When it comes to Asian case studies, especially the use of an existing personal network within the shipping and logistics industry as a 'bridge' into the right people has been very useful also for this research. In addition, the network of friendly people from other industry segments has been used effectively to create an initial wind energy industry 'platform' of relationships to operate from. These people from other industry segments were effectively acting as similar 'bridges' to get to the right people within the wind energy shipping/logistics/SCM vertical. From this initial 'platform', additional 'bridges' then had been created in order to have a solid foundation for the Chinese case study efforts presented as part of this research to be based on and further developed from.

One of the challenge with interviewing in Asian case study settings is one of culture and the Asian mentality's fear of 'loosing face': Within the Asian culture, participating in a case study means the risk that the interviewee willingly or unwillingly expose a co-worker/superior by saying something that may somehow affect them and this Asian cultural challenge is not always fully described in case study method literature [60]. The interviewee may also risk 'loosing face' by being quoted for something which could later be contested by others as being wrong or only partially true. These cultural barriers and the inherent fear of 'loosing face' make the interview part of case study work in Asia particularly challenging. Nevertheless, a Chinese case study [61] with both semi-structured and formal interviews [62] has formed a major part of this research.

The Chinese offshore wind case study consists of a total of 143 encounters of which 103 are interviews and 40 are participant observation site visits (see Table 1). The case study empirical data collection efforts have been divided into primary and secondary empirical data collection efforts with 102 and 41 encounters respectively. 88 of the 103 interviews as well as 6 of the 40 participant observation site visits were conducted using a semi-structured interview process [62] with interview and site visit guides that were iteratively developed. This initial work led to a more formalized embedded case study opening up as part of the primary empirical data collection efforts with support from a Chinese WTG OEM [61]. The embedded case study consisted of 15 formal interviews supplemented by 34 participant observation site visits that enhanced the validity and reliability of the empirical data collected as the site visits included more in-depth interaction with the interviewees and often entailed long car rides across vast distances and many hours spent together.

Table 1. Summary of all encounters of the China offshore wind case study included in this research.

China Offshore Wind Case Study—Empirical Data Collection Efforts	Interviews	Participant Observation Site Visits	Total Number of Encounters
Secondary data gathering—semi-structured interviews	41	0	41
Primary data gathering—initial semi-structured "bridge" interviews	47	6	53
Primary data gathering—15 formal interviews	15	34	49
	103	40	143

Overall, the China offshore wind case study has five Asia visits included as part of the primary empirical data collection efforts during the lifespan of 33 months comprising this research (see Table 2). During the five trips, approx. 2 months were spent in China itself. Shipping and logistics was used as the entry point but a more elaborate interview guide had been developed to cater for the research questions outlined in Section 2.1 above.

Table 2. Trips to Asia and China as part of the primary empirical data collection efforts of this research.

Trip Timing	Geographical Scope	Total Time Spent	Interviews in China	Participant Observation Site Visits	Earlier Dissemination Efforts
September, 2013	China, Hong Kong, Singapore	2 $\frac{1}{2}$ weeks	32 (semi-structured)	4	[11]
February, 2014	South Korea, China, Singapore	2 $\frac{1}{2}$ weeks			
October, 2014	China	2 weeks	15 (semi-structured)	2	N/A
July, 2015	Taiwan, South Korea, China	2 $\frac{1}{2}$ weeks	15 (structured, with bi-lingual interview guide)	34	[3]
October, 2015	China	2 weeks			

In addition, an associate researcher spent two months in China during the first half of 2014 and this is considered the secondary empirical data collection efforts of this China offshore wind case study. During the time spent in China, the associate researcher carried out a total of 41 semi-structured interviews [62] which form part of the secondary empirical data collection efforts presented in Sections 5.1 and 5.2 of this research. The research design for these interviews performed by the associate researcher was different in nature inasmuch as these secondary empirical data collection interviews focused more on non-Chinese nationals and non-Chinese firms in China as this was the easier approach for the associate researcher who did not have prior experience with the Chinese culture [60] before the visit to China. In addition, the associate researcher did not have a prior network in China nor any available 'bridges' to forge relations and therefore had to utilize the network and 'bridges' available from the primary research efforts of this research. As a result, the secondary data collection efforts were narrow in terms of the reach.

The research design of the associate researcher was duly correlated with the overall research design of this China research and the results form part of the overall case study and research analysis presented here (from a funding perspective, the work performed by the associate researcher was structured as part of a separate endeavour not covered by the funding mentioned in the acknowledgements section below).

3. Method

Culturally, trust is gained through relationships in China. This means that in order to get to the right person and be able to obtain empirical data of use in academic research, a fairly sizeable investment in relationship creation is required [3,11]. For our Chinese empirical data collection and research design (see Section 2.5 above), the first three primary empirical data collection visits to China were focused on building the right relationships and getting to the right people by means of other people acting as the 'bridge' to get there [11]. During the fourth visit, the right people had been identified and a 'shepherd' had emerged to lead the way in the form of a leading Chinese WTG OEM and this became our embedded case study. As a consequence, interviewing could now take place in earnest with a proper bilingual English/simplified Chinese character interview guide [60,62] constructed from knowledge gathered during the prior visits [3].

3.1. Primary Empirical Data Collection Efforts in China

During the fourth and fifth visits to China, a total of 15 structured and formal interviews took place during using the bilingual interview guide. The interview process in China was slightly less rigorous than that applied e.g., for the Ørsted (formerly DONG Energy Wind Power) logistics R+D strategy paper process [12] conducted in parallel with the China interview process as compared and contrasted by Poulsen and Lema [3]. The China interviews lasted from 45 min to 7.5 h, 2–8 people including observers and/or translators participated in the formal interview meetings, and audio taping was either not permitted or not practically feasible. 12 of the 15 formal interviews in China included an element of participant observation site visits and in some cases, this enhanced the interview for example because of a car ride for several hours with only 1 or 2 English speaking persons where more informal dialogue could be had. Details of the primary research encounters have been detailed in Table 3.

Besides the 15 formal interviews in China, a total of 34 participant observation site visit encounters were organized in the form of site visits to the actual Chinese supply chain locations such as WTG/balance of plant (BOP) component manufacturing facilities, shipyards, ports, and OWF sites (of which one such OWF site was visited offshore two times during the embedded case study [3]). This took the total number of participant observation site visits in China to 40 during the embedded case study primary empirical data collection efforts over the 5 trips to China (see Table 4 for a select overview of key participant observation site visits).

The total number of 143 encounters [62] forming part of our China case study is presented in more detail in Table 3 and in addition, Table 4 offers a listing of a select portion of the participant observation site visits in more detail. As part of the overall research design, the Danish nation state apparatchik/infrastructure has been successfully applied to develop networks abroad. For example, dialogue with and intense collaboration enjoyed from the Danish Foreign Ministry through their Embassy network, including the Danish Trade Council as well as their Innovation Center Denmark organizations, has proven useful to establish relations. Traveling as part of official Danish government delegations has also worked very effectively to create a network of relevant firms and people [63]. Given the five Asia visits performed at different times of our 33-month China case study, a broader reach could be established with our primary empirical data collection efforts (see Tables 2–4). The 15 formal interviews enabled the creation of a gap analysis for China offshore wind as of early 2016 which is presented in Sections 5.3–5.5 of this research.

Table 3. Primary empirical data collection efforts in China.

Research Design	Interviews	Participant Observation Site Visits	Total Encounters	Number of Visits to China	Timing of Visits			
Initial semi-structured "bridge" interviews	47	6	53	3	2013–2014			
15 formal interviews	15	34	49	2	2015			
	62	40	102	5	-			
Initial Semi-Structured "Bridge" Interviews	**Developers**	**WTG OEMs**	**Shipping/Logistics/Ports**	**BOP Manufacturing**	**Sub-Suppliers**	**Offshore Wind Farm**	**Other Supply Chain [1]**	**Total**
Top management in China	-	-	6	-	4	-	5	15
Middle Management in China	-	4	14	1	3	-	7	29
Execution layer in China	-	-	-	-	-	-	3	3
Site layer in China	-	-	-	-	-	-	-	0
Total	0	4	20	1	7	0	15	-
Grand total	47	-	-	-	-	-	-	-
15 Formal Interviews	**Developers**	**WTG OEMs**	**Shipping/Logistics/Ports**	**BOP Manufacturing**	**Sub-Suppliers**	**Offshore Wind Farm**	**Balance Supply Chain [2]**	**Total**
Top management in China	-	-	2	1	3	-	-	6
Middle Management in China	2	1	2	1	1	-	2	9
Execution layer in China	-	-	-	-	-	-	-	0
Site layer in China	-	-	-	-	-	-	-	0
Total	2	1	4	2	4	0	2	-
Grand total	15	-	-	-	-	-	-	-
Participant Observation Visits	**Developers**	**WTG OEMs**	**Shipping/Logistics/Ports**	**BOP Manufacturing**	**Sub-Suppliers**	**Offshore Wind Farm**	**Balance Supply Chain [2]**	**Total**
As part of initial semi-structured bridge interview process	-	2	2	1	-	-	1	6
As part of process for 15 formal interviews	1	6	8	4	6	2	7	34
Total	1	8	10	5	6	2	8	-
Grand total	40	-	-	-	-	-	-	-
Grand grand total	102	-	-	-	-	-	-	-

[1] Other supply chain includes education, cluster associations, other support firms, etc.
[2] Balance supply chain includes China Wind Power conference, education, cluster associations, other support firms, etc.

Table 4. Participant observation examples from the primary empirical data collection efforts—site visits during the five trips performed to China.

No.	Timing within Research	Site	Timing of Visit	Location	Rationale and Relevance
1	First three China trips	ZPMC Offshore Wind	September, 2013	Nantong, Jiangsu	Port-side offshore wind facility built in accordance with the 12th Five Year Plan
2	First three China trips	Goldwind Offshore Base	September, 2013	Dafeng, Jiangsu	Offshore wind WTG manufacturing plant of key OEM
3	First three China trips	Dafeng port	September, 2013	Dafeng, Jiangsu	Port candidate in Jiangsu for offshore wind focus
4	First three China trips	Goldwind headquarters (HQ)	February, 2014	Beijing	HQ discussions on market development and O&M
5	First three China trips	China Wind Power	October, 2014	Beijing	China's premier wind conference, conducted annually in Beijing
6	First three China trips	China Ocean Shipping Company (COSCO)	October, 2014	Guangzhou	Opening of case access
7	Last two China trips	Case OEM Shanghai sales office	July, 2015	Shanghai	Formal interviews
8	Last two China trips	Case OEM HQ and manufacturing facilities visit	July, 2015	Shainghai, Jiangyin, Jiangsu	HQ discussions and WTG manufacturing facilities site visit of case OEM
9	Last two China trips	Non-Chinese blade manufacturer	July, 2015	Jiangyin, Jiangsu	Blade manufacturing supplier to case OEM
10	Last two China trips	Jiangyin port	July, 2015	Jiangyin, Jiangsu	Export port for case OEM nacelles and LM Windpower blades
11	Last two China trips	Longyuan Rudong Intertidal Trial Offshore Wind Farm	July, 2015	Rudong, Jiangsu	Test OWF of Longyuan with 9 different OEMs and 10 different foundation types represented
12	Last two China trips	Haili Wind Power Equipment Technology	July, 2015	Rudong, Jiangsu	Tower and monopile manufacturing facilities of Haili
13	Last two China trips	Jiangsu Longyuan Zhenhua Marine Engineering	July, 2015	Nantong, Jiangsu	Offshore wind engineering, procurement, construction, and installation (EPCi) type JV between Longyuan and ZPMC division of China Communications Construction Company (CCCC) with focus on shipping and logistics/EPCi
14	Last two China trips	China Wind Power	October, 2015	Beijing	China's premier wind conference, conducted annually in Beijing
15	Last two China trips	Tianjin Economic Development Area	October, 2015	Tianjin	China's third major export processing zone after Guangdong and Pudong
16	Last two China trips	Non-Chinese WTG gear sub-supplier	October, 2015	Tianjin	Gear sub-supplier manufacturing facility in Tianjin
17	Last two China trips	Non-Chinese WTG cooling systems sub-supplier	October, 2015	Tianjin	Cooling systems sub-supplier manufacturing facility in Tianjin
18	Last two China trips	Tianjin Orient Container Terminal	October, 2015	Tianjin	DP World container terminal in Tianjin
19	Last two China trips	Shanghai Haitong International Automobile Terminal	October, 2015	Pudong, Shanghai	Wallenius Wilhelmsen Logistics Roll-On/Roll-Off terminal in Shanghai where e.g., GE wind modules are frequently shipped from

Table 4. *Cont.*

No.	Timing within Research	Site	Timing of Visit	Location	Rationale and Relevance
20	Last two China trips	Case OEM Shanghai sales office	October, 2015	Shanghai	Formal interviews
21	Last two China trips	Case OEM HQ and manufacturing facilities	October, 2015	Shanghai and Jiangyin, Jiangsu	HQ discussions and WTG manufacturing facilities site visit of case OEM
22	Last two China trips	Non-Chinese blade manufacturer	October, 2015	Jiangyin, Jiangsu	Blade manufacturing supplier to case OEM
23	Last two China trips	Longyuan Rudong Intertidal Trial Offshore Wind Farm	October, 2015	Rudong, Jiangsu	Test OWF of Longyuan with 9 different OEMs and 10 different foundation types represented
24	Last two China trips	COSCO Nantong	October, 2015	Nantong, Jiangsu	Shipyard of the COSCO Group with experience in constructing wind turbine installation vessels (WTIVs)
25	Last two China trips	Jiangsu Longyuan Zhenhua Marine Engineering	October, 2015	Nantong, Jiangsu	Offshore wind EPCi type JV between Longyuan and ZPMC division of CCCC with focus on shipping and logistics/EPCi

3.2. Our Asian Case Study Work outside China

In terms of work on offshore wind in Asia not directly associated with China itself, the efforts rendered within this project may be summarized at a high level as follows:

- Due to the very costly nature of travels to and within ***Japan***, our efforts to understand the Japan market for offshore wind have been rendered remotely and our analysis and results have as of now not been widely disseminated.
- Our efforts to understand the market potential of offshore wind in ***South Korea*** as well as the shipping and logistics scene did not materialize to the extent conceived at one point within the research project and the actual analysis results pertaining to South Korea have been described separately [3,11].
- A brief visit to ***Taiwan*** in 2015 (see Table 2) has been coupled with remote efforts to understand the market there as well as detailed dialogue by phone and email with key Taiwanese partners engaged in offshore wind. In general, Taiwan is very open to foreign direct investment and knowledge sharing. Efforts have been rendered within academia to assist the Taiwanese government to map out the potential for offshore wind electricity generation in Taiwan and to analyze the extreme wind speeds experienced on the West Coast of Taiwan [64]. Also, academia has provided useful answers regarding alternative types of foundations for deeper waters such as modified jacket foundations suitable for local conditions and seabed structures in Taiwan [65]. In addition, simulations including earthquake impact on the jacket foundation piling structure have been performed, duly considering the special soil conditions [66]. The windy South China Sea has also been studied from the other coast line across the Strait, in China. Chinese scholars have analyzed the special weather conditions with focus on the damage inflicted to offshore wind turbines by typhoons which has been coupled with thoughts on potential implications on WTG design efforts [67]. In addition, implications for wind and waves respectively as seen from a floating offshore wind turbine perspective have been analyzed [68,69].
- Somewhat similar to how the offshore wind market in Japan has been researched remotely, the ***India*** market has been reviewed remotely in a similar manner as part of this research. As part of wrapping up a separate project on competition and collaboration between Europe and Asia, several final draft versions of a very informative and useful working paper (mimeo) on the wind industry in India were circulated [70,71]. The status of the offshore wind industry in India along with policy considerations for the Indian government to speed up diffusion has furthermore been described very well by Govindan and Shankar [72]. In addition, a total of four interviews about

the Indian market have been performed in Asia as well as in Denmark as an extended part of this research.

3.3. The Journey across Many Bridges to Reach Our Embedded Case Study Panacea

The on-site case study research within China itself forming directly part of this research consisted of three main phases of primary empirical data collection efforts:

(a) Building bridges to form a platform of relations: The first three of the five primary empirical data collection trips to China (the trip which took place during 2013 and the two trips in 2014—see Table 1) were utilized in order to build 'bridges' into the Chinese offshore wind energy industry including the opportunity to perform participant observation site visits to key locations, firms, and events. The lens applied was shipping and logistics as the 'access point' enabling the discussions. A total of 47 semi-structured interviews and 6 participant observation site visits [62] made up the empirical data collection foundation assembled during these initial trips (see Table 3). The interview part of the encounters made use of interview protocols with open-ended keywords [60,63] to enable a smooth flow of conversation as the interview settings were often informal and always semi-structured and iterative in nature [11]. This work was rendered in order to be able to understand the shipping and logistics aspects of Chinese offshore wind in more detail.

(b) Understanding China as seen by non-Chinese constituencies: The two-month stay in China of the associate researcher during the first half of 2014 was designed mainly in order to understand the Chinese wind market as seen through the lens of non-Chinese firms and non-Chinese people in China. Again, focus going in was put on shipping and logistics as the 'access point' (see Table 5 for details).
The interviews of the associate researcher were designed as iterative and semi-structured interviews which concurrently developed as more empirical data was amassed and analyzed [62]. This part of the overall research design was made in such a way that the 41 semi-structured interviews performed would contribute to a primarily non-Chinese understanding of key developments that occurred in the past [63], mainly in terms of providing a contextual understanding of the revolutionary development of the onshore wind market in China as well as a to serve as a point of departure on the future of the more steadily progressing evolution of offshore wind in China.

(c) Embedded case study: The remaining two of the five primary empirical data collection trips to China were conducted during July and October, 2015 in parallel with a European case study [3]. The initial relationship platform created in China had resulted in several full case studies now being available. The two most prominent case studies included that of a major SASAC-controlled CSOE shipping firm and that of a leading private Chinese WTG OEM. The leading Chinese WTG OEM case study opportunity was chosen as the embedded case study [60,61] as it was believed to hold the promise and potential to bring unparalleled insight into the layering of buyer-supplier relations [73] of offshore wind in China by the OEM providing case access to their customers as well as suppliers [61]. This embedded case study was executed during the last two primary empirical data collection visits to China (see Tables 2–4) and comprised a total of 15 structured interviews using a bi-lingual interview guide as well as a total of 34 participant observation site visits [3,62,63].

Table 5. Secondary empirical data collection efforts in China.

Research Design	Number of Firms	Firm Split (Percentage)						
Danish Firms/Danish Personnel	25	61.0%						
Chinese Firms/Chinese Personnel	16	39.0%						
	41	-						
Organizational Levels	**Developers**	**WTG OEMs**	**Shipping/Logistics/Ports**	**BOP Manufacturing**	**Sub-suppliers**	**Offshore Wind Farm**	**Other Supply Chain**	**Total**
Top management in China	-	-	4	-	5	-	2	11
Middle Management in China	-	2	3	-	4	-	9	18
Execution layer in China	-	-	2	-	-	-	10	12
Site layer in China	-	-	-	-	-	-	-	0
Total	0	2	9	0	9	0	21	-
Grand total	41	-	-	-	-	-	-	-

4. Contextual Analysis

This research is based partly on our empirical case study findings as well as a separate contextual study on the legislative framework and background at a policy level in China to be able to bring a macro level and geopolitical understanding forward. The contextual analysis is presented in Sections 4.1–4.3, which follow here. This is superseded by Section 5, which presents an analysis of the empirical data collected as part of the case study.

4.1. Contextual Study on Legislative Framework and Policy Level Background

A number of macro level policy observations which were partly identified during the first two trips to China and also detailed in parallel within academia [1,6,74–78]. These early observations were further probed for during the interviews performed by the associate researcher with non-Chinese individuals and the observations coupled with the secondary empirical data collection efforts had very significant impact at firm level and thus became part of shaping this research further. A summary of the macro level policy observations may be provided as follows:

- Particularly the government of Denmark assisted the Chinese government to ***set up the administrative infrastructure for renewable energy*** in particular and wind energy in general. As such, the China National Energy Administration of China is very much modeled after the Danish Energy Administration [79,80].
- As the initial targets for wind energy diffusion were set by the Chinese government essentially creating a 4-phased evolutionary path of the onshore wind industry much akin to the generic ILC taxonomy [1], three ***wind energy deployment 'accelerators'*** were put in place at a macro/policy level:

    (1) A set of rules, regulations, and incentives were organized at a policy level to help administer, deploy, and support the wind energy diffusion [1,76,78].
    (2) A number of firms controlled directly by the Chinese government were given objectives in terms of adding renewable energy capacity [81,82].
    (3) To leapfrog the wind energy technology barriers of entry [1,76] Chinese firms were mandated by the Chinese government to either forge strategic partnerships with foreign firms in China or acquire firms overseas [74–78,83].

In 2011, the Chinese Ministry of Commerce and other ministerial departments jointly issued "*The opinions for promoting the internationalization development of strategic emerging industries*" and a year earlier, seven industries including that of the 'New Energy Industry' had been identified by the State Council as such strategic emerging industries [78]. Expanding on the account by Zhang et al. [78], the 'strategic emerging industries' should achieve the internationalization development by:

(1) promoting the market competitiveness at industry level,
(2) improving the internationalization capabilities of firms,
(3) creating a support system at the institutional level, and
(4) ensure a domestic foundation is in existence for the strategic emerging industries in the form of a strong Chinese domestic home market.

To accelerate indigenous innovation capacity building, the strategic emerging industries had been directed to put emphasis on collaboration with overseas research institutes and industry clusters as well as the setting up of overseas research and development (R+D) centers. For the wind industry, the above mentioned 2011 ministerial decree [78] stipulated that JV formations, equity investment, and M&A transactions would be particularly encouraged by the government and institutionally the banks were needed in order to support this in terms of financing. The banks were decreed, e.g., by the 2015 "*Guidelines on risk management of commercial bank merger and acquisition loans*" issued by the China Banking Regulatory Commission [53] to support the internationalization efforts. Accordingly, the Chinese banking sector, led by China Development Bank and Export-Import Bank of China, as well as commercial banks such as Bank of China, Bank of Shanghai, China CITIC Bank, and Bank of Communications, was mobilized by the Chinese government and this led to increased outward cross-border M&A activity by the Chinese wind energy industry. As detailed Zhang et al. [78], China Development Bank funded the United States Dollars (USD) 2.2 billion investment on the part of Sinovel to form the JV with Ireland-based Mainstream to be part of the global wind energy scale and scope created by Mainstream. Later on, the series of China Three Gorges (CTG) ventures with Energias de Portugal (EdP) was also funded by the China Development Bank, as outlined below.

- No ***offshore wind feed-in tariff*** (FIT) existed for offshore wind up to June 2014 where it was finally implemented by the central government [3,5].

4.2. Policy Drivers Correlated to Specific Firm Behaviour in the Chinese Wind Energy Industry

At a firm level, these strategies set out by the Chinese government at the industry level meant that based on the prospects for the Chinese wind market, overseas firms such as Vestas [1], Gamesa, and GE orchestrated onshore wind market entries with a domestically focused manufacturing footprint. In 2006, those three firms enjoyed a 23.6%, 15.9%, and 12.7% onshore wind market share in China respectively [84].

Conversely for Chinese firms, a number of implications arising from the government accelerator strategies can be evidenced by the following analysis performed separately after the conclusion of our empirical data collection efforts in China:

- In terms of M&A activities of Chinese firms, academic research analyzing 512 outward M&A deals by Chinese firms across 36 industries showed that developing Chinese firms are more likely to acquire overseas firms in industries with a high technology intensity and where a technology gap exists favouring overseas firms [83]. Within the wind industry, the most prominent recent examples with a direct bearing on offshore wind are those of SASAC overseen CSOE developers/operators China General Nuclear (CGN), CTG, and State Development and Investment Corporation (SDIC). Onshore wind antecedents to these recent offshore wind M&A cases include the internationalization efforts of Goldwind, HydroChina, United Power/Longyuan, Beijing Construction Engineering Group, and the significant investment made by Sinovel into the JV with Ireland-based global wind farm developer Mainstream [77]. Some academic studies have been made to understand the decision process within Chinese firms when making such outward cross-border M&A transactions across several emerging economies including China [85,86] and specifically for the Chinese wind energy industry [78]. Conversely, the rationale of European target firms selling to Chinese firms was analyzed academically across five firms sold to Chinese firms in a German setting [87].
- ***CGN*** is a South China-based utility that has completed a partial IPO in Hong Kong which confirmed the intent to also diversify in the area of renewables. CGN recently completed the acquisition of 14 onshore wind farms in Ireland for Euro (EUR) 350 million [88,89].
- ***CTG*** is the operator of the Three Gorges Dam in China and CTG has set aggressive renewable energy targets for 2020. By the end of 2011, CTG entered into a strategic partnership pertaining to renewable energy [81,82] with EdP. In the strategic partnership, CTG was first to take over a 21.35% share in EdP for EUR 2.7 billion [90]. The stake in EdP was acquired by CTG from the Portuguese government as part of a privatization process of EdP. Subsequently, CTG was to acquire existing fully operational and/or ready-to-build/projected renewable energy projects for EUR 2 billion [82]. Last but not least, CTG was to ensure that a 20-year credit facility of EUR 2 billion be orchestrated by the China government backed lender, China Development Bank [91]. The different parts of the strategic partnership have since been executed including CTG investments in EdP renewable energy assets in Brazil hydro power [92] as well as EdP shares in power generation and distribution assets in former Portugese colony in Asia, Macau [93]. Within the offshore wind segment,

an investment by CTG via an EdP subsidiary of 30% of the shares in the ready-to-build Scottish 1+ GW OWF, Moray [94]. A similar investment in a ready-to-build OWF project in France has been jointly announced by EdP and CTG for early 2017 [95]. Separate to the EdP deals, CTG has acquired 80% of already operational 288 MW German OWF MeerWind Süd/Ost from US private equity firm Blackstone [96,97].

- ***SDIC*** acquired the UK-based offshore wind business of Spain's Repsol [98] for EUR 238 million [99]. This acquisition gave SDIC 100% control of the 784 MW Inch Cape OWF project and a 25% stake in the 588 MW Beatrice OWF project. The Beatrice OWF project achieved financial close in 2016 [100] and the partners of SDIC in Beatrice are SSE (40%) and Copenhagen Infrastructure Partners with 35% [101].
- Other and less prominent and technology infusion [75] driven M&A examples include the ***Goldwind*** acquisition of Vensys in Germany (for the full Goldwind internationalization case study up to 2013, see Zhang et al. [78]), the ***XEMC*** acquisition of Dutch OEM Darwind [102], the ***Titan*** acquisition of a tower factory in Denmark from Vestas, and the ***CASC Direct*** Chinese market JV with Dutch EWT.
- Establishing R+D centers overseas is commonly done in an organic manner as exemplified by ***Envision***, ***Ming Yang***, and most recently ***Goldwind*** [103] who have all set up R+D offices in Denmark.
- Several Chinese OEMs make use of technology transfer partnerships and as an example, this includes ***Ming Yang***, ***Shanghai Electric***, and ***Zhejiang Windey*** [104], who have all formed partnerships with Germany-based Aerodyn as well as ***Dongfang Electric*** and ***Sinovel*** who each respectively formed a partnership with American Superconductors.
- Overseas investments outside China to build organic manufacturing plants to perform final assembly of partly Chinese-constructed wind component in Europe have also been done. Most prominently this was announced and set-up by the ***Jiangsu Hantong*** shipyard group as they set up their EUR 50-million investment in Jade Werke in Wilhelmshafen, Germany [105] to construct/perform final assembly of steel foundations for OWFs [106]. However, due to the fluctuating offshore wind plans of the German government, the plans were not finalized and the manufacturing facility not finalized [107].

4.3. Review of the Revolutionary Diffusion of Onshore Wind in China

In parallel with the market entry of foreign firms, the Chinese onshore wind market gave birth to a high number of local OEMs which, according to our detailed analysis performed as part of the field trips with support from Chinese Renewable Energy Industries Association and our research partnership with Chinese Wind Energy Association, reached a number as high as 71 by the peak in 2014 (see Table S1.). This compares to other academic research which determined that 28 OEMs who could either produce, sell, and/or install a full prototype WTG by 2012 [78]. Building further on this, Chen et al. [76] discuss entire wind turbine system integrators versus component provider manufacturers. In line with ILC theory (see Section 2.2), the growth phase of the Chinese onshore wind market could not sustain this very high amount of Chinese OEM constituencies coupled with some 10+ foreign OEMs also operating in China and a shake-out took place as also observed by Dai and Xue [1] in their description of the 4 ILC-type phases of the industry development. A granular review up to 2010 also deals with some of these life-cycle phases [74]. Chen et al. [76] provide a detailed account of how the technology base of Chinese OEMs was created and also characterizes the onshore industry evolution using four life-cycle phases framed in the 'business ecosystem lifecycle'. This view is further supplemented in terms of development of intellectual property rights (IPR) and patents by Zhou et al. [108]: According to the detailed analysis based on the empirical findings of this research, many of the Chinese OEMs only reached a prototype R+D stage as opposed to serial production, some of the privately funded firms only received a certain level of investment, and others again stopped production after a while after which they exited the market (e.g., Hanwei, Baonan Machine, and Sinovel Wind Group Co., Ltd.).

Several overseas firms with a strong wind energy technology base chose to enter the seemingly booming Chinese onshore market for wind energy in different ways:

- US-based ***GE Energy*** (GE) first entered the Chinese wind market with a wholly owned foreign enterprise (WOFE) strategy including a fully owned wind turbine manufacturing plant in Shenyang. In 2010, GE and long-term GE China gas turbine partner Harbin Electric announced the formation of two wind turbine OEM JVs in China where Harbin would take over 49% of the GE onshore plant in Shenyang and GE would take over 49% of a new Harbin offshore plant in Zhenjiang in the Jiangsu province of China. The JVs were ended by mid 2013 [109] with GE citing " ... *fundamental differences in commercial priorities and business strategy* ... " as the reason for the JV dissolutions [110]. Pursuing the Chinese wind market separately hereinafter, GE took back over 100% of their Shenyang plant and Harbin gained 100% control over the Zhenjiang plant.
- Before the merger of Siemens Wind Power and Gamesa, now Spain-based ***Siemens Gamesa Renewable Energy*** (SGRE) first had the Siemens Wind Power business enter the Chinese wind market with a WOFE strategy including a brownfield factory set-up the Nanhui (formerly Lingang) district of the Eastern part of Shanghai. Near to other fossil fuel JV manufacturing sites with longstanding Siemens Group JV partner in China, Shanghai Electric [111,112], the first SGRE WOFE blade manufacturing site was opened in 2010 [113]. However, already in 2011, two JVs for wind energy in China were entered into with Shanghai Electric [114–116] which came into effect in 2012 [117,118]. Towards the end of 2014, Shanghai Electric publicly stated at the China Wind Power conference in Beijing that the " ... *complex structure of the joint ventures resulted in great operating difficulties, high administrative costs and low efficiency* ... " [84] and this was also conveyed by Shanghai Electric in public elsewhere [118]. During 2015, SGRE (then Siemens Wind Power) pulled out of the domestic Chinese wind energy market and licensed its' core WTG technology to Shanghai Electric [119]. SGRE maintained an export focused WOFE manufacturing footprint e.g., for blades in Nanhui.
- Denmark-based ***Vestas*** entered the Chinese wind market with a WOFE set-up and has not deviated from this strategy, however, the China manufacturing footprint has had to be reduced as demand decreased over time [120,121].

In the case of Vestas, the China market entry was coupled with a seemingly forced market entry of the top European sub-suppliers of the firm. One sub-supplier interviewed by the associate researcher explained:

> *"Vestas was one of our biggest customers in Europe and they asked us to join them and enter the Chinese market when they [Vestas] did. At that time, local Chinese regulations apparently stipulated that a minimum of 70% nationally produced content form part of the wind turbines produced by foreign firms with a WOFE set-up in China".*

In the case of SGRE and GE, the JV set-ups did not fare as originally intended and some of the root causes for the collapse of these JVs which although not fully understood might be found in the partner selection and partner validation process [46].

To summarize the revolutionary pace of development of Chinese onshore wind, please refer to Table 6.

Table 6. Chinese onshore wind development growth factor and compound annual growth rate (CAGR) compared to development of onshore wind in the US, Europe, and globally (Source: Own construct using own database based on several sources, such as BTM, BTM a part of Navigant, FTI Consult, Global Wind Energy Council, EIA, [7,74,84]).

Onshore—Installed Capacity (MW)	2000	2005	2010	2015	Growth Factor (2015 over 2000)	CAGR (2005–2015)
China	346	1260	44,781	145,513	420	60.8%
Europe	12,887	40,898	86,619	147,099	10	13.7%
USA	2578	9149	40,298	74,744	28	23.4%
Globally	17,400	59,091	198,065	436,308	24	22.1%
China share in % of globally installed	2.0%	2.1%	22.6%	33.4%	-	-

5. Empirical Data Collection Analysis

The primary empirical data collected on the Chinese onshore and offshore wind markets enabled an initial and somewhat early cross case comparison with the European offshore wind market [11] which was followed up by a more focused and qualitatively rich supply chain readiness comparison of Europe and Asia in a later publication [3]. However, the key contribution of this China offshore wind case study research, presented in full in this paper, is a complete gap analysis of the Chinese offshore wind market with a focus on why diffusion has been slower than planned in the 12th Five Year Plan where targets were not met for offshore wind.

In the following, the analysis of the secondary empirical data collection efforts are presented initially (Sections 5.1 and 5.2) as these initial findings set the scene for the findings of the primary empirical data collection efforts. The China offshore wind industry gap analysis is subsequently presented from three different dimensions in Section 5.3 (macro level), Section 5.4 (developer/operator level), and Section 5.5 (WTG OEM level).

5.1. Secondary Data Collection Efforts: Turbine Manufacturer Level

The interviews by the associate researcher produced direction at a general level about a number of WTG OEM topics in China as follows:

- Warranty period. From the interviewees, it was gathered that WTGs were normally sold by OEMs with a 2-year warranty period and that developers would release the last 10–15% of the WTG payment only after warranty period. In other cases, non-Chinese OEMs had given up to 10 years of warranty in China.
- Export focus. Several Chinese OEMs wanted to export WTGs to other parts of the world. Several strategies were quoted in the interviews. One interviewee stated that " … *one OEM had developed a strategy where they plan to start with the outer areas of Europe like Turkey. Here, less certification requirements exist and they would then work their way in to the core European markets* … ". An account of Chinese wind turbine exports has also been performed academically [78].

5.2. Secondary Data Collection Efforts: Sub-Supplier Level

A number of interviewees were representatives from surviving sub-supplier firms who had joined their respective OEM partners such as Vestas when the China market was first poised to take off. The reason for many colleagues to have failed was advised as being due to the local content regulations (so-called localization rates) introduced in 2003 at 50%, increased to 70% in 2004, and finally abolished in 2009 [1,74]. The sub-suppliers described a series of more specific sub-supplier related topics to the associate researcher as part of our secondary empirical data collection efforts:

- Patents/IPR. Protecting patents and intellectual property rights was listed as a key concern by many non-Chinese interviewees and has also been dealt with extensively by academia [2].

One detailed academic analysis comprising 17 WTG OEM firms with a more elaborate perusal of 6 sample firms concluded that based on their first-mover advantages from the European wind market, several European firms seemed to possess the dominant design but later Chinese market entrants caught up to the European firms in terms of number of patents filed on an annual basis [108] which could indicate the emergence of a separate dominant design [26] in the Chinese submarket [27]. One European sub-supplier explained to the associate researcher that " . . . *during the first years, we did business with all top ten Chinese OEMs. However, they bought in very low quantities from us. Afterwards, we only continued to do some substantial business with one OEM, later two* . . . " and this has been depicted graphically as an evolution of firms' networks in Zhou et al. [108].

- Payment terms. Many non-Chinese interviewees stated that cash-flow was challenging in the Chinese market. One sub-supplier stated that " . . . *payment terms from developers and OEMs could often be 6-12-18 months and this makes it challenging to run the business* . . . ". Within academia, a comprehensive recent literature review covering supply chain integration [122] identified only one paper [123] that deals with integration of the financial supply chain into the supply chains that deal with the movement of goods as well as information/documentation.
- 'Us' and 'Them'. From our interviews, it was clear that the China-based management of the Chinese subsidiaries of non-Chinese firms often felt that they were very often " . . . *left to be very alone* . . . " with the complex Chinese market and that their overall situation was " . . . *not well understood* . . . " by their corporate colleagues back at the corporate offices in e.g., Europe.

The Chinese onshore market developed in such a way that overseas OEMs lost market share very quickly. By 2013, the market shares of Vestas/Gamesa/GE had dropped to 3.2%/1.6%/1.1% respectively [84]. This also meant that of the 100 or so sub-suppliers who joined Vestas on their China journey, the interviewees generally agreed that only some 20% remain in China today [121] as many of these non-Chinese firms formed part of supply chains of the overseas OEMs as opposed to the Chinese OEMs who had different supplier networks [6,76,108].

From the interviews performed by the associate researcher in China, initial knowledge of the gaps in the Chinese offshore wind market was amassed through the empirical data collection efforts. However, this was the view on gaps in the Chinese wind market as seen by non-Chinese firms and non-Chinese representatives: A Chinese view would be more valuable and display a more realistic view of the world and in the following three sections (Sections 5.3–5.5), the Chinese view will be presented as obtained from the primary empirical data collection visits to China including the embedded case study with the 15 formal interviews.

5.3. Primary Data Collection Efforts: Macro Level China Offshore Wind Industry Gap Analysis

The obvious macro level gap is a conundrum in itself for readers with a non-Chinese background: Why did the Chinese government simply not use greater force to make Chinese SOEs execute the plans comprised in the 12th Five Year Plan? One of the recent and very extensive research efforts on China (offshore) wind looked at exactly this [5] and concluded that a stand-off between the government and the SOEs was on-going for a long time [124]. The answer as derived from the empirical data collection efforts of our case study work is that SOEs have strict earnings targets imposed upon them by the very same nation state responsible for the Five Year Plans. It was therefore not until the implementation of the new central government defined offshore wind FIT in June 2014 that those profitability targets came close to being realizable for Chinese firms, SOEs included [3]. This FIT had been called for by academia (and industry) for a long time as reviewed in Poulsen and Lema [3]. Incidentally, provinces are independently allowed to add incremental FIT incentives on top of the central FIT as they deem to be of value.

The pace of construction has since then picked up quite dramatically (see Table 7), initially fueled by the fast-tracking given to 44 potential offshore wind farm projects with the December 2014 "*National offshore wind power development and construction program (2014–2016)*" decree issued by the National Energy Administration [125]. However, fear exists especially on the part of Western observers that

China will repeat Europe's early ILC teething problems of installing onshore wind technology in the rough and harsh offshore environment with salt, water, and corrosion challenges faced [3]. In our primary empirical data collection work in China, this stance was largely confirmed also by the Chinese OWF operators and OEMs with offshore wind test install bases. Towards the end of 2015, operators of Chinese onshore wind farms started to openly reveal even in conference and seminar settings that the lower prices of Chinese onshore WTGs also had the adverse effect that severe O&M challenges were being faced [3]. In private talks and during interview sessions, it was indicated that Chinese OEMs had built onshore WTGs to be able to last closer to 10 years as opposed to the 25-year operations span expected from a European WTG and this was to some extent confirmed also within academia [2].

Table 7. "*National offshore wind power development and construction program (2014–2016)*" compared to original 12th Five Year Plan offshore wind targets, by province (Own construction based on [125]).

Province	Number of Projects Included in Feed-In-Tariff	Corresponding Capacity in Feed-In-Tariff (MW)	Original 12th Five Year Plan Target (MW)
Liaoning	2	600	-
Hebei	5	1300	5600
Tianjin	1	90	-
Shandong	-	-	7000
Jiangsu	18	3490	9450
Shanghai	-	-	1750
Zhejiang	5	900	3700
Fujian	7	2100	1100
Guangdong	5	1700	1400
Hainan	1	350	-
Total	**44**	**10,530**	**30,000**

5.4. Primary Data Collection Efforts: Developer/Operator Level China Offshore Wind Industry Gap Analysis

The bilingual interview matrix design applied in China for our embedded case study was centered around a top five, and thereby market leading, Chinese WTG OEM. The WTG OEM case firm opened up their supply chain and provided case access into the mechanics and workings of itself as a firm at both strategic and tactical levels. In addition, our WTG OEM case firm provided case study access to its clients as well as its suppliers in a very focused and direct manner which we helped orchestrate from an overall research design perspective. Due to the fact that the WTG OEM was in a direct business relationship with its clients as well as its suppliers, the interviews and site visits were particularly meaningful, serious, and organized. The WTG OEM firm organized the interviews in such a way that translation from English to Mandarin and/or from English characters to Chinese characters was supplemented in cases where the skills and competencies of the research team did not suffice. Also, the daunting task of the sheer logistics of transporting the research team over great physical distances within China was eased considerably with the support of the OEM firm. The motivation to participate in the case study on the part of the OEM firm was three-fold:

(1) It was a case of the relationship having been established,
(2) gaining access to European knowledge/relations, as well as
(3) the ability to bring a new and academically driven dimension into their already strong and continuously improving client/supplier relations.

Critical knowledge of the composition of the Chinese offshore wind supply chain was obtained: This was directly comparable to the structure of the European offshore wind supply chain and from a shipping/logistics scope contrasting perspective, one major example was that of the WTG offshore transportation and installation scope [3]. WTG transportation and installation tasks were insourced by the developers in China whereas in Europe, the structure of having the WTG transport, installed, commissioned, operated, and maintained by the WTG OEM has been the precedent for many years.

Chinese developers/operators were very clear on their motivation to structure the supply chain with more control residing in-house with them in an insourced manner: Over time, the large Chinese SOEs involved in OWF construction and operations wish to align with the Five Year Plan vision to be able to export turn-key OWFs including WTGs and BOP components in a fully installed, turn-key manner including full life-cycle operations and decommissioning [3].

With this radical industry vision for China offshore wind as our back-drop, our empirical data collection efforts in China were rendered mainly with shipping and logistics as the stated objective of our research. However, our interview guide was deliberately structured much more broadly as we also had a vested interest in understanding the overall wind market, the dynamics, and the objectives going forward. Our case study with Chinese firms and based on interviews with Chinese nationals revealed a series of critical gaps faced by the Chinese offshore wind industry by early 2016.

From a developer and operator perspective, the following items were identified during our research:

- ***European showcase construction*** of OWFs in China. At government level and also at SOE level, a wish was put forward for a European OWF developer to construct and operate an OWF in China based on European standards but subjected to Chinese conditions.
- Full OWF life-cycle ***cost modeling*** capabilities. At the project approval stage, critical capabilities around cost modeling for the entire life-cycle of an OWF were sought also including the O&M and de-commissioning life-cycle phases.
- Full OWF life-cycle ***project planning*** capabilities. From a project planning perspective, tools and IT systems were mentioned as critical gaps. One developer expressed that " ... *we will construct the offshore wind farm in less than 18 months which matches the standards set in Europe* ... " but when asked how long the project had been in planning phases, the answer was eight years.
- Full OWF ***risk management and insurance*** capabilities as well as experience. Risk management was mentioned as a critical factor for OWFs as these projects are not yet well understood. Insurance as an option to cover risks was discussed and it could be particularly relevant for private operators and SOEs alike. However, not much risk management and insurance underwriting experience exists for OWFs in China yet.
- ***EPCi firms*** willing to bring experience from Europe to China. The ability to buy a turn-key and fully engineered, procured, constructed, and installed OWF is something some of the SOE developers aspire to become able to sell as an export package in the future. However, to gain such experience in China, a wish was expressed to have overseas EPCi firms enter China with this experience from the offshore wind sector. One Chinese EPCi representative expressed that in driving past an offshore WTG with the Group CEO, the head of their, at that time, troubled offshore wind division had received a comment from the CEO as follows:

  > *"We build bridges, cranes, and ships. How can a small wind turbine generator like that cause us this amount of challenges?"*

  A good answer did not exist to this challenge from the CEO...

- ***BOP supply chain*** infrastructure and experience. The BOP supply chain was not very built out in China. As an example, it was not until 2015 that the first offshore substations (OSS's) were needed and subsequently imported into China for installation. According to ABB [126], they delivered the first OSS to CTG's Xiangshui Offshore Wind Farm. At the same time, also the Huaneng/Huadian JV OWF Rudong Baxianjiao Offshore Wind Farm [127] as well as CGN [128] have been eager to take credit for OSS's and foundations that were installed as China-first and Asia-first milestones respectively. Similarly, export cables and array cables represent challenges in the China BOP supply chain.
- ***Decommissioning*** experience and calculation methods. The decommissioning life-cycle phase was now being considered according to our research. One developer explained that they are now

considering how to do this in an onshore setting and that " ... *offshore decommissioning is much more complex. We need to consider this from the beginning as our projects are planned*".

5.5. Primary Data Collection Efforts: Turbine Manufactgurer Level China Offshore Wind Industry Gap Analysis

In terms of topics specific only to WTG OEMs, our research indicates that support with manufacturing facility design, optimization, and management experience is sought after in China. This was cited due to the fact that the wind industry is still young and that efficiencies are therefore sought after.

From developers and OEMs alike, a series of WTG related challenges were commonly mentioned:

- ***Partnerships with European firms*** to customize European experience to the unique Chinese conditions. In general, Chinese constituencies interviewed expressed that they did not see a direct application of European knowledge, technology, or assets into the Chinese market: A certain degree of customization to China would be necessary and this would be one of the tasks for which a Chinese partner of a collaboration constellation would be ideally suited. Chinese interviewees expressed concern about overseas solutions being too costly, inefficient, and not sufficiently focused on the Chinese SOE social responsibility to also generate jobs locally in the provinces where the OWFs are constructed.
- ***O&M*** concepts, experiences, and factual operational data. Significant challenges were faced by operators of onshore wind farms and this was shared rather openly with photos and commentary during public conferences [3]. Based on these challenges onshore [2], knowledge of O&M from a conceptual design as well as an actual operations perspective was actively sought. Offshore wind O&M experience coupled with actual operational data were key dimensions sought by developers as well as OEMs alike.
- ***Offshore native WTG technology*** able to withstand the harsh offshore environment. Especially in the South, harsh weather including typhoons had long had a severe impact on onshore WTGs. Relevant experience particularly from the North Sea was sought in terms of typhoon impact prevention. Similarly, for icy conditions, especially experience from the Baltic Sea Region was sought.
- ***Offshore wind turbine foundations***. Especially in the porous inter-tidal OWF development zones for the Yellow River, Yangtze River, and Pearl River, demands for different offshore wind foundations have been very apparent. Especially the Longyuan Rudong Intertidal Trial Offshore Wind Farm features more than 100 WTGs made by 10+ OEMs including SGRE, Sinovel, Goldwind, CSIC Haizhuang, Dongfang Electric, Envision, United Power, Ming Yang, SANY, SEwind, Wuxi Baonan, and XEMC. As observed during our visits to the OWF in 2015, each offshore wind OEM has tested several WTG designs and in some cases also several foundation designs. OWF operator Longyuan has patented a solution to eliminate the transition piece between the foundation and WTG [129,130].
- ***Shipping and logistics*** knowledge, processes, and experience across all life-cycle phases. This part was particularly expanded upon due to this forming the crux of our interview protocol and because shipping and logistics topics were presented in advance of the interviews as our key reason for wanting to take up time of the interviewees. In the development & consent OWF life-cycle phase [12], studies of road conditions and studies of seabed conditions were cited as critical areas where exchange of information with overseas counterparts could be of use. In addition, studies of the environment and animal protection opportunities were also cited as key development and consent opportunities for collaboration. In general, vessels based on European operations experiences were sought. However, it was highlighted that such vessels would need to be customized for the unique Chinese OWF set-ups with focus on inter-tidal, river delta, near shore, and 10-10-10 definition (the 'double-ten' or '10-10-10' standard) of the China State Oceanic Administration [128] across the different OWF life-cycle phases [12]. Specific vessel knowledge including piling hammer vessels, cable laying vessels, and WTIVs (installation and

commissioning life-cycle phase [12] of an OWF) and crew transfer vessels (O&M life-cycle phase) was commonly requested along with specific capabilities and skills such as jacking, dynamic positioning, and cranage. Especially in terms of the quite expensive WTIVs, overseas investments to bring both experience and assets to China were sought: In terms of WTIVs, a gap existed in terms of capacity necessary for China to complete the construction of the 44 OWF projects [125] within the new June, 2014 implemented central government FIT stipulations [3].

6. Discussion

Getting to the 15 structured and formal interviews in China supported by participant observation sit visits was not trivial (see Sections 2.5 and 3). As with any other market, significant knowledge and understanding of local issues is necessary on the part of the researcher in order to make a good interviewer who can be part of the conversation with, in this case, the Chinese interviewee counterparts. Perhaps more so in a Chinese setting:

- First, to understand 'local' issues in a country with almost 1.4 billion inhabitants is also no small task. To some extent, offshore wind in China can be seen as the three distinctively different regional areas as in the North, Central, and Southern parts of the East Coast of China where particularly the wind speeds differ (similar to the Mediterranean, Atlantic, North Sea, and Baltic Sea conditions of Europe). Within each offshore wind regional area, several provinces exist like Fujian and Guangdong in the South or Shanghai and Jiangsu in the Central offshore wind regions. Within each province, major cities, counties, and ports exist and this geographical and political structure of province/city/county/port may to some extent be compared to a country set-up in Europe or the structures of individual states in the US.
- Second, a barrier of understanding also existed in the form of the language (written and spoken) where especially the more senior generation Chinese often chose to speak and write English only through interpreters which could indicate a power stance [131].
- Third, the idea of getting quoted or cited in academic work was not always very culturally desired for the interviewees as the risk was perceived to be great in terms of saying something which may be quoted wrongly and/or could be interpreted as criticism of the firm, the country, and/or colleagues.
- Fourth, respect of Chinese ways of interacting and the construct of the concurrently developing personal relations deserves mention.
- Finally, cultural topics such as general Chinese protocol and etiquette may seem insignificant but should not be omitted.

The analysis presented in this research provides insight into how the Chinese government systematically decrees state-owned Chinese firms to expand into overseas markets for select emerging industries [78] of strategic importance to China. Overseas expansion is driven by a government decreed desire on the part of China to speed up learning efforts at a national level. The systematic alignment of policies, financing options [53], and particularly SASAC-controlled CSOE firm policy including the use of M&A [81,82,88,89] described in this research has provided an example of how China may deliberately fast track industry evolution. The nation-level strategic plans and institutional support policies mobilized by China described in Sections 4.1 and 4.2 are instrumental for the Chinese wind industry in order to be able to conquer market shares internationally by initially building a strong home market and then facilitating an end-to-end export solution. Essentially, exporting a complete offshore wind farm is a turn-key and fully financed complex billion-dollar megaproject [36] with an expected lifespan of 30+ years from the first site preparations start through the completion of the final decommissioning [12].

The analysis presented in this research points to a need for European and Chinese firms to successfully forge long-term alliances in order to quickly close some of the offshore wind gaps in China and benefit from not making the same mistakes as Europe did in the early days of offshore wind pioneering from 1991–2005. Such alliances would have an immediate impact on the domestic Chinese offshore wind market in the short term but also be valuable for future Chinese turn-key offshore wind energy export projects. As successful alliances and partnerships may be studied both based on in-depth analysis of examples of past efforts that worked well, this research has also presented a rich catalogue of examples of past collaboration efforts not yielding desired results as well.

At policy level, it is important that the evolution of the Chinese offshore wind power industry is fast-tracked in order to somewhat match the (r)evolutionary pace, volume, and velocity which the Chinese onshore wind power industry had demonstrated in the past (see Table 6). Our secondary empirical data collection efforts indicate that the local content rules in place from 2003 through 2009 has not yet been forgotten by a number of especially European firms who either survived or succumbed during the shake-out that incurred as part of the onshore Chinese market development. To repeat such a regulatory regime is agreed by practitioners and scholars [1,74,76] alike to not be necessary nor the preferred path forward not would it seem to be necessary based on the much more mature state of major parts of the Chinese wind supply chain. A more open, engaging, and collaborative environment should be stimulated by the Chinese government in order to forge the partnerships and alliances needed to close the offshore wind industry gaps identified in this research. On the part of governments outside China, support to firms engaged in e.g., the European offshore wind sector should be given and research projects involving also Chinese researchers and firms should be encouraged.

The role of CSOEs under the direct control and oversight of the SASAC cannot be underestimated as a very powerful tool for the Chinese government to execute national policy. Major offshore wind endeavours in China such as the role of CSOE Guodian's Longyuan subsidiary to test 10+ local OEMs against imported SGRE technology off Rudong is a good example detailed above (see Section 5.5). However, also the role of CSOEs CTG and SDIC to amass overseas project experience in Europe (see Section 4.2 above) shows how China is able to use some of the national wealth from its' sovereign wealth fund holdings and dispense this through China Development Bank as in the case of CTG and EdP.

It seems clear from our findings that overseas knowledge was first brought to China for the onshore (r)evolution in various different ways and that this is now also being pursued for the offshore market evolution. The use of M&A at a national level with the involvement of the CSOEs (see Sections 4.1 and 4.2) exemplifies a much more mature political position of the Chinese government in Beijing when it comes to wind energy at this time compared to at the time when onshore wind developments were first initiated.

There seems to be little doubt as evidenced by this research, however, that some of the (negative) experiences gained by non-Chinese investors in the onshore Chinese wind market (see Section 4.3) have left a degree of caution and tension in the market place: After a period of strong local content requirements [1,74], the onshore market is clearly a Chinese-dominated market where the top 10 domestic OEMs account for 81% of the market and the top 3 foreign manufacturers have very small market shares including Gamesa (1.4%) (now part of SGRE), Vestas (0.9%), and GE (0.4%) according to Global Wind Energy Council [132]. In the rest of the world, the wind energy market is open to all OEMs and as detailed by Zhang et al. [78], the Chinese OEMs have started to export their machines overseas to be attain market shares globally [133]. However, the growth of the Chinese home market remains daunting with an install base of 168.7 GW by the end of 2016 [7]. Academic research from another R+D prone industry (pharmaceuticals) suggests that foreign firms should partner with Chinese firms with a predefined and agreed long-term task allocation model duly considering R+D capabilities of foreign firms and access to large-scale human capital on the part of domestic Chinese firms [134]. If expanded upon further, Chinese firms—as well as integrated foreign supply chain partners—would initially benefit from the domestic China market opportunities and later also from Chinese firms exporting from China to other markets wind markets globally.

7. Conclusions

The actual achievement of 1 GW of offshore wind installed by the end of 2015 was rather far from the 12th Five Year Plan target of 5 GW at this time. With the revised 13th Five Year Plan goal of 12 GW of offshore wind in operations or under construction by 2020 [135], the ambitions of the Chinese government to have 30 GW in operation by 2020 have been significantly adjusted for offshore wind and installation of 1.6 GW [7] had been achieved by the end of 2016.

Following the onshore (r)evolution of wind energy in China, the offshore wind evolution has been slower due to the lack of a dedicated offshore wind FIT which was only introduced in June 2014 [3]. Following the FIT implementation, the 44 fast tracked projects [125] have been developing quickly based on the support of the central government, provincial governments, municipalities, and local counties. Based on industry sources, many more projects, beyond the initial 44 fast tracked projects, are under now under way and a detailed mapping of the actual pipeline of offshore wind farm projects by province in China could be a very valuable task for other researchers to perform in order to understand exactly how much offshore wind power will realistically be grid connected by when. However, as this research has shown, gaps exist for major Chinese offshore wind constituencies at different levels and we have outlined the key gaps identified at a macro, developer/operator, and turbine manufacturer level. These gaps play a major role in terms of why offshore wind diffusion has not yet picked up the (r)evolutionary speed seen in terms of onshore wind China and each gap identified in this research could therefor form the basis of further study by other researchers.

As in Europe, logistics [12] plays a significant role in offshore wind diffusion. The wind energy constituencies in China realize the importance of shipping and logistics inasmuch as this lens got us the 15 formal interviews that formed the basis of the embedded case study within our overall China offshore wind case study. Logistics is part and parcel of the entire life-cycle of an offshore wind farm and our interview guide with a logistics vantage point yielded a much broader dialogue ultimately able to generate the gap analysis contained in this research (see Sections 5.3–5.5 above). Moreover, shipping and logistics topics require careful focus and much attention as these derived disciplines within the offshore wind industry represent physical constraints in terms of the ability to speed up diffusion of offshore wind in China.

Supplementary Materials: The following are available online at www.mdpi.com/1996-1073/10/12/2153/s1, Table S1: Chinese wind turbine original equipment manufacturers as of 2014 (Source: Own analysis based on collaboration with Chinese Renewable Energy Industries Association and Chinese Wind Energy Association).

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Abbreviations

The following abbreviations are used in this manuscript:

BOP	Balance of plant
CAGR	Compound annual growth rate

CCCC	China Communications Construction Company
CGN	Chinese utility firm China General Nuclear
COSCO	China Ocean Shipping Company
CSOE	Central state-owned enterprise overseen by the State
CTG	Chinese utility firm China Three Gorges
EdP	Energias de Portugal
EUR	Euro
EPCi	Engineering, procurement, construction, and installation
FIT	Feed-in tariff
GE	GE Energy
GW	Giga-Watt
HQ	Headquarters
ILC	Industry life cycle
IPO	Initial public offering
IPR	Intellectual property rights
JV	Joint-venture
LSOE	Local state-owned enterprise in China owned by the provincial and/or local municipality government
M&A	Mergers & acquisitions
MW	Mega-Watt
O&M	Operations and maintenance
OEM	Original equipment manufacturer
OSS	Offshore sub-station
OWF	Offshore wind farm
PLC	Product life cycle
PMI	Post-merger integration
PPP	Public-Private Partnership
R+D	Research and development
SASAC	State-owned Assets Supervision and Administration Commission of the State Council in China
SCM	Supply chain management
SGRE	Siemens Gamesa Renewable Energy
SOE	State owned enterprise
SDIC	State Development and Investment Corporation
US	United States of America
USD	United States Dollars
WOFE	Wholly owned foreign enterprise
WTIV	Wind turbine installation vessel
WTG	Wind turbine generator

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Supplementary Materials: The (R)evolution of China: Offshore Wind Diffusion

Thomas Poulsen and Charlotte Bay Hasager

Table S1. Chinese wind turbine original equipment manufacturers as of 2014 (Source: Own analysis based on collaboration with Chinese Renewable Energy Industries Association and Chinese Wind Energy Association).

No.	Chinese Name	English Name	Comments	Head-Quarters
1	华锐	Sinovel	-	Beijing
2	金风	Goldwind	-	Urumchi
3	东汽	DEC	Commonly referred to as Dongfang Electric	Deyang
4	联合动力	United Power	Owned by Guodian [1] Group which is also a wind farm operator (Longyuan)	Baoding
5	明阳	Mingyang Wind		Zhongshan
6	湘电风能	XEMC-Wind		Xiangtan
7	上海电气	SEwind	Shanghai Electric Group	Shanghai
8	运达	Windey		Hangzhou
9	华创	CCWE	-	Shenyang
10	北重	BZD/JCNE	-	Beijing
11	远景	Envision	-	Jiangyin
12	南车时代	TEG/CSR	-	Zhuzhou
13	华仪	HEAG	-	Leqing
14	银星	Yinxing Energy	Owned by Ningxia Electric Power	Yinchuan
15	海装	CSIC Haizhuang	-	Chongqing
16	常牵新誉	New Unite	Huadian Group bought into the firm	Changzhou
17	天威	BTW	Commonly referred to as Tianwei	Baoding
18	航天万源	CASC-Direct	-	Beijing
19	锋电能源技术	Sharpower	-	Beijing
20	长星风电	Changxing	-	Zouxian
21	三一电气	SANY	-	Beijing
22	汉维	Hanwei	-	Daqing
23	国测诺德	GC Nordic	-	Wuhan

24	中科天道	Tewind	-	Shenyang
25	许继风能	XJ Wind	-	Xuchang
26	东方电气新能源	DEC New Energy	-	Hangzhou
27	盛国通元/中科风电		-	Tongliao
28	兰州电机	LEC Wind	-	Lanzhou
29	宝南机器	Baonan Machine	Sometimes referred to as Wuxi Baonan	Wuxi
30	久和能源	Gehoo		Xi'an
31	哈飞工业	Hafei industrial	-	Harbin
32	瑞其能	Swiss Electric	-	Weifang
33	西船工业		-	Xi'an
34	太原重工	Taiyuan Heavy Industy	-	Taiyuan
35	天地风能	Tiandi Wind	-	Rugao
36	风盈风电	Fengying	-	Foshan
37	沈阳远大	CNYD	-	Shenyang
38	江西麦德	Maide Wind	Commonly referred to as Jianxi Maide	Jian
39	上海万德	Wande Wind	Commonly referred to as Shanghai Wande	Shanghai
40	中钢西重	-	-	Xi'an
41	天洁	Tianjie Wind	-	Zhuji
42	金港机电	-	-	
43	苏州特普	-	-	Suzhou
44	沈鼓	-	-	Shenyang
45	南京瑞风新能源	-	-	Nanjing
46	江西格林艾文新能源有限公司	-	-	-
47	福建省南平市南店水电设备制造有限公司	-	-	-
48	南京汽轮机	-	-	Nanjing
49	雅图（阳江）风电设备制造有限公司	-	-	Yangjing
50	江西文德	-	-	Yangzhong
51	山东鲁科	Shandong Luke	-	Jinan
52	星火科技	-	-	Dalian
53	贵州航空	-	-	-

54	广州英格风电设备制造有限公司	-	-	-
55	四川矿山机器有限责任公司	-	-	-
56	胜利油田北方实业有限责任公司	-	-	-
57	**Beijing能优技术有限公司**	-	-	-
58	上海尔华杰机电装备制造有限公司	-	-	-
59	沈阳金祥	-	-	-
60	沈阳瑞祥	-	-	-
61	白城通业	-	-	-
62	哈空调	-	-	-
63	河南森源集团有限公司	-	-	-
64	四川风瑞能源事业有限公司	-	-	-
65	国晶电气	-	-	-
66	汇全稀土	-	-	-
67	南京某企业	-	-	-
68	**Beijing某企业**	-	-	-
69	银河艾万迪斯	Yinhe-Avantis JV	-	Baotou
70	现代	Hyundai JV	-	Shenyang
71	航天万源安迅能	CASC-Acciona JV	-	Yinchuan
72		REpower JV	China-sz	Beihai
73		GE JV	HEPC (Harbin Electric Machinery Company)	Weihai
74		Nordex JV	Ningxia Electric Group	-

[1]. At the time of completion of this manuscript, merger plans for China Guodian Corp. and China Shenhua Energy Corporation Ltd. to jointly become China Energy Investment Corp. had just been announced.

PAPER E: IS THE SUPPLY CHAIN READY FOR THE GREEN TRANSFORMATION? THE CASE OF OFFSHORE WIND LOGISTICS

Written by Thomas Poulsen and Rasmus Lema.

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Is the supply chain ready for the green transformation? The case of offshore wind logistics

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ABSTRACT

The transition from fossil fuel-based energy systems to renewable energy systems is a cornerstone of the green transformation to decarbonize our economic systems and mitigate climate change. Given the urgency of effective climate change mitigation, renewable energy diffusion needs to accelerate drastically. Among the many constraints to renewable energy diffusion, the important role of the supply chain is often overlooked. Therefore, this article addresses the role of the supply chain in the renewable energy diffusion process. Using the offshore wind energy sector as a case, this article presents an analysis of supply chain readiness to ascertain the role of the supply chain in the green transformation. Examining Europe and China mainly within offshore wind logistics, the research findings show that this segment of the supply chain constitutes a key bottleneck for accelerated deployment. For Europe, the key findings indicate that legislation for offshore wind beyond 2020 is necessary to ensure the implementation of the required investments in logistics assets, transport equipment, and personnel. In China, the key findings indicate that the Chinese supply chain of wind energy is mainly organized around onshore wind. Key bottlenecks exist, predominantly in logistics, and this article identifies specific areas of the supply chain where international collaboration and knowledge transfer may speed up deployment.

1. Introduction

There is growing consensus that a green transformation of our economy is necessary in order to avoid significant reduction in human wellbeing resulting from multiple environmental stresses including pollution, biodiversity loss, and climate change [1–4]. Climate change mitigation is a cornerstone in the green transformation and depends on a sweeping process of 'creative destruction' in which new renewable energy sources replace old fossil fuel-based sources. Reaching the targets for renewable energy will hinge on both technological change and massive public and private investments [5,6]. Diffusion, so far, has been varied in different geographies [7–10]. This article analyzes an often overlooked - yet crucially important - element in the transition to renewable energy systems: The ability of the supply chain to support precipitous growth and rapid technological change. This is not a trivial issue. Deployment numbers need to be exponential rather than linear. To reach current targets, the renewable energy industry would need to double its capacity every seven years for the next seventy years [11]. Such an expansion of capacity at the sector level is unprecedented in history. The challenge is grand but a mitigating factor is that the doubling of renewable energy capacity is not equal to a doubling of the numbers of workers and factories in the renewable energy industries. This is because of technological change where the energy generation capacity of each unit produced and installed is gradually increased. Yet, the technological changes pose their own challenges to the supply chain. Nowhere is this clearer than in the offshore wind power industry, the focus of this article.

Whereas wind energy has been used for electricity production at an industrial scale since the 1980s [12], the advance in offshore wind energy production is much more recent. It was not until the mid-2000s that governments and energy firms started to move from experimental pilot projects to full-fledged deployment [6,13,14]. Offshore wind is projected to play an important role in the future energy mix of many countries as further onshore wind opportunities are becoming constrained and because offshore wind provides better wind speeds as well as more area for installing larger farms which enable electricity production at scale [15]. While crucially important to future climate change mitigation efforts, offshore wind depends on a transformation of supply chains. The offshore segment differs from the onshore segment as it tends to use larger wind turbines and because the installation process at sea depends on entirely different technologies and skillsets. In particular, the offshore wind segment depends on

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challenging shipping and logistics processes which are entirely novel or which at least are new to the main constituencies who have hitherto been involved in electricity production [16]. That is why this article is particularly focused on shipping and logistics as a case study within the overall supply chain for offshore wind power.

Our research sets out to answer the following questions:

a) How ready is the supply chain for the exponential expansion of offshore wind?
b) What are the key barriers, bottlenecks, and/or constraints to offshore wind diffusion?
c) Are there differences between Europe and China as the largest markets in this regard?
d) How can the diffusion challenges be addressed with new solutions?
e) Where will the solutions come from?

The main contributions of this article are as follows:

First, we bring the supply chain perspective into the debate about renewable energy technologies in the context of climate change. Most discussions focus on the availability of different technologies to mitigate climate change or the availability of finance [17–20]. The crucial question of whether the supply chain is ready to buttress widespread deployment tends to be overlooked. The offshore wind industry provides an exemplary case of supply chain readiness for diffusion of renewables.

Second, the analysis is based on conceptual advances supplemented by our case study work in mainly Europe and China. Most articles have discussed basic value and supply chains mainly in the context of the onshore segment [21–23], or have reviewed supply-chain trends without a fine-grained analysis of the many steps involved in deployment [24–26]. This article decomposes the supply chain for offshore wind to make an analysis of sub-supply chains per life-cycle stage of offshore wind farms.

Third, this article provides a cross-continental comparison of shipping and logistics capabilities for offshore wind power. Prior comparative work has focused on policies and innovation systems [27] or has researched broader technological trajectories [28]. This article provides an in-depth analysis of the offshore segment in order to identify specific leverage points for future deployment.

This article is organized in five sections. Section 2 provides background and framing for the empirical analysis. In Section 3, we identify the main barriers, bottlenecks, and constraints challenging offshore wind diffusion and analyze to what extent and how supply chain readiness differs between Europe and Asia. Section 4 discusses ways forward by reviewing solutions for each of the main challenges for diffusion. Section 5 brings together the insights and conclusions.

2. Renewable energy systems: The role of the supply chain

Current scientific scenarios for reducing carbon emissions to avoid climate change [29] are far more demanding than the current political targets.[1] According to climate change scientists, the current political targets for carbon emissions reductions are not ambitious enough to avoid a two degree Celsius rise in the global average temperatures [20,30,31]. However, even the political goals far exceed the transformative capacity of the key sectors involved in the green transformation. The transformative capacity for renewable energy is limited by a number of barriers, bottlenecks, and constraints which we will look at in the next subsection.

2.1. Barriers, bottlenecks, and constraints

Within this article, these terms will be used as follows:

- *Barriers* are elements in the supply chain that slow down, hinder, or block the diffusion of offshore wind and renewable energy. Academically, barriers to diffusion can be traced back to the medical sciences, veterinary sciences, and physics. The opposite of a barrier are factors that facilitate or enable the diffusion of offshore wind and renewable energy.
- *Bottlenecks* are imbalances in the supply chain where the supply chain capacity is smaller than the demand. Traditional mathematical, statistical, and economic approaches to bottlenecks include capacity planning, queuing theory, calculations of optimal supply/demand balances, and simulations of the equilibrium. Goldratt and Cox [32:139] define a bottleneck as "…any resource whose capacity is equal to or less than the demand placed upon it."
- *Constraints* are challenges faced by certain resources in the supply chain that cause the capacity to be less than optimal compared to demand. Within math or engineering, constraints equal conditions that must be satisfied by the solution in question. The theory of constraints [33] outlines that for a broad definition of a system "…at least one constraint exists that limits the ability of the system to achieve higher levels of performance relative to its goal".

In the case of wind energy, the output is estimated to be 372 gigaWatt ("GW") of installed capacity per annum as of end, 2014 [13,34]. The output surpassed 400 GW during 2015 [35] with China as the world's largest market for wind energy. Using scenarios for 2050, the wind energy output required will be between 1600–4000 GW per annum [36]. There is a massive shortfall in current industrial capacity to meet an output of this scale. There are many well-known bottlenecks when it comes to producing and installing wind energy technology on an adequate scale to support the green transformation. These include:

– Scarcity of sites for new turbine installations[2] [15]
– Technologies for dealing with intermittency [13]
– Financial resources [17–19]
– Government policies [19,37–40]
– Subsidies and tariffs [18,41,42]
– Human capital and skills [43]
– Storage capacity for wind energy after production [34]
– Grid expansion and interconnection [44–46]

Acknowledging constraints in all of these areas, this article is focused on a particular set of constraints – those found in the supply chain. In order to provide a framing for the analysis, the next subsection starts by outlining the role of wind power in climate change mitigation.

2.2. Diffusion of wind power for climate change mitigation

Wind power is a central technology when it comes keeping global temperature increases below two degrees Celsius by ensuring that carbon-dioxide emissions peak and then decline before 2020 as e.g. observed in the European Union ("EU") 20-20-20 policy to reduce dependency on fossil fuels by 2020 [47]. During recent years, a boom in global wind power supply has been witnessed taking wind power output from 17 GW in the year 2000 to 372 GW in 2014 [13,34]. In a 'moderate scenario' according to Global Wind Energy Council [36], this output number will grow to 1480 GW in 2030 while in an 'advanced scenario' it will grow to 1934 GW. This latter scenario expresses a best

[1] Such as EU's 20–2020 regime; China's 12th Five Year Plan, and international agreements within the UNFCCC.

[2] Arising from local opposition, referred to as the NIMBY "not in my back yard" movement and decreasing returns on investment as the best sites are taken.

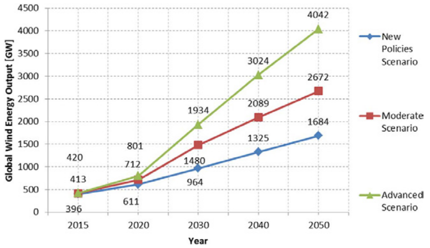


Fig. 1. Global wind energy output scenarios by 2050 measured in GW (Derived from [36]).

case wind energy vision "…which could only occur with a robust climate regime in place and the kind of political will to tackle the climate challenge across most of the global which has been missing to date…" [36:13]. In this 'advanced scenario' as depicted in Fig. 1 below, wind power capacity would reach 4042 GW in 2050 with a potential to constitute 25–30% of the world's electricity consumption [36:11] by then.

The challenges involved in such an ambitious scenario are enormous. It is highly dependent upon reducing the time scale involved in building technological capabilities, boosting the upstream capital goods industries as well as the underlying supply chains [48], and the generation of real cost savings [19,49].

Compared to onshore wind, the diffusion of offshore wind is more demanding and it is also more likely to be affected by supply chain bottlenecks. Globally, 10,000 wind turbines equal to 50 GW of offshore wind generating capacity will be installed during 2016–2025 [50]. As will be discussed, there are many bottlenecks that are general to wind power diffusion (shortage of rare earth materials, lack of skilled personnel for operations and maintenance "O & M"), while other bottlenecks are specific to offshore deployment (e.g. shortages of vessels, trained personnel, port infrastructure). To overcome these bottlenecks, a major transformation is required across the entire supply chain. Utilities are the main constituencies responsible for transforming supply chains. The next subsection addresses the main utilities and their offshore wind activities in Europe as well as China in order to provide context for the analysis.

2.3. The organization of wind power markets: The role of lead firms

The wind market is highly concentrated with the top-ten wind power original equipment manufacturing ("OEM") firms producing 71,8% of turbines installed in 2014 [34]. The capacity of these firms has grown rapidly over the last 10 years. Richter [51] argues that the utilities will play a major role in the green transformation because they control the electricity generation, electricity distribution, and electricity retail value chains to a large extent. Within the offshore wind market, the very significant upfront capital expenditure ("CapEx") commitments put the utilities in the leadership role for each project [19,49] as firstly, developers and then respectively as operators. As project leaders, developers and operators become the 'lead firms' of the total supply chain. This means that the logistics strategy of the developers will have significant ramifications for the logistics set-up of the rest of the supply chain.

With most offshore wind installations situated in Europe thus far [15], the primary experience and skills reside with European utilities. The developer constituency group of Europe has so far been dominated by utilities [14,15,52]. If we compare the business models of these European developers/utilities, the Danish government took a lead role early on in the development of offshore wind early on [51,53]. As a result, Danish state-owned utility DONG Energy is now the leading developer and operator of offshore wind farms globally as measured in already installed capacity and development pipeline [14,34]. The DONG Energy strategy has been to embrace the entire offshore wind farm construction process and to use in excess of 200 contracts to build an offshore wind farm [54]. To craft, manage, and supervise the many contracts including their implementation, DONG Energy employs in excess of 1600 people in their offshore wind energy business. This so-called *"multi-contract business model"* is very much contrasted by most other European developers where much fewer contracts are awarded in larger "contract packages" [55]. This larger group of non-DONG Energy developers is characterized by each firm having smaller number of employees. Due to having less employees, the non-DONG Energy developers are mostly relying on engineering, procurement, construction, and installation ("EPCi") firms to take on very large, individual contracts with a very wide scope of responsibilities and significant contract value. Depending on the contracting structure at the utility firm level, the overall 'lead' in the supply chain and decision making center of gravity changes which makes it complex for a single supply chain constituency to be part of both markets: In the multi-contracting market segment, small and distinctively defined contracts are offered for different slivers of the offshore wind farm value chain whereas EPCi firms and wind turbine OEMs [55,56] have specialized in taking a very large responsibility within the supply chain where the utilities go for very large individual contracts, referred to as *"single contracting business model"*.

In China, the 'big 5' utilities are tasked to implement the majority of the very aggressive national offshore wind strategy which is closely aligned with the Five Year Plans of China at a country level [57]. In the 12th Five Year Plan, central targets for offshore wind in China were 5 GW by 2015 and 30 GW by 2020. With only 487 MW installed as of the end of 2014 [13,34], the 2015 target was hard to reach even with the June 2014 decree providing a national Feed-In-Tariff for offshore wind issued by the central government in Beijing [58] valid up to the end of 2016. This Chinese offshore wind Feed-In-Tariff has been called for by industry and academia constituencies alike [59–62] for several years and is critical for diffusion forecasts to be realized [13,34,50]. The option for the individual provinces to "further top up" the centrally provided Feed-In-Tariff levels [63] is an important factor in reaching the overall targets for offshore wind in China.

From our China case study, it seems clear that the 'big 5' Chinese utilities generally resemble the DONG Energy multi-contracting model with an even stronger degree of vertical integration in the supply chain [56,64,65]. Similarly, the other and smaller developers seem to be challenged with a lack of economies of scale, more limited financial capabilities, and therefore critical challenges in terms of how to realize the implementation of offshore wind farms [66].

For wind energy, supply chains are becoming increasingly global [52] for the wind turbine itself as argued by Yuan et al. [57] "in China a system capable of manufacturing key components as blade, gearbox, generator, variable yaw system, wheel hub and tower is established." However, technological advancement is quite rapid which Yuan et al. [57] acknowledge; "…domestic components manufacturing can hardly keep up with the trend of global technology development." During the recent financial-economic crisis, a situation arose globally with austere financial policies that cited overcapacity in the markets and effectively put major projects on hold in many countries. Many wind power OEM firms can produce wind turbines, however, the main challenge lies in developing technologies to meet the demand for mega-turbines in the future. Moreover, a key challenge for expansion of direct production is the coordination of up- and downstream linkages which span many industries. The value chain may be thought of as being divided between a preparation chain, a manufacturing chain, a deployment chain, and a re-deployment chain (see Table 2ii) below).

To compare within Asia, our case study efforts in South Korea indicate that this 'runner-up' market for offshore wind in Asia

Table 1
Visits to offshore wind farms during research project.

Name of offshore wind farm visited	Country	Life-cycle focus	Timing of offshore visits
Anholt OWF	Denmark	Installation & Commissioning	April 2013 and September 2015
Middelgrunden OWF	Denmark	Operations & Maintenance	March 2015
Horns Reef I OWF	Denmark	Operations & Maintenance	June 2015
Longyuan Rudong Intertidal Trial OWF	China	I & C and O & M	July and October 2016

Table 2 i)
Offshore wind farm supply chain lead firm groupings and examples.

Activity	Project management and financial planning
Sub activity	Wind farm design
Supply chain lead firm	Utilities
Lead firm examples	DONG Energy, RWE Innogy, Vattenfall, Iberdrola, Statoil, Statkraft, Guodian Longyuan, China General Nuclear, Daneng, KEPCO, Masdar

(realistically, the second most ambitious after China) has developed a more 'modest' target of 2.5 GW by 2019 [15,67] and 7.5 GW installed by 2030 [68]. The first larger South Korean wind farms will be erected as test sites where several OEMs exclusively of South Korean origin are allowed to participate up to 2017 in order to give the local OEMs an installation base and O & M 'testing grounds'. Utilizing an effective strategy to test and improve the quality of the home market technology supported by extensive academic studies [69–71], our research indicates that the South Korean OEMs will initially try to enter the very lucrative neighbouring market of China where the quality standards are somewhat lower than those of Northern Europe. As the quality rapidly improves in the combined South Korean and Chinese 'home markets', South Korean OEMs will also wish to compete for a share of the more lucrative European and US markets: Our emperical data indicates that this may include possibly on-shoring production in Europe and the Americas to supplement South Korean exports as was also seen in the case of the South Korean car and consumer electronics industries.

A number of Chinese state-owned mega-firms (e.g. Guodian, China General Nuclear, Huaneng, Three Gorges, China Communication Construction Company) as well as South Korean conglomerates (e.g. Korea Electric Power Corporation, Hyundai, Doosan) are in the process of getting into the offshore wind business [15,56].

There is only little focus on the industrial capacity required to support the transition to renewable energy systems [72]. While all observers seemingly agree that wind power needs to play a major role in the green transformation, the main bottleneck is typically discussed as a question of finance, not as scaling up capacities. In this article, we discuss this issue as both direct production capacity and as upstream and downstream linkages. In the next subsection, we review the existing literature in the field from different angles.

2.4. What does the literature tell us about renewable energy supply chains?

Only limited attention has been paid to renewable energy supply chains in the scholarly literature. In the literature focused specifically on supply chain management, there has recently been a surge of interest in sustainability performance of supply chains [73] and some recent analysis has been targeted specifically towards reduction of carbon emissions [74]. However, these studies have been aimed mainly at the environmental impact of supply chains in manufacturing industries (resource use, transportation, recycling) rather than on supply chains in the energy sector, let alone renewables. One important exception is the paper by Halldórsson & Svanberg [75] which provides a conceptual framework for analyzing energy supply chains from energy sources (raw materials) to consumption. They show that various steps in energy supply chains overlap while other elements are specific to specific energy types (coal, oil, gas, biomass etc). In their paper focusing on supply chains for various renewable energy forms, Wee et al. [76] define conversion cost, location constraints, and complex distribution networks as barriers to generation and utilization of renewable energy. They argue that the barriers may be overcome "through the involvement of governments, researchers, and stakeholders in the development of renewable energy". The downstream distribution and use of energy is based on a shared source availability of electricity (coal, nuclear, solar, wind etc.) whereas the energy conversion step is specific to each source. However, there are many overlaps when it comes to upstream supply of technology for different energy sectors. The implication is that analysis must transcend the specific sector in question: "Building up supply chains of, e.g. wind energy requires producers to become attractive customers of suppliers of turbines and maintenance services already developed in other industries such as automotive and aerospace" [75:70]. This seems particularly important in offshore wind for example, as there are many overlaps with the offshore oil and gas sector (vessels, floating cranes, maintenance service, de-commissioning, etc.).

In the energy and sustainability literature focused on the role of renewables in low carbon transformation, the specific topic of supply chain capacity has been surprisingly absent [77]. One example is a recent study of the European onshore and offshore wind energy installations [25] which reveals a decoupling process between the onshore and offshore supply chains. The authors argue that this will result in higher research & development costs for those firms active in onshore as well as offshore wind which should be accounted for by policy makers in the form of subsidies and regulations.

Conversely, in the supply chain management and logistics literature, very little focus has been given to renewable energy supply chain except the aforementioned paper linking supply chain management and energy using three different trajectories of which the energy supply chain is one [75]. Within areas of marine planning and offshore wind planning, little attention has been paid to the topic of shipping and logistics. A few exceptions include a review of all decision support tools for offshore wind [78] which includes logistics within three segments (overall project cost segment, installation, and O & M), a comprehensive guide to offshore wind farm installation [79], a decision support simulation tool for logistics strategies during the offshore wind farm construction phase [80], and a simulation tool for logistics considering weather and vessel costs during the installation phase [81].

Within the area of O & M, a comprehensive literature review for offshore wind O & M logistics exists [82] and in addition, several papers provide some input regarding shipping and logistics including simulation of offshore fleet operations optimization [83], a verification and validation of four O & M models of which three have a shipping/logistics/maritime component [84], a proposed approach to O & M where logistics is a key focus regarding availability [85], and a PhD thesis focusing on safety (subassembly operations and crew transfer) and efficiency (optimization of maintenance support organization) of O & M [86]. With this review of existing literature as a point of departure, the next subsection introduces our case study used to generate the empirical data to support the research findings of this article.

2.5. Data collection

This article seeks to assess bottlenecks for offshore wind supply chains. No statistical data exists to measure the discrepancy between supply chain capacity and current/future needs, nor is there an established method for produce such measurement.

Table 2 ii)
Offshore wind farm life-cycle activity summary with examples from Europe and Asia.

The wind farm supply chains		Development & consent (D & C chain)	Installation & commissioning (I & C chain)					Operations & Maintenance (O & M chain)	De-commissioning (De-comms chain)
			Inbound				Outbound		
			WTG inbound	BOP inbound			Construction/installation /commissioning		
			WTG	Foundations	Cables	Sub-station			
Sub activity		Surveys	Assembly Modules production	Assembly Modules production	Manufacturing	Assembly Modules production	Installation landside Installation BOP Installation WTG	Preventive maintenance Unscheduled maintenance Contingency maintenance	WTG de-commissioning BOP de-commissioning Site restoration
Supply chain lead firm		Utilities Government authorities	WTG OEMs Module OEMs	Foundation BOPs	Cable OEMs	Sub-station OEMs Foundation OEMs	Utilities EPC providers WTG/BOP OEMs Shipping companies Logistics companies	Utilities EPC providers WTG/BOP OEMs Shipping companies Helicopter companies	Utilities Government authorities Shipping companies Logistics companies
Main firm examples	*Europe*	Crown Estate	Siemens Wind Power	Bladt	Nexans	Semco Marine	A2SEA	World Marine Offshore	DONG Energy
		Energinet.dk	MHI Vestas	Bilfinger	NKT	Bladt	Fred Olsen	N-O-S	Vattenfall
		DONG Energy	LM Windpower	Rambøll		ABB	DSV Baltship	Esvagt	Crown Estate
		Vattenfall	Gamesa Areva (Adwen)	Per Aarsleff			Seajacks	Blue Water Shipping	Energinet.dk
		RWE	GE Alstom	Ambau			Van Oord	DONG Energy	Swire Blue Ocean
	Asia	Longyuan	Goldwind	CCCC/ZPMC	Zhongtian Technologies	ZPMC	SBSS	SINO-HITECH	CGN
		KEPCO	Titan	China Offshore Oil Eng	Qingdao Hanhe	CGN	CCCC	SEwind	
		CGN	United Power	Nantong Ocean Water	Ningbo Orient		Longyuan Zhenhua	Envision Energy	
		Daneng	Haili	Jiangsu Daoda Heavy	Fujikura Shanghai		Daneng		
		Huadian	Sinovel	Haili			Profundo		

This research used a case study approach focusing on the world's largest markets, Europe and China. We focused on critical embedded sub-unit cases [87], namely the leading offshore wind developer and operator in Europe (DONG Energy) and China (Guodian Longyuan). The primary source of information for our case studies are 30 formal interviews with interview layout defined by Kvale & Brinkmann [94] conducted within the shipping and logistics sphere of the supply chain in and around these firms. The interviews were conducted in the period from November 2014 through October 2016. The interviews were divided equally between Europe and China. There are limits to the methodology used in this research as the studies were exploratory in nature. The use of critical cases enabled an insight into the situation as it looks from the vantage point of the most advanced offshore wind farm developers in Europe and China, but extrapolation of the results needs careful interpretation. We hope that the conceptual framework and methods used here will enable further, large scale survey research.

Our case study builds on prior research on the wind power sector with focus on China and a comparison of innovation paths for wind power between China, India, Germany, and Denmark [88–92].

In Europe, we opted to mainly use a single-company case study approach within the leading offshore wind farm developer and operator firm [14,93]. In China, several advance study trips with pre-interviews had to be made to build the relationships enabling the authors to gain access to the interviewees and as such, the total research time spent in China amounted to approx. 2 months. In Europe, the interviews were conducted over a 4-month period from November 2014 through February 2015 with interview guides and interview planning carried out from July through October 2014. In China, the interviews were carried out during 2 research trips taking place over a 4-month period from July 2016 through October 2016. In Europe, each interview lasted between 60 and 90 minutes and each interview was largely based upon the interview guide developed for the purpose. In China, the different interviews lasted from 45 minutes to 7.5 hours and contained different elements of translation and clarification during the meetings even though the interview guide had been prepared in a written presentation format in advance, using both English and Chinese characters. In Europe, 14 of the 15 interviews were audio taped and later transcribed with full consent from the 17 interviewees. In China, many more people attended each meeting (from 2 to 8 interviewees including translators and observers in each of the meetings) and audio taping was not permitted or not possible. In Europe, one of the interviews was supplemented by participant observation. In China, 12 of the 15 interviews included an element of participant observation. Our European case study has been published [93]. Our China case study is in the process of being published.

For the South Korean part of our case study, South Korea visits were supplemented by email follow-up and discussions with relevant stake-holders in the UK, Denmark, and the US during 2014 and 2015.

In the period from 2013 to the end of 2016, our case study efforts were supplemented by additional participant observation and semi-structured interviews [24,94]. These included site visits and semi-structured interviews pertaining to four offshore wind farms [54,95] as depicted in Table 1. In addition, our research efforts included the participation in a 20-month long cross-industry cost reduction initiative pertaining to the logistics part of the O & M life-cycle phase, conducted from August 2014 through April 2016. The research findings from this case study were supplemented with an in-depth analysis of 11 significant studies on offshore wind levelized cost of energy with focus on the logistics share of Operational Expenditure (“OpEx”) and O & M costs. This case study is in the process of being published.

3. Supply chain constraints

Section 2 outlined a number of bottlenecks for the diffusion of renewable energy. In this article, we do not deal with these ‘relatively known’ bottlenecks. Instead, we focus on a largely overlooked issue: The constraints in the supply chain. Our perspective is both upstream and downstream, we focus on CapEx, OpEx, and the cost for de-commissioning/site abandonment (“AbEx”) [130]. To further focus and exemplify, we put the logistical challenges contained in the supply chains in the center. The logistics and shipping support to the offshore wind industry has not been researched in much detail as a stand-alone topic; it usually forms part of a broader supply chain review [43,55,89,96]. In the next subsection, we will review the different supply chains within the life-cycle of an offshore wind farm including the associated shipping and logistics challenges faced.

3.1. Logistical challenges in offshore wind supply chains

Building on BTM a part of Navigant & Poulsen [16], Poulsen et al. [54,95], and Poulsen [24], a wind farm life-cycle can generically be split into four key phases:

- Development & consent
- Installation & commissioning
- Operations & maintenance (O & M)
- De-commissioning

Table 2ii) above outlines key activities/sub-activities within the offshore wind farm cradle-to-grave life-cycle and identifies the sub-supply chains for each of the life-cycle phases.

As outlined above, utilities act as wind farm developers/operators. As the offshore wind farm supply chain lead firm, these firms maintain overall project management and financial management functions for the duration of the entire wind farm life-cycle [97]. Each wind-farm life-cycle phase contains several bespoke supply chains:

1. In the *development & consent* phase, special geophysical, geotechnical, ornithological/mammal, and other survey vessels enable different *surveys* to be carried out as part of the site *planning* efforts. Sometimes, survey aircraft are also used and surveys may continue into the construction phase [97]. The surveys are executed to ensure that the offshore wind farms can be built in the right locations with the least impact on animal life [98,99] or nature in general [100,101], and are based on the correct conditions/assumptions e.g. the seabed being made available to the developer [54]. The timing is often in advance of awarding the offshore wind farm sites to developers as well as during the bidding process.
2. The *installation & commissioning* phase has a distinctive *inbound* and a substantially different - but similarly very distinctive - *outbound* supply chain. In the *inbound supply chain*, key offshore wind farm components such as nacelle, blades, tower, foundation, cables, and sub-station are assembled/built using very different manufacturing and shipping/logistics processes. By far the most complex individual wind turbine module is the nacelle which in some cases consists of up to 65,000 individual parts and components [91]. The assembly process is sometimes a combination of certain sub-assembly routines, just-in-time practices, on-site warehousing, and vendor managed inventory [102]. In other cases, key suppliers are co-located within the nacelle assembly plant premises to ensure effective transfer of pre-assembled components to be mounted in the nacelle [103] and smooth factory/plant logistics. The somewhat nascent and not yet industrialized offshore wind industry is often compared to the automotive industry in terms of how especially the component assembly/manufacturing process could be improved [104–107]. However, to illustrate the diversity of the inbound supply chains involved in assembling/manufacturing, BVG Associates [108] (2014) conducted an extensive UK offshore wind supply chain readiness study for the UK Crown Estate where parallel sectors considered include aerospace, composites, nuclear, oil & gas, and rail as well as automotive. Transport giant DP-DHL

furthermore included truck assembly, fibre optic cables, and shipyards in their analysis of relevant parallel industries [109]. The *outbound installation & commissioning phase* for offshore wind farms includes construction of land-based structures such as onshore sub-stations, ports, storage sites, and warehouses. In addition, the installation of offshore Balance of Plant components such as cables, offshore sub-stations, and foundations may happen with different supply chain constituencies acting as lead supply chain firm [55] for different parts of the process such as the export cable, offshore sub-station, array cables, offshore accommodation solutions, wind turbine foundations, and finally wind turbine erection/installation/commissioning.

3. The *O & M phase* has a *preventive servicing* supply chain which can be scheduled in advance as different parts and modules are expected to come to their end-of-life. This supply chain lives for the entire duration of the offshore wind farm operational phase which can be some 20–25 years or possibly longer. Because of the predictability of this planned supply chain coupled with the long duration of the life-cycle phase, the field is starting to be researched in greater detail. Studies include a general review of O & M transport logistics organization literature [82], O & M fleet size optimization modelling [110], and O & M logistics planning [83]. Studies from the offshore oil & gas sector may also be useful given the more mature stage of development here [111,112]. However, when unpredicted break-downs to individual wind turbines occur, *unscheduled maintenance* is needed. This maintenance is more expensive and also more logistically challenging [113]. This requires a different and very flexible logistical response where the break-down is first diagnosed and then repaired. An unexpected *stoppage of the entire offshore wind farm* due to e.g. a broken cable or a mal-functioning sub-station is the worst challenge of an offshore wind farm operator: According to Møller et al. [114], shipping and logistics capabilities are critical when a wind turbine or the entire offshore wind farm break down. The response warranted is different for the entire farm compared to a single wind turbine.
4. The *de-commissioning* phase has only been tested in a very limited manner so far for offshore wind according to Feld [115]: Only a few met-masts and LiDAR buoys have been de-commissioned. During 2016, 5 offshore wind turbines at Yttre Stengrund in Sweden were fully decommissioned according to Patel [116] and another 11 turbines at Vindeby, Denmark will follow also in 2016 [117]. Conversely, wind turbine de-commissioning for onshore wind farms is now taking place fairly frequently [118,119]. A project called Offshore De-commissioning of Installations ("ODIN-Wind") has been established by the Technical University of Denmark and industry partners led by NIRAS [120]. As part of the on-going O & M efforts described above as well as de-commissioning, different parts and components are brought to shore for refurbishment and/or recycling according to Møller et al. [114]: This reverse supply chain flow is, however, still very immature for offshore wind at this time.

In addition, Table 2i) outlines examples of actual supply chain constituencies including those acting as lead firms within the respective activities. It should be noted that differences exist for different activities and sub-activities across different geographies. One example is the developers in China who wish to remain in control over 'all parts of the offshore installation process for the outbound supply chain': According to Zhang [64], the wind turbine installation scope is kept 'in-house' for now and not outsourced to the wind turbine OEM nor EPCi providers as is the case in Europe. Elaborating further on this matter, Xu [65] highlighted that it is "…necessary for Chinese developers to first gain full control over the sub-processes and then only later-on decide upon strategic insource vs. outsource and make vs. buy decisions in terms of both logistical matters and the actual supply chain…" itself. Both Zhang [64] and Xu [65] explained that this was attributed to internationalization aspirations as also described by Zhang et al. [56]. In Europe, it is common that the leading wind turbine OEMs act as supply chain lead firms responsible for the wind turbine installation and commissioning process [55]. In Europe, some wind turbine OEMs aspire to become full EPCi or turnkey providers of complete offshore wind farm solutions including Balance of Plant components [121]. In the next subsection, we identify logistics and shipping bottlenecks in Europe and China.

3.2. Logistics and shipping bottlenecks: Europe and China

During a wind farm life-cycle, a wide range of vessels are used. This includes geophysical survey vessels (development & consent phase), cable laying vessels (installation & commissioning phase), and wind turbine installation vessels (installation & commissioning, O & M, and de-commissioning phases). In the Anholt offshore wind farm case [54,122], more than 100 different individual vessels were used during the development & consent and installation & commissioning phases comprising 17 different vessel types.

For monopile/transition piece wind turbine foundation installation, different gravity based systems have been tried, and quite often a piling hammer mounted on top of a heavy-lift vessel or barge was the preferred solution. In the Anholt case [54], the heavy-lift vessel "Svanen" was used to hammer the monopiles into the sea bed and the transition pieces mounted on top. A layer of special grout has acted as the "glue" between the monopile and transition piece where the two converge. For earlier installations in the North Sea, instability of this grout layer has caused challenges and may need to be replaced [24,123]. Supposedly fairly straight-forward to construct to specifications transition pieces were ordered for one wind farm project in the UK from China which were constructed near Shanghai and transported to the UK by the manufacturer [124]. Subsequently, a dispute arose on quality issues in the monopile construction and this caused a lot of extra work and cost for the original owners (Fluor in partnership with Scottish and Southern Energy) and the Chinese provider of the monopiles. Although seen as a damper on further integration of large Chinese components (and potentially wind turbines), there is no doubt that inter-regional transport of both wind turbine and Balance of Plant components will increase in the future as global competition gets under way.

The findings of our case work in China indicate that the wind turbine generator part of the Chinese supply chain is fully developed whereas the Balance of Plant component supply chain seems to be lacking behind. Also overall financial modelling, project management, shipping/logistics, O & M, and de-commissioning solutions [64,65] have not been fully developed for offshore wind in China. The already approved near-shore and inter-tidal offshore wind farms have now been activated and swiftly moved into the installation & commissioning phase along with key "real offshore" projects. A total of 44 projects were activated in June 2014 with the new Feed-In Tariff. Given the relatively low offshore install base up to 2014, our research findings indicate that a number of wind turbines may face quality challenges with e.g. rust and corrosion once operational: This was the case for the initial European offshore wind turbines and is also the case for current Chinese onshore wind turbines. Our research findings also indicate that it will be challenging for China to install the many offshore wind farms at the desired pace given the lack of experience including lack of installation assets and trained personnel. However, as was the case for onshore wind in China [89], close alignment exists between the national goals as set out in the Five Year Plan and the execution of the supply chain process. As such, the revised 2020 target of 10 GW of offshore wind in China may still be reachable.

3.2.1. Offshore wind farm construction logistics

For offshore construction, wind turbine installation vessels are used in the North Sea and as a shortage in the supply of these vessels was predicted during 2007–2008, different risk mitigation strategies were pursued by wind farm developers/operators, EPCi firms, and utilities. Denmark-based state-owned utility DONG Energy acquired wind turbine installation vessel operator A2Sea in 2009 and subsequently sold 49% of the firm to wind turbine OEM Siemens Wind Power [24]. A2Sea now operates in a public-private partnership set-up and with financially strong owners, A2Sea contracted a Chinese shipyard[3] to build further wind turbine installation vessels which have since then been delivered. Constructed to comfortably install 4 MW wind turbines, the 2 most recently delivered A2Sea vessels may not be fully suitable to install wind turbines yielding an output of 6, 7, 8, 10, 12, or 15 MW. Therefore, the vessels were to some extent already "too small" once delivered to A2Sea in Denmark from the yard in China as the weight of nacelles, length of blades, and height of towers will cause the vessels to have challenges carrying the larger wind turbines to the installation site and for the cranes on the vessels to perform the installation task.

3.2.2. Offshore wind farm operations logistics

Once operational, a 20–25 year O & M period commences in order to service the offshore wind farm. Here, the O & M tasks require technicians, personal protection equipment for the technicians, spare parts, tools, and sometimes major wind turbine modules or components to be transported to the wind farm site for scheduled preventive maintenance or ad-hoc emergency maintenance. To transfer technicians, their gear, tools, and spare parts, helicopters, transport vessels, and crew transfer vessels of different kind are used along with accommodation platform and accommodation vessel solutions. To replace entire wind turbine modules or components, smaller wind turbine installation vessels are often utilized to e.g. replace a blade or gear box. In other cases, it is necessary to lift off the entire rotor and nacelle to be able to perform major overhauls to nacelles which have been damaged or are malfunctioning. These operations may take place in rough seas causing the technicians to be seasick while making transfer operations from the vessels to the wind turbine challenging as the technicians need to alight the crew boats in affected by wind and waves in order to access the stationary monopile/transition piece construction upon which the wind turbine is mounted.

3.3. Supply chain readiness comparison: Logistics in Europe and China

In Table 3 below, the correlations between offshore wind farm lifecycle phases, the different supply chains involved (discussed above), the different financial terms used (CapEx/OpEx/AbEx), and the overall value chain structure (planning chain, manufacturing chain, deployment chain, re-deployment chain) have been depicted. Based on the inter-regional case study work performed, key European and Asian firms/constituencies within each sub-activity have been listed as outlined by the squares for each supply chain. China has been chosen as our specific Asian comparison market[4] due to its relative mature state compared to the rest of Asia [13,15,34,50] and we have deselected Americas in our analysis because the most promising market in the US [13,15,34,50] has no significant install base yet except the 5 Block Island turbines erected off Rhode Island in August 2016 (in the US, Siemens Wind Power had been selected as the supplier of wind turbines for the more significant Cape Wind Project which was, however, subsequently delayed). Traffic light colour codes (red/orange/green signifying logistical readiness) have furthermore been applied in Table 3 to highlight the present logistics and shipping status of the supply chain in Europe (outer square) and China (inner square).

The findings outlined in Table 3 indicate that the logistics and shipping market supporting the offshore wind energy industry is more mature in Europe in the form of a more ample supply of assets, personnel, systems, procedures, as well as knowledge. This mainly has to do with the diffusion of offshore wind in China vs. Europe: By the end of 2014, China was the world's largest onshore wind market with almost 115 GW of installed capacity [34]: Conversely, China had an offshore wind install base of 1 GW compared to Europe's 11 GW of offshore wind track record by the end of 2015 [138].

3.3.1. Global wind turbine supply chain and largely European offshore wind experience

The research depicted in Table 3 furthermore shows that China's journey towards offshore wind is building upon the technological advancement trajectory from its giant onshore wind industry [23,89] and ensuing supply chain. As a result, key onshore / offshore wind farm wind turbine components such as nacelle, rotor, and tower are in reasonable supply, also for offshore wind. However, the findings similarly indicate that when it comes to the Balance of Plant supply chain/manufacturing base, offshore wind farm construction, component installation, commissioning, O & M, de-commissioning, and recycling, the offshore wind industry in China is just starting to take off. As such, the Balance of Plant supply chain and surrounding logistical infrastructure may be considered more of a regional European capability so far.

3.3.2. Weight and size of components: Direct impact on logistics

With new offshore wind turbine requirements for 5, 6, 7, 8, and even larger MW output ratings, nacelles are already weighing above 350–400 t[5] in total. This puts a lot of pressure on the OEM designers/engineers to talk to the shipping and logistics planners early in the design phase in order to ensure that the final nacelle can indeed be transported [125]. Often, transport considerations need to include country and/or regional infrastructure such as roads, bridges, tunnels, and ports [126]. Modularized construction and ultimate final assembly in port areas are the latest tools utilized by OEM's such as Siemens Wind Power and MHI Vestas in Denmark.[6] Testing is also required especially before serial production and for this purpose, Denmark has developed a large-scale test-bench at LORC near Odense and an onshore test site in Østerild near Aalborg where offshore wind test machines need to be transported to for testing. With wind turbines yielding 10–15 MW presently under design in China, South Korea, Denmark, Germany, and the US, the transport challenges will only be further exacerbated.

When it comes to foundation production, the steel structures are very large and heavy. Consequently, a manufacturing location near to or in a port area is therefore preferred. During site visits to construction sites of tripod foundations in Germany,[7] monopile/transition piece foundations in Denmark,[8] and foundations in China,[9] it was found that in almost all cases, port proximity and port access is a crucial factor when selecting a site for offshore wind foundation production. Foundation producer Bladt Industries in Aalborg, Denmark uses areas at both the Port of Aalborg and LORC to have enough space for both wind turbine foundation construction and production of offshore wind high-voltage alternating current transmission sub-station top side structures/foundations. Similarly, Shanghai-based ZPMC division of the China Communication Construction Company EPC conglomerate utilizes a dedicated 2+ square-kilometre site with a 3-kilometre port

[3] Interviews with A2Sea in Denmark (April 2013), interviews and site visit with the owners of the Chinese yard/construction facility ZPMC (September 2013), and site visit to the Chinese yard COSCO Nantong/Qidong (October 2015)

[4] Our case study work in Asia also comprises offshore wind developments in India, South Korea, Japan, and Taiwan

[5] Discussions with OEMs in China (September 2013) and Denmark (February 2014)

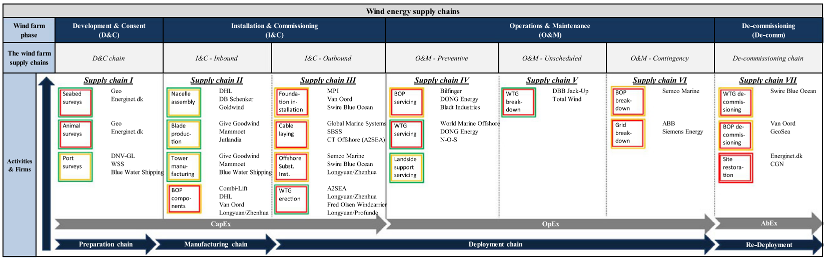
[6] Visit to the Port of Esbjerg (December 2013)

[7] Visit to the port of Wilhelmshafen (March 2011)

[8] Visit to LORC (August 2013) and interview with the port of Aalborg (December 2013)

[9] Visits to Nantong, China (September 2013; July 2015; October 2015)

Table 3
Life-cycle phases, supply chains, and correlation with CapEx/OpEx/AbEx as well as chain view.



quay access on site near Nantong in the Jiangsu province for offshore wind module production (towers, monopiles, transition pieces, etc.). At this manufacturing site, ZPMC also constructs wind turbine installation vessels specialized for the Chinese inter-tidal and offshore markets. Finally, ZPMC houses their logistics/shipping joint-venture with Longyuan division of the China 'big 5' utility, Guodian.

Cable production is an area that may occasionally be overlooked. However, the production of both export and array/infield cables has sometimes been faced with bottlenecks and logistically, so has the area of cable laying. As a consequence of cable laying vessel supply shortages, the DONG Energy/Siemens Wind Power joint-venture firm, A2Sea, acquired cable laying specialist firm CT Offshore which has now been fully integrated into A2Sea. Possibly the most infamous case of cable laying delays is the situation for the offshore wind farms in Germany [91]. According to Feld [114], severe shortages in trained offshore wind cable laying vessel personnel is a bottleneck and overall threat to the industry as a whole.

3.3.3. Supply chain readiness: Logistics in Europe and China

In Table 4 below, the supply chain readiness has been depicted in summary form as a result of our cross-case analysis work. Focus has been put on those supply chains which our research indicates to have had the largest impact on the levelized cost of energy (supply chains II, III, IV, V, and VI) from a logistics perspective [127–130]. Our cost focus areas are based on the European case study with the world's leading offshore wind farm developer and operator [93]. A score from 0 to 3 has been applied in terms of supply/demand for shipping and logistics service offerings within Europe (depicted as 'EU') and China (depicted as 'PRC') as follows:

- 0 indicates that supply seems to be non-existing and that this factor *blocks* offshore wind diffusion
- 1 indicates a supply constraint with a *negative impact* on offshore wind diffusion
- 2 indicates supply/demand balance with a positive yet *limited impact* on offshore wind diffusion
- 3 indicates sufficient supply with a *positive impact* on offshore wind diffusion

A traffic light colour coding has been applied in Table 4 as well in order to make the findings more clear (0 and 1 marked as red, 2 marked as yellow, and 3 marked as green).

4. Addressing supply chain constraints

In Section 3, we unveiled the logistics and shipping constraints of the supply chain gradually through our inter-regional case study. We detailed the life-cycle phases including the major sub-supply chains and argued why they are distinctively different from a logistics perspective. We concluded with a logistics readiness assessment where we contrasted Europe with China along a 4-dimensional scale focused on offshore wind energy diffusion. In the following subsections, we will discuss how to alleviate these constraints.

4.1. How the supply chain constraints may be alleviated – construction logistics

When we review the CapEx findings of Table 4 above (supply chains II and III), EU based developers will mainly need to be able to deal with the logistical challenges associated with transporting, lifting, and installing a new generation of jacket foundations which are now being constructed. As offshore wind farms move further offshore and into deeper waters, jacket foundations will replace the previously used monopile/transition piece foundation type [131]. Similarly, the EU developers and governments will also need to better deal with the logistical challenges associated with both offshore sub-stations and export cables. In terms of offshore sub-stations, DONG Energy's order of 5 locally made UK offshore wind farm substations[10] for their UK pipeline of offshore wind farms is a good example of how market leading DONG Energy starts to industrialize and modularize the supply chain while simultaneously creating jobs locally in the markets they serve. However, the logistical infrastructure needs to follow: With some 60–70% of wind farm life-cycle cost related to upfront CapEx [121], accurate planning and forecasting processes including logistics have proven to be crucial for European developers in terms of pay-back and profitability of the offshore wind farms. This directly affects the ability on the part of the developers to secure adequate offshore wind farm project financing [121,132]. The wind farm construction process has undergone several stages of development and improvement in Europe over the past 20+ years since the first Bonus (now Siemens Wind Power) wind turbines were installed offshore in Vindeby, Denmark. Although much more advanced ashore, in the ports, and offshore today compared to 1991, 2005, or even 2010, the installation & commissioning process is far from being considered to be in a mature or steady-state condition as evidenced by new construction transportation

[10] Announced during the UK offshore wind conference in Glasgow, Scotland during June 2014

Table 4
Offshore wind supply chain readiness with focus on shipping and logistics in Europe and China.

	0	1	2	3
Supply chain #II - Inbound to manufacturing				
Nacelle				EU, PRC
Tower				EU, PRC
Blades/hub				EU, PRC
Wind turbine foundation monopile/transition piece		PRC	EU	
Wind turbine foundation jacket	PRC	EU		
Onshore sub-station/booster station			PRC	EU
Offshore sub-station/booster station		PRC	EU	
Offshore sub-station foundation		PRC		EU
Export cables	PRC			EU
Array/infield cables		PRC		EU
Supply chain #III – Installation and commissioning				
Onshore sub-station/booster station			PRC	EU
Offshore sub-station/booster station	PRC	EU		
Export cables	PRC	EU		
Array/infield cables		PRC	EU	
Wind turbine/offshore sub-station foundations		PRC	EU	
Wind turbine generator		PRC	EU	
Supply chain #IV – Preventive operations & maintenance				
Preventive/planned (wind turbine generator)		PRC	EU	
Return flow (reverse supply chain)		PRC	EU	
Supply chain #V - Unscheduled maintenance				
Unscheduled/Break-down (wind turbine generator)	PRC	EU		
Supply chain #VI – Contingency maintenance				
Contingency (entire offshore wind farm)	PRC	EU		

concepts introduced for safety purposes using roll-on/roll-off vessels to minimize vertical lifts, for example [133]. *Our research indicates* that the European supply chain is largely ready to match the future market requirements but that the area of logistics is suffering for a single reason: No binding legislation about offshore wind exists in Europe beyond 2020. It follows that because offshore wind is not yet competitive in its own right compared to other electricity generation e.g. levelized cost of energy of nuclear or coal generated energy, none of the supply chain lead firms seem willing to enter into the necessary and binding long-term agreements with the shipping and logistics industry firms that would enable these firms to invest in the necessary infrastructure, assets, and personnel necessary to support the planned diffusion in the "home market" of Europe. To alleviate this challenge, *our recommendation is* that the EU considers implementing binding legislative offshore wind energy targets by member country up to 2030.

Conversely for the offshore wind CapEx in China, strong logistical capabilities only exist in relation to the manufacturing the wind turbine itself as well as onshore sub-stations. For the remaining logistical needs, assets, and infrastructure, the Chinese supply chain faces a steep logistical learning curve [64,65]. *Our research indicates* that China's formidable roster of ultra-large state-owned conglomerates - led by the 'big 5' utilities and supplemented by the massive supply of state-owned and private Chinese firms - are of course theoretically capable of leading China down the path of massive and rapid offshore wind diffusion as politically desired. Our research also suggests that the 12th Five Year Plan mandate for China to focus on indigenous innovation had caused some degree of isolated Chinese sub-optimization. This has occurred in many areas including the Balance of Plant supply chain itself which is not yet fully developed in China and also within the critical diffusion area of offshore wind shipping and logistics. This sub-optimization is both costly and time consuming for China. To alleviate this challenge, *our recommendation is* that China considers implementing legislation that supports Chinese firms in embracing European experience, know-how, and skills. The authors believe that this is the only option to jointly create the necessary Chinese offshore wind logistics infrastructure with suitable assets, trained personnel, and the right competencies for China's very special logistical conditions. These special conditions include inter-tidal zones and the – for China as a whole – critical main rivers, the Yellow River, the Yangtze River, and the Pearl River, with river delta offshore wind construction location opportunities being exploited.

4.2. How the supply chain constraints may be alleviated – operations logistics

When we consider the OpEx findings summarized in Table 4 above (supply chains IV, V, and VI), EU based operators are gaining traction when it comes to preventive maintenance logistics (supply chain IV) with the exception of the reverse supply chain for the return flow. Academia is supporting this with relevant research as outlined above [82,83,110]. Europe is just now getting enough streamlined information in terms of operational "big data" type data sets for offshore wind farms and this is crucial to measuring performance, comparing wind turbines, and working with the OEMs to improve performance quality in different kinds of weather and wind conditions at sea [113]. *Our research indicates* that EU operators still need to deal more appropriately with the logistical challenges pertaining to unscheduled maintenance challenges for individual wind turbine positions (supply chain V) and with logistics contingency plans (supply chain VI) when the entire offshore wind farm shuts down (supply chain VI). *It is our assessment* that during 2017, the operational European offshore wind farm install base will reach a point of critical mass at least for leading operator DONG Energy as well as other prominent operators E.On, RWE, and Vattenfall. This critical mass milestone will most likely enable these operators to individually create a level of industrialization, a degree of operational synergies, and produce some economies of scale across their respective portfolios of operating offshore wind farms. A considerable challenge does, however, exist for smaller offshore wind operators because their OpEx cost base will remain relatively stabile as they have fewer options to make improvements within a small portfolio. To alleviate this challenge, *our recommendation* is again for EU to implement binding legislative targets and speed up diffusion up to 2030 by when offshore wind should be a viable stand-alone energy form also compared to other energy forms from a levelized cost of energy perspective due to the industry's on-going drive for cost savings. Only with a much larger and blended portfolio of "old 2010s" and "newer 2020s" offshore wind farms may proper OpEx critical mass be obtained across Europe.

In China, it has long been suspected that onshore wind farm operators have faced challenges from an O & M perspective. However, as many challenges derived from the Chinese wind turbine OEM industry, the actual O & M challenges faced have not been shared openly outside China so far. Basic challenges with bearings, yaw gears, and gearboxes produced in the localized Chinese onshore supply chain are now being shared publicly due to the extent and severity of the challenges faced [134]. This has implications for the offshore aspirations of the Chinese wind industry. In the 1990s when Europe started the offshore wind journey, many technological 'teething problems' were faced with e.g. corrosion, rust, and other issues as Europe essentially moved onshore technology into the salty waters offshore using onshore personnel to do so. With this 25-year track-record, Europe has learned that all operations offshore are much more expensive than similar operations carried out ashore. Therefore, some of the basic challenges with the onshore wind turbine generator technology could advantageously be sorted out with support from European firms and academia before China executes a revolutionarily paced push of onshore technology into the offshore sphere.

5. Conclusion

The main question addressed in this article is provided in the title: *Is the supply chain ready for the green transformation*? Our analysis of the supply chain readiness was presented by using our case studies focusing on the logistics and shipping aspects of the overall offshore wind supply chain. Due to the global plans for offshore wind diffusion, we chose to contrast Europe with Asia because the Americas development is still at an early stage. Within Asia, we opted to focus on the fastest maturing market which is China although our case study is pan-Asian in nature. By drawing on prior research that broke down the wind farm life-cycle into phases, we introduced seven sub-supply chains and this allowed analysis of the logistical readiness of the supply chain broken down into different segments. These sub-supply chains were reviewed with an objective of how to alleviate the constraints. This was done in several steps based on our 5 research questions and this concluding section summarizes and brings together the key insights.

We first analyzed the current situation through a set of questions pertaining to how *ready the supply chain is* for the exponential expansion of offshore wind in the energy system. This included our review of the *key barriers, bottlenecks, and constraints*. Through our case study, we subsequently analyzed and highligted the *differences between Europe and China* as the largest markets in this regard.

The second set of questions looked at the situation in the future. Here, we first analyzed how the diffusion challenges can be *addressed with new solutions*. And finally, we looked at *where the solutions will come from*.

The research presented in this article provides grounding for directing the effforts in the drive to expand offshore wind. The efforts should involve government policy and research efforts, corporate investment, as well as collaboration in knowledge transfer. Our overall answer in terms of supply chain readiness for the green transformation is: When analyzing the logistics part of the global supply chain for offshore wind, the supply chain is *not ready*.

Based on current scenarios for 2050, wind energy could make up as much as 25–30% of global electricity consumption by then [36]. *Our empirical data gathering efforts* [11] *indicate* that the Chinese offshore wind operations & maintenance set-up is quite rudimentary compared to Europe when it comes to ports, vessels, tools, personnel, and skills. This may have less impact in moderate wind speed areas visited in the Jiangsu Province of China: However, when provinces like Fujian and Guangdong start to execute their extensive plans to add wind capacity, the typhoons and higher wind speeds resemble conditions similar to the North Sea in Europe. It is our assessment that China will need to carefully study the European operations & maintenance experiences for both onshore and offshore wind. The Chinese onshore diffusion has exceeded all targets set by the Chinese government since the 2006 implementation of the Renewable Energy Law [89]. This rapid diffusion comes with clear and present operations & maintenance quality challenges. These already existing onshore operations & maintenance challenges could be exacerbated further for offshore wind at a much higher cost for China. To alleviate this sizable conundrum for China, *our recommendation* is to openly collaborate and innovate together with especially European counterparts both at government level, at academia level, and at firm level.

It seems clear from our contextual research and empirical data gathering efforts that the wind industry is very much an industry which has been created largely by governments [6,24]. The drivers seem to be two-fold: To meet a political demand for both abating the emission of greenhouse gasses whilst at the same time driving a geopolitical agenda.

The geopolitical agenda in Europe seems to try to avoid dependence on Russia and simultaneously try to prevent the oil and gas rich countries, especially in the Middle East, from amassing an even more disproportionate amount of wealth than what has already happened [135]. With that being said, different EU regions and countries have very different drivers to promote offshore wind with Denmark taking on an early-mover role mainly for historical reasons [12] and because changing Danish coalition governments have shared both greenhouse gas emission and political drivers as outlined above. In other European countries, such as UK [19] and France, the key driver has been the EU 20-20-20 binding renewable energy targets. In Germany, wind energy has flourished simply because German firms are traditionally involved in many aspects of wind turbine and Balance of Plant production related to engineering and mechanical parts in general.

According to the last Five Year Plans of China, the key driver of offshore wind diffusion seems to be the Central Government's wish to

[11] Offshore wind farm site visits in China's Jiangsu Province conducted on July 29, 2015 and October 23, 2015

fight the ever worsening pollution by building power plants in the available space in the oceans near the big consumption centers of the large cities mainly on the East Coast. Compared to onshore wind turbine projects, offshore wind farms are a lot more difficult as well as costly to plan, finance, manufacture, install, commission, connect to the grid, operate, and de-commission. Therefore, global learning, collaboration, and innovation are even more important factors for offshore wind than for onshore wind going forward. Europe has learned offshore wind farm life-cycle management 'the hard way' since the Vindeby offshore farm was first erected in 1991. Our case study in Asia reveals that whereas the global wind industry is acutely aware of the upcoming rush for offshore wind installations in China - based on the Beijing decree for the offshore wind 2014 Feed-In Tariff - many Chinese developers and wind turbine manufacturers have seemingly almost exclusively had a 'fully installed wind turbine price' focus as selection criteria in the early years of onshore wind development in China. Other critical onshore wind success criteria such as connecting the wind turbines to the grid, how to ensure a steady 20–25 year phase of operations, and the de-commissioning of the wind turbines do not seem to have received the same proactive attention levels in China so far. This is being seen now as onshore wind turbines are starting to incur considerable operations and maintenance costs for Chinese wind farm operators to maintain. Early-movers from Europe who set up in China as sub-suppliers to the growing onshore wind turbine OEM industry got somewhat caught off-guard by the subsequently introduced local content requirements [89,136,137]. *Our research findings indicate* that European firms are hoping that the on-going onshore wind price/quality debate in China may generate a renewed offshore wind momentum for knowledge transfer from Europe to China with a main focus on quality.

Central to this continuous knowledge transfer is that the offshore wind industry in Europe may continue to develop and evolve. For logistics, this requires a long-term investment horizon in terms of key infrastructure, assets, equipment, personnel, and skills. Binding EU legislation up to at least 2030 is a must to create the right investment climate.

Our recommendations are two-fold and split by geography: In Europe, binding national targets across EU countries are necessary in order for the sizable and long-term logistics investments to be made by the private sector. The EU and national governments should also further invest in research to address technological development in identified supply chain bottlenecks and address them with tailored engineering education programs focused on offshore installation and maintenance, logistics being one such area. Additionally, there is a need for creative initiatives aimed at supporting EU-China collaboration in terms of research and establishment of collaborative business models. In China, the very ambitious offshore diffusion could be very costly and prolonged unless collaboration with Europe is embraced in an open manner to build on the learning from the rapid onshore wind diffusion in China. Chinese offshore wind constituencies ought to openly collaborate and jointly innovate with especially European counterparts both at government level, academia level, and at firm level. *Our research indicates* that if offshore wind diffusion will indeed happen, as evidenced by political ambitions globally, governments must provide the right settings for the supply chain to be flexible and adaptive.

And this is also true within the field of logistics.

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APPENDICES

APPENDIX 1: ABOUT THE AUTHOR - CURRICULUM VITAE

Name: Thomas Poulsen

Family status: Living together with Stine and our son Sander (born May, 2016)

Year born: 1970

Academic tenure:

Research Assistant, Aalborg University, Copenhagen
May 10, 2017 – present

PhD Stipend, Aalborg University, Copenhagen
February 1, 2014 – May 9, 2017

Research Assistant, Aalborg University, Copenhagen
February 1, 2013 – January 31, 2014

Education:

MBA Shipping and Logistics, Copenhagen Business School
August, 2009 – August, 2011

Work experience:

1989 – present

Toys"R"Us, Paramus, New Jersey
Director, International Traffic
Responsible for all global logistics contract negotiations and freight movements from factories to distribution centers

A.P. Møller-Mærsk, Copenhagen/Jakarta/Shanghai/Singapore Deputy Regional Manager, Asia-Pacific/Oceania/Middle East
Responsible for business development and operations within the logistics company of A.P. Møller-Mærsk, Damco (then Mercantile)

NOL/APL Logistics, Oakland, California/London
Vice President, Europe
Responsible for Europe within the logistics company of the NOL Group, APL Logistics (now a part of Kintetsu World Express)

ABF-DelCon, Hong Kong
President and COO, DelCon (Asia) Limited
Responsible for Asia-Pacific

Self-employed, Fort Lauderdale, Florida/Dubai/Copenhagen
Shipping and logistics consultant

Countries lived:

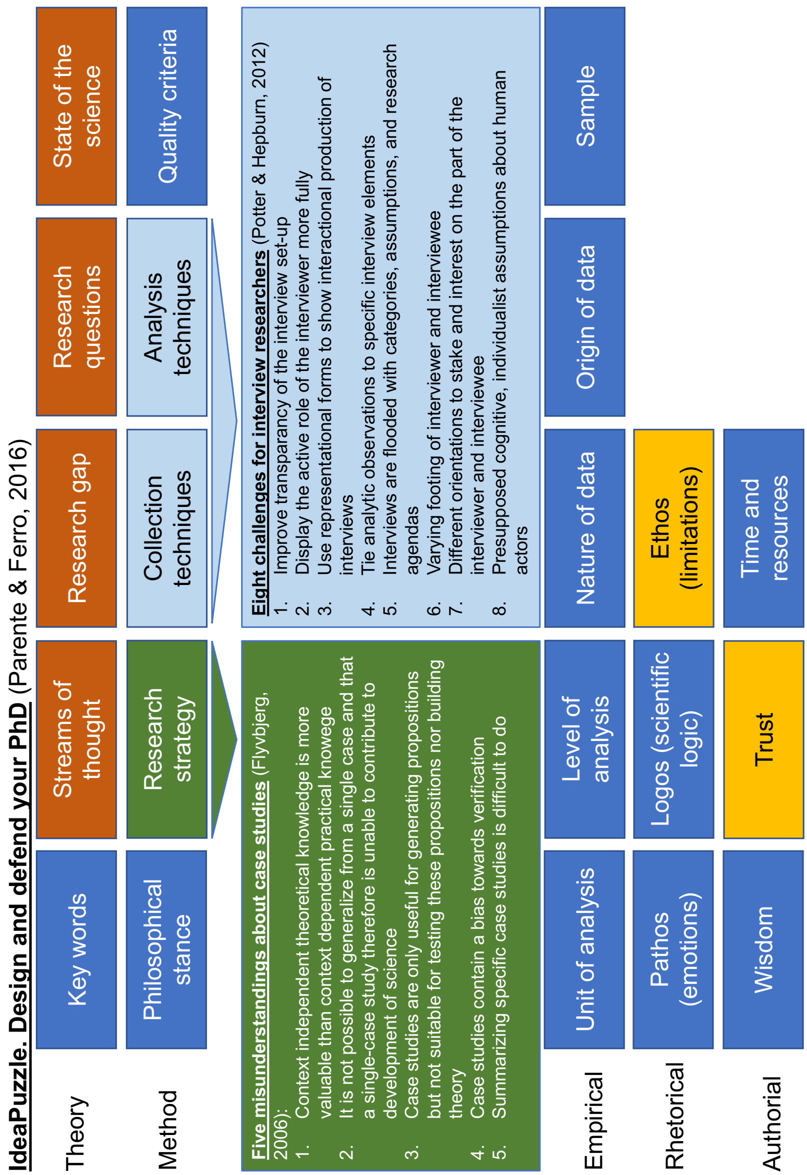
Denmark *(1970-1991; 2009-present)*
Indonesia *(1991-1994)*
China *(1994)*
Singapore *(1995-1997*)
Hong Kong *(1997-1998)*
USA *(1998-2001; 2003-2007)*
UK *(2001-2003)*
UAE *(2007-2009)*

APPENDIX 2: THE 21 IDEAPUZZLE DIMENSIONS (PARENTE & FERRO, 2016)

Key words	Usually two key words or concepts forming the basis of the research. For example, 'logistics' and 'offshore wind'
Streams of thought	Usually two main streams of thought or academic disciplines of the research. For example, 'logistics' and 'logistics costs in offshore wind'
Research gap	One or more gaps to be filled in academic literature. For example 'logistics in offshore wind', 'the cost of logistics in offshore wind', and 'the characteristics of mature versus emerging market logistics in offshore wind'
Research question or hypothesis	One or more research questions to be answered by the research. The research objective
State of the science	State-of-the-art. The current answer to the research question or hypothesis (i.e. before the research is conducted)
Philosophical stance	The 'ism' of the research. For example, pragmatism or constructive realism
Research strategy	Qualitative, quantitative or mixed method research. Case study
Collection techniques	Data collection techniques. Interviews, survey, and participant observation/action research
Analysis techniques	Different analysis techniques applied and software utilized
Quality criteria	Validity and reliability considerations
Unit of analysis	Which measure is applied to perform the analysis
Level of analysis	For example, individual level of analysis
Nature of data	For example, text, multimedia, and figures. Interview transcripts, survey responses, documents, web sites, figures from reports and survey responses
Origin of data	Primary data from literature reviews / interviews / surveys / participant observation and secondary data from desktop studies
Sample	Sample size. For example, 15 interviews and 38 usable survey responses in the Ørsted case study
Pathos	Positive and negative emotions of the research. Positive emotions include scientific publications and recommendations for public policies. There are no negative emotions such as ethics issues or conflicts of interest in the research
Logos	Scientific logic
Ethos	Delimitations, scoping, or limitations of the research. For example, offshore wind only, China as a representative for emerging markets, and logistics as a representative for the supply chain
Wisdom	Education and experience of the researcher

Trust	Partners of the research. Academic and otherwise
Time	Availability of time and resources on the part of the researcher to conduct the research. For example, this research started in 2012

Layers of methodological frameworks *(Parente & Ferro, 2016; Flyvbjerg, 2006; Potter & Hepburn, 2012)*



APPENDIX 3: THE EIGHT PHD PROJECT REFERENCE GROUP MEETINGS

	Date	Hosting organization	City in Denmark	After work / 'gå-hjem'
1	August 28, 2013	Aalborg University	Copenhagen	No
2	March 20, 2014	Ørsted	Gentofte	Yes
3	September 2, 2014	Offshoreenergy.dk	Esbjerg	Yes
4	March 17, 2015	Per Aarsleff A/S	Hvidovre	Yes
5	September 2, 2015	Siemens Gamesa	Brande	Yes
6	March 9, 2016	Port of Esbjerg	Esbjerg	Yes
7	August 24, 2016	Danish Shipowners' Association	Copenhagen	Yes
8	March 29, 2017	DHL Global Forwarding Industrial Projects	Copenhagen	Yes

APPENDIX 4: EXAMPLES OF INTERVIEW GUIDES AND SURVEYS

Interview guide

Ørsted

R+D logistics strategy project

Updated interview protocol
RM5 Logistics questionnaire
Autumn, 2014

Office interviews

Dialogue during the interview

1. Interview high level information

Visit date:	(Circle)	November 7	November 11	November 17	November 18	November 19	November 21 ____________
Location:	(Circle)	Skærbæk	Gentofte	Grenå	Other: ____________		
Allowed to tape interview:	(Tick)	____	Yes	____	No		
Time slot:	(Circle) 0900-1030	1030-1200	1300-1430	14:30-1600	Other: ____________		
Name person 1:	____________				Title: ____________		
Name person 2:	____________				Title: ____________		
Department name:	____________						
Contact details:	____________						
	____________						
Organizational info:	____________						

2. Comments/dialogue about interview introduction (Script)

R&D backgrounder:	____________
Other 4 roadmaps:	____________
Strategic collaboration AAU:	____________
Confidentiality/NDA:	____________
Creation of RM5 Logistics:	____________
Details RM5 Logistics:	____________
RM5 Logistics Ref Group:	____________
RM5 Logistics R&D strategy:	____________
Objective of interviews:	____________
Other:	____________
	____________
	____________
	____________
	____________

3. Background questions

Area of responsibility:	____________			Mandate/remit in organization:	____________			
Hierarchy	____	Top Mgmnt	____	Middle Mgmt	____	Execution	____	Site
Wind farm life-cycle pos:	____	Proj Devlmt	____	Proj Execution	____	Operations	____	Staff functions
	________	Other	________	Other	________	Other	________	Other
Experience	________	DONG Energy	________	DONG E Wind	________	Wind general	________	Geography
Educational background	____________							
Work background	____________							
	____________							
Perspective	____________			DONG E Wind	____________			Incl suppl/cust
Definition of SCM/logistics:	____	Shipping	____	Warehouses	____	Trucks	____	Trains
(Tick to the left)	____	Cranes	____	Parts/compon.	____	Modules	____	Inventory
	____	Sourcing	____	Procurement	____	Contracts	____	Risk Mng
	____	Planning	____	Interface Mgt	____	IT	____	Weather
	____	SCADA/O&M	____	Service	____	Lead time	____	People
	____	Knowledge	____	Skills	____	Grid	____	Transmission
	____	SCM	____	HSSEQ	________	Other	________	Other
	________	Other	________	Other	________	Other	________	Other
Definition of R&D:	**Research**							
(Tick to the left)	____	Analysis	____	University coop	____	Industry partn	____	Data collection
	________	Other	________	Other	________	Other	________	Other
	Development							
	____	Proj execution	____	Analysis	____	Implementat.	____	Prod devlpmt
	________	Other	________	Other	________	Other	________	Other
	R&D							
	____	Innovation	____	Creativity	____	Testing	____	X-tech coop
	____	High risk	____	Long leadtime	____	New prod dev	____	Launch
	________	Other	________	Other	________	Other	________	Other
Other:	____________							
	____________							
	____________							
	____________							

4. Key interview topics

Generic questions (to all)

How can RM5 Logistics add value to you?	____________
	____________
	____________
What logistics topics keep you awake at night?	____________
	____________
	____________
What is your biggest wish in terms of logistics?	____________
	____________
	____________

Role of logistics in life-cycles (to all):

Development	Idea	
	Analysis	
	Maturation	
Execution	Contract in to effect	
	Contractor prep	
	Manuf & fabrication	
	Constr, install, commissioning	
	Project closure, transfer to ops	
Operations	Preventive maintenance	
	Break-down maintenance	
Abandon	De-commissioning	

Role of logistics within key focus areas (to all):

R&D RM1	Offshore meteorology	Wind	
		Wave	
		Other	
		Other	
R&D RM2	Foundations	TP/MP	
		Jacket	
		Other	
		Other	
	Geoscience	Soil	
		Geotechnical	
		Other	
		Other	
	Marine	Other	
		Other	
R&D RM3	Electrical Infrastructure	Substations	
		Cables	
		Other	
		Other	
R&D RM4	WTG	Other	
		Other	
	O&M	Other	
		Other	
R&D RM5	Ideas	Vessels/shipping/maritime	
		Ports/storage	
		IT/data/information/systems	
		Processes/methods/SOP	

Knowledge and ideas for strategic objectives of RM5 Logistics (specific):

a) Reduce Cost of Electricity

- Areas to improve	
- Opportunities to optimize	
- Possible logistics cost reductions	
- Options for logistics standardization	
- Logistics IT and data flow	
- Other	

b) Logistics within overall processes

- Manufacturing/fabrication	
- Transport	
- Installation	
- Cranage	
- Commissioning	
- O&M	
- Other	

c) Specific logistics tasks

- Survey	
- Installation	
- Vessels	

- Ports
- Storage
- O&M
- Other

c) Logistics impact on safety, CSR, quality

- HSSEQ
  - Health
  - Safety
  - Security
  - Environment
  - Quality
- Other

d) Capacity, supply/demand, bottlenecks, and implications

- Logistics bottlenecks and implications
- Supply chain capacity and shortfalls
- Supply and demand imbalances and equilibrium
- Pricing and cost considerations
- Implications of bottlenecks, shortages, and imbalances
- Other

e) Strategic considerations

- Contract structure for logistics
- Roles and responsibilities in the supply chain
- Task allocation within the supply chain
- Logistics within core competencies framework of DONG E
- Outsourcing
- Insourcing
- M&A
- The A2SEA example
- Other

f) Financial considerations

- Logistics considerations in analysis phase of development
- Planned logistics spend versus actual spend
- Cost - delays in first electricity production milestone
- Cost - delays in key milestones (TOC, ROC, etc.)
- Cost - key modules/components/parts not on time
- End-to-end costs of logistics/SCM
- Share of overall wind farm life-cycle costs
- Other

g) Organizational implications

- Do you see logistics/shipping/SCM stand-alone?
  - Or as an end-to-end integrated process?
  - Within a single project?
  - Across multiple projects? Pipeline, portfolio view
- Are we organized correctly?
- Should we be organized differently?
- Other

g) Other

5. Additional data sources and follow-up

Others to interview:

Who to include in survey:

Access to other data/info:

Other:

Follow-up

Available for follow-up?

Wish copy of transscript?

Wish a copy of RM5 strategy?

Time frame May-June 2015

Thank you!

Other:

7. Other observations

____
____
____
____
____
____
____
____
____
____
____
____
____

Own reflections - after the interview meeting

Top take-aways

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________

Critical observations

____
____
____
____
____

Related ideas

____
____
____
____
____

Additional thoughts to research

____
____
____
____
____

Site interviews

4. Key interview topics

Port related tasks

Receiving land	____________________
Receiving sea	____________________
Storage/put-away	____________________
Warehousing	____________________
Load-out	____________________
Disposal	____________________
Tracking	____________________
Other	____________________
	____________________
	____________________
	____________________

Storage tasks

Hubs	____________________
Blades	____________________
Towers	____________________
Nacelles	____________________
Foundations	____________________
Export cables	____________________
Array cables	____________________
Substations	____________________
Parts/components	____________________
Other	____________________
	____________________

Warehouse tasks

Parts	____________________
	____________________
Components	____________________
	____________________
Wind modules	____________________
	____________________
WMS	____________________
	____________________
Categories/movement	____________________
Other	____________________
	____________________

Vessel tasks

Planning	____________________
Mooring	____________________
Unloading	____________________
Loading	____________________
Stevedoring	____________________

Cranage	
Port workers	
Unions	
Other	
HSSEQ	
Health	
Safety	
Security	
Environmental	
Quality	
Other	
Installation tasks	
Foundations	
Cables	
Sub-stations	
WTG	
Parts/components	
Crew/technicians	
Other	
O&M tasks	
WTG preventive	
WTG break-down	
BOP	
Parts/components	
Wind modules	
Crew/technicians	
Other	
Other	

Ørsted
R+D logistics strategy final survey

DONG Energy Wind Power logistics R+D strategy
Final survey (100 respondents)

The future of Logistics R&D within DONG Energy Wind Power

1. INTRODUCTION AND BACKGROUND
The goal of Roadmap 5 (RM5) Logistics is to be the Roadmap/Program of all R&D ideas developed within Logistics and together with other parties.
RM5 Logistics will help describe, quantify, and prioritize all incoming R&D ideas within the area of "logistics" that can influence the DONG Energy Wind Power either in the short, medium, or long term. In this first section of the survey, we will set the scene, explain the ground rules, and obtain basic information about you as a respondent.
The survey is structured in 2 main Parts.

Part 1 covers 7 sections that explore the **main aspects** of Logistics R&D. This part is mandatory and takes about 15 min to complete.
Part 2 deals with **strategic and in-depth aspects** of Logistics R&D. This part is optional and takes another 12 min to complete.

The input you provide will be used for setting the strategy for RM5 Logistics including possible implementation of any ideas put forward in your response. Following this survey, we will form a Reference Group for RM5 Logistics. The Reference Group will work closely with the RM5 Logistics Project Manager. The Project Manager for RM5 Logistics will peform the initial review of all incoming R&D project ideas for logistics within DONG Energy Wind.

The Reference Group will assist with prioritization, approval, and ensure that the individual logistics R&D projects are moved forward. The Reference Group will furthermore assist with the allocation of appropriate resources and review on-going projects in the future. We expect that the RM5 Logistics R&D Strategy will be ready in June, 2015.

The rules are simple:
You will be presented with a question where you can tick multiple possible answers that

you agree to. These you can supplement also with a commentin a field where you can write what you wish to say. If you do not understand the question, you can indicate that or you may skip the question.
The other option is that you are presented with a sentence that you can then either agree or disagree to a varying degree. You tick the appropriate degree of agreement/disagreement or you can indicate that you do not understand the question. You may also skip if you do not wish to answer.

To answer the different questions, it is important that five different terms are clear and understood in the same manner by all who participate in this survey. These terms are:
Project. A project refers to an individual wind farm project or operational wind farm.
Portfolio or pipeline. A portfolio means a series of wind farms under construction or in operation managed by one operator. A pipeline means a series of wind farm under construction or in development by a single wind farm operator.
Life-cycle. A life-cycle refers to an individual wind farm or wind farm project's total life-cycle in different from conceptual planning through construction through operations and finally until abondonment/de-commissioning.
Supply chains. Supply chains are referred to as the flow of goods, information, documentation, and money within the wind farm life-cycle phases.
Logistics. Logistics is generally referred to in a broad sense that includes logistics, shipping, transportation and/or supply chain management.

1.1 Please state your gender:

(1) ❑ Male
(2) ❑ Female
(3) ❑ Skip

1.2 Please state your age:

(1) ❑ 20 - 30
(2) ❑ 31 - 40
(3) ❑ 41 - 50
(4) ❑ 51 - 60
(5) ❑ 60+
(6) ❑ Skip

1.3 How long have you worked in the wind energy industry?

(1) ❑ 0 - 3 years
(2) ❑ 3 - 5 years
(3) ❑ 5 - 10 years
(4) ❑ 10 - 20 years
(5) ❑ 20 + years

1.4 Name the company you work for:

(1) ❑ DONG Energy
(2) ❑ Other (Company name): _____

1.5 Select your job function and where you work: (please select at least one category)

(1) ❑ Board
(2) ❑ Top Management
(3) ❑ Middle Management
(4) ❑ Management
(5) ❑ Staff function
(6) ❑ Office
(7) ❑ Project
(8) ❑ Site
(9) ❑ Other (if selected, please provide your own example): _____

1.6 What is your vantage point/position/phase/view point of the wind farm? (please select one or more)

(1) ❑ DONG Energy Group function
(2) ❑ Portfolio management
(3) ❑ Pipeline development
(4) ❑ Staff functions
(5) ❑ Finance
(6) ❑ Product Lines
(7) ❑ Engineering
(8) ❑ Project Development
(9) ❑ Asset Projects
(10) ❑ Operations/service/O&M (Operations & Maintenance)
(11) ❑ Abandonment/de-commissioning
(12) ❑ Other (please give your own example/s): _____
(13) ❑ Skip

1.7 What is your involvement in the supply chain? (please select one or more)

(1) ❑ Planning

(2) ❑ Exploration of the site in advance of construction
(3) ❑ Surveys
(4) ❑ Contracting
(5) ❑ Procurement
(6) ❑ Manufacturing
(7) ❑ Construction
(8) ❑ WTG (Wind Turbine Generator) Installation
(9) ❑ Export Cable Installation
(10) ❑ Array Cable Installation
(11) ❑ Foundation Installation
(12) ❑ Sub-station Installation
(13) ❑ Civil works/ onshore construction
(14) ❑ Site management
(15) ❑ Commissioning
(16) ❑ Preventive Maintenance
(17) ❑ Corrective Maintenance
(18) ❑ Contingency Maintenance
(19) ❑ Abandonment/ De-commissioning
(20) ❑ Other (if selected, please provide your own example): _____
(21) ❑ Skip

2. DEFINITION OF LOGISTICS

The term "logistics" was originally coined in a military setting to encompass the supply of ammunition, food, and other supplies for an army on the move. In more modern time, "logistics" has been defined in many ways and most commonly refers to activities pertaining to movement of goods including shipping/transportation type activities by air, sea, and land. In some cases, "logistics" is defined in a more narrow form to encompass only warehousing and distribution type tasks.

In our case, we have defined logistics in a broad sense that includes logistics, shipping, transportation, supply chain management. The objective of this section of the survey is to for you to share how YOU understand the term logistics from your vantage point within the wind farm life-cycle.

At the time of issuing this survey, DONG Energy Wind does not have a separate strategy for logistics nor is there a central logistics department or logistics competence center. Logistics is treated as a necessary part of the overall operations in all life-cycle phases of a wind farm project and is as such organized in a decentralized manner.
We thank you for answering the following questions pertaining to your view on the

definition of logistics within offshore wind.

2.1 In your opinion, should logistics be considered across multiple wind farms in a portfolio?

(1) ❑ Strongly disagree
(2) ❑ Disagree
(3) ❑ Somewhat disagree
(4) ❑ Neither agree or disagree
(5) ❑ Somewhat agree
(6) ❑ Agree
(7) ❑ Strongly agree
(8) ❑ Question not understood
(9) ❑ Skip

2.2 In your opinion, is logistics an end-to-end discipline within the entire wind farm life-cycle?

(1) ❑ Strongly disagree
(2) ❑ Disagree
(3) ❑ Somewhat disagree
(4) ❑ Neither agree or disagree
(5) ❑ Somewhat agree
(6) ❑ Agree
(7) ❑ Strongly agree
(8) ❑ Question not understood
(9) ❑ Skip

2.3 Which of the following items/terms/categories match YOUR definition of logistics? (please select at least one option)

(1) ❑ Shipping
(2) ❑ Cranes
(3) ❑ Sourcing
(4) ❑ Planning
(5) ❑ Supervisory, Control and Data Acquisition (SCADA) / Operations & Maintenance (O&M)
(6) ❑ Knowledge
(7) ❑ Supply Chain Management (SCM)
(8) ❑ Warehouses
(9) ❑ Parts/components
(10) ❑ Procurement
(11) ❑ Interface Management
(12) ❑ Service

(13) ❑ Skills
(14) ❑ Health, Safety, Security, Environment and Quality (HSSEQ)
(15) ❑ Trucks
(16) ❑ Modules
(17) ❑ Contracts
(18) ❑ Information Technology (IT)
(19) ❑ Lead time
(20) ❑ Grid
(21) ❑ Trains
(22) ❑ Inventory
(23) ❑ Risk Management
(24) ❑ Weather
(25) ❑ People
(26) ❑ Transmission
(27) ❑ Other (if selected, please give your own definition): _____
(28) ❑ I don't know

3. DEFINITION OF Research & Development

When put together, the terms "research" and "development" become "research & development", or "R&D". R&D is commonly defined as an active effort to improve existing/develop new products, services, processes, and/or procedures. The term R&D generally refers to the creative and innovative process surrounding this new development or improvement.

Within DONG Energy Wind, a definition of R&D already exists: http://workspaces/sites/RENTD/default.aspx

The R&D efforts have so far been organized in 4 roadmaps where a roadmap manager has been responsible to sieve through the different ideas, prioritize the suggestions for improvements, organize the projects, and report to a Reference Group. Going forward, a 5th roadmap for logistics has just come into effect.

3.1 Which of the below terms do you associate with your definition of research? (please select one or more)

(1) ❑ Analysis
(2) ❑ University cooperation
(3) ❑ Industry partnerships
(4) ❑ Data collection

(5) ❑ Other (if selected, please give your own example): _____

(6) ❑ I don't know

3.2 Which of the below terms do you associate with your definition of development? (please select one or more)

(1) ❑ Project execution

(2) ❑ Analysis

(3) ❑ Implementation

(4) ❑ Product development

(5) ❑ Technological advancement

(6) ❑ Service process improvement

(7) ❑ Other (if selected, please give your own example): _____

(8) ❑ I don't know

3.3 Which of the below terms do you associate with your definition of Research & Development (R&D)? (please select one or more)

(1) ❑ Innovation

(2) ❑ Creativity

(3) ❑ Testing

(4) ❑ High risk

(5) ❑ Long leadtime

(6) ❑ New product development

(7) ❑ Cross-technology cooperation

(8) ❑ Other (if selected, please give your own example): _____

(9) ❑ I don't know

4. PERCEPTION OF LOGISTICS

In this section, we would like to concentrate on how YOU perceive logistics in your daily work with offshore wind based on the definition you gave earlier.

4.1 Which of the below terms describe how you are involved in logistics tasks as part of your daily work? (please select at least one category)

(1) ❑ Planning

(2) ❑ Exploration of a site in advance of construction

(3) ❑ Surveys

(4) ❑ Procurement

(5) ❑ Manufacturing

(6) ❑ Construction

(7) ❑ WTG (Wind Turbine Generator) installation

(8) ❑ Export Cable Installation

(9) ❑ Array Cable Installation

(10) ❑ Foundation Installation
(11) ❑ Sub-station Installation
(12) ❑ Site management
(13) ❑ Civil works/onshore construction
(14) ❑ Commissioning
(15) ❑ Preventive Maintenance
(16) ❑ Corrective Maintenance
(17) ❑ Contingency Maintenance
(18) ❑ Abandonment/De-commissioning
(19) ❑ Other (if selected, please give your own example): _____
(20) ❑ Skip

4.2 From a core competence perspective, how should logistics be handled in the future in your opinion? (please select at least one category)

(1) ❑ Logistics is not a core competence to DONG Energy Wind and can be outsourced fully
(2) ❑ Logistics is a core competence of DONG Energy and should be insourced completely
(3) ❑ We are organized well today with some knowledge residing in DONG Energy Wind and some within the A2SEA subsidiary
(4) ❑ We should rely more on sub-contractors and suppliers
(5) ❑ We should leave logistics matters to experts and make more use of sub-contractors
(6) ❑ Other (please give your own example): _____
(7) ❑ I don't know
(8) ❑ Skip

4.3 Do any logistics topics keep you awake at night? (please select at least one category)

(1) ❑ The safety of DONG Energy Wind personnel and the personnel of our suppliers/partners
(2) ❑ Penalties resulting from delays
(3) ❑ Bottleneck situations causing costs to be higher than planned/budgeted
(4) ❑ No logistics topics keep me awake at night
(5) ❑ Other (e.g. please give your own example) _____
(6) ❑ Skip

4.4 What is your biggest wish in terms of logistics? (please select at least one category)

(1) ❑ More knowledge within the organization of DONG Energy Wind
(2) ❑ More qualified suppliers
(3) ❑ More financially strong suppliers
(4) ❑ Suppliers able to take responsibilities for larger parts of a project
(5) ❑ Suppliers able to support multiple projects in the pipeline of future wind farms
(6) ❑ I don't have any wishes in terms of logistics
(7) ❑ Other (please give your own example): _____
(8) ❑ Skip

4.5 How could improved logistics assist in reducing cost of electricity? (please select at least one category)

(1) ❑ Better logistics management could result in shorter time to construct a wind farm
(2) ❑ More proactive Operations & Maintenance/Service Logistics could reduce service costs
(3) ❑ A reduction of logistics costs would in itself lead to a reduction of LCoE (Levelized Cost of Electricity)
(4) ❑ Other (please give your own example): _____
(5) ❑ I don't know
(6) ❑ Skip

4.6 What percentage of the overall cost does logistics represent in your opinion?

0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100 %	I don't know
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(21)	(22)	(23)
❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑

4.7 Please define how you answered the question 4.6:

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a5. PERCEPTION OF R&D (Research and Development)

In this section, we would like to concentrate on how YOU perceive R&D in your daily work with offshore wind based on the definition you gave earlier.

5.1 Which of the following terms describe how you are involved in R&D tasks in your daily work? (please select one or more categories)

(1) ❑ R&D Roadmap 1 Offshore Meteorology
(2) ❑ R&D Roadmap 2 Foundations, Geoscience and Marine
(3) ❑ R&D Roadmap 3 Electrical Infrastructure
(4) ❑ R&D Roadmap 4 WTG O&M
(5) ❑ R&D Roadmap 5 Logistics
(6) ❑ Planning
(7) ❑ Exploration
(8) ❑ Surveys

(9) ❑ Contracting
(10) ❑ Procurement
(11) ❑ Manufacturing
(12) ❑ Construction
(13) ❑ Wind Turbine Generator (WTG) installation
(14) ❑ Export cable installation
(15) ❑ Array cable installation
(16) ❑ Foundation installation
(17) ❑ Sub-station installation
(18) ❑ Commissioning
(19) ❑ Preventive maintenance
(20) ❑ Corrective maintenance
(21) ❑ Contingency maintenance
(22) ❑ Abandonment / De-commissioning
(23) ❑ I have not been involved in R&D projects
(24) ❑ Other (if selected, please give your own example) _____
(25) ❑ I am not involved in R&D tasks
(26) ❑ Skip

5.2 How have you participated in R&D projects? (please select one or more categories)

(1) ❑ I have been R&D project manager
(2) ❑ I have been supporting R&D project(s)
(3) ❑ I was a member of R&D project work group(s)
(4) ❑ I gave input to R&D project(s)
(5) ❑ I was in R&D project steering committee(s)
(6) ❑ I have not been involved in R&D projects
(7) ❑ I have been involved in R&D project(s) outside DONG Energy Wind Power
(8) ❑ Other (if selected, please give your own example) _____
(9) ❑ Skip

5.3 How did you work with suppliers/vendors/sub-contractors on R&D projects? (please select one or more categories)

(1) ❑ Suppliers/vendors/sub-contractors actively suggest new R&D opportunities
(2) ❑ Suppliers/vendors/sub-contractors are asked to provide their thoughts and ideas as a perquisite to continuing to do business with DONG Energy Wind Power
(3) ❑ Suppliers/vendors/sub-contractors are unable to innovate and be creative
(4) ❑ We never work with suppliers/vendors/sub-contractors on R&D matters
(5) ❑ Other (please give your own example): _____

(6) ❑ I have never worked on R&D projects
(7) ❑ Skip

5.4 How many times have you worked on R&D projects in DONG Energy Wind Power? (please select one category)

(1) ❑ Worked on 1 R&D project
(2) ❑ Worked on 2-3 R&D projects
(3) ❑ Worked on 4-5 R&D projects
(4) ❑ Worked on 5-10 R&D projects
(5) ❑ Worked on more than 10 R&D projects
(6) ❑ Other (please give your own example): _____
(7) ❑ I have never worked on R&D projects
(8) ❑ Skip

5.5 How could the new R&D Roadmap 5 Logistics add value to your work? (please select one or more categories)

(1) ❑ Now I know where to go with ideas
(2) ❑ Now I understand that we have a process for organizing R&D input for logistics
(3) ❑ Visibility to Roadmap 5 Logistics can help me understand if new R&D initiatives can make my current work easier
(4) ❑ Other (please give your own example): _____
(5) ❑ I don't know
(5) ❑ Skip

6. IDEAS FOR R&D PROJECTS WITHIN LOGISTICS

In the previous sections, you have provided your thoughts on both logistics and R&D. We are thankful for this contribution! In this section, we would very much like to solicit your input and thoughts when it comes to actual real-life R&D needs you may have encountered.

One goal of this survey is to obtain a pool of logistics R&D ideas which can be categorized and prioritized in order to benefit the future DONG Energy Wind pipeline and portfolio of wind farms. In the following, we will therefore provide you with a completely open option to provide any thoughts/ideas you may have.

6.1 Do you have any ideas for R&D projects within logistics for DONG Energy Wind Power? (feel free to express all your ideas in free text)

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If you have any ideas or comments you wish to discuss in person, you may also get in touch with the project manager for R&D Roadmap 5 Logistics directly. Please feel free to email Anders Greve Pihlkjær at andpi@dongenergy.dk or mobile phone +45 9955 5853.

7. INPUT FOR ROADMAP 5 LOGISTICS R&D STRATEGY

We first of all wish to make it easy for any employee to come up with his/her ideas for R&D within logistics. The ideas could be developed alone or with partners, suppliers, universities, or others. It should be possible to submit the ideas to the responsible RM5 Logistics team where a qualified process by a qualified team of people will take place. Feed-back should be provided to the person originally responsible for coming up with the idea.

In this section, we are seeking your thoughts and input for how we should design the strategy for DONG Energy Wind within the area of R&D for logistics. The purpose of the R&D strategy for logistics is to facilitate that employees, partners, suppliers, universities, and others can come up with ideas for R&D within offshore wind logistics which will then be listened to, reviewed, and prioritized for potential implementation. In order to do this, we are seeking your input based on where you belong in the organization.

The DONG Energy Wind Power strategy is to:
- Create gross capacity of 6.5 GW of offshore wind by 2020
- Lost time injury frequency has to be reduced to 1.5 hours per million hours by 2020
- Levelized cost of electricity below EUR 100 per MW/h by 2020 (UK calculation method)
- Return of capital employed to be 12-14 %

Within RM5 Logistics, the R&D strategy will most likely entail the following:

- Standardization of logistical practices, procedures, processes, and set-up
- IT systems integration and optimization
- Support to on-going asset projects including staff functions
- Support to all wind farm life-cycle phases
- Support to product lines and engineering
- Support to realization of 2020 pipeline
- Support to overall portfolio management and optimization

7.1 Do you have any ideas on how to prioritize incoming R&D logistics initiatives? (feel free to express all your ideas in free text)

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7.2 Do you have any ideas on how to capture logistics improvements/innovations created during an asset project for use in future projects? (feel free to express all your ideas in free text)

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7.3 Do you have any ideas for collaboration with suppliers on logistics improvements/innovations? (feel free to express all your ideas in free text)

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7.4 Do you have any ideas for collaboration with universities/learning institutions on logistics improvements/innovations? (feel free to express all your ideas in free text)

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7.5 Other ideas/comments (feel free to express all your ideas in free text)

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Do you wish to receive a copy of the Roadmap 5 Logistics strategy once completed?

(1) ❑ Yes (If so, please provide your e-mail address below) _____

(2) ❑ No

May we contact you with any questions?

(1) ❑ Yes (If so, please provide your e-mail address below) _____

(2) ❑ No

Thank you for completing Part 1 of the Survey!

We kindly encourage you to **continue with Part 2** by clicking "Next", where strategic topics of R&D Logistics are explored more in-depth. This part is split in three sections:

- Logistics Perception
- R&D Perception

- Roadmap 5 Mechanics.

We would sincerely appreciate if you could help us by spending another 12 minutes of your valuable time to complete Part 2.
Or you may choose to end the survey here. In order to do so, please close the survey window.

8.1 Which of the below terms describe how you have participated in logistics operations? (please select at least one category)

(1) ❑ Planning
(2) ❑ Exploration of the site in advance of construction
(3) ❑ Surveys
(4) ❑ Contracting
(5) ❑ Procurement
(6) ❑ Manufacturing
(7) ❑ Construction
(8) ❑ WTG (Wind Turbine Generator) Installation
(9) ❑ Export Cable Installation
(10) ❑ Array Cable Installation
(11) ❑ Foundation Installation
(12) ❑ Sub-station Installation
(13) ❑ Civil works/ onshore construction
(14) ❑ Site management
(15) ❑ Commissioning
(16) ❑ Preventive Maintenance
(17) ❑ Corrective Maintenance
(18) ❑ Contingency Maintenance
(19) ❑ Abandonment/ De-commissioning
(20) ❑ Other (if selected, please provide your own example): _____
(21) ❑ Skip

8.2 In your opinion, which of the below terms/options/categories are more likely than others to negatively impact health, safety and security issues? (please select at least three of the categories below)

(1) ❑ Lifting operations ashore/offshore
(2) ❑ Road transportation
(3) ❑ Ocean transportation

(4) ❑ Push/pull operations
(5) ❑ Air transportation by helicopter
(6) ❑ Crew transfer from vessel to WTG (Wind Turbine Generator)
(7) ❑ Subsea/diving operations
(8) ❑ Cable laying activities
(9) ❑ Civil works/onshore construction
(10) ❑ Offshore construction
(11) ❑ Erection of WTG (Wind Turbine Generator)
(12) ❑ Other (please give your own example): _____
(14) ❑ I don't understand the question
(15) ❑ Skip

8.3 In your opinion, how may logistics CSR (Corporate Social Responsibility) policy impact the environment? (please select at least one category)

(1) ❑ Safety on the roads
(2) ❑ Health of employees
(3) ❑ Safety of suppliers
(4) ❑ Security of operations
(5) ❑ Prevention of environmental damage
(6) ❑ Safety in operations onshore and offshore
(7) ❑ Other (e.g.: crane lifting) _____
(8) ❑ I don't understand the question
(9) ❑ I don't know
(10) ❑ Skip

8.4 From a logistics perspective, which of the below mentioned terms may impact quality within your area of responsibility? (please select at least one category)

(1) ❑ On-time performance
(2) ❑ Milestone management
(3) ❑ Event management
(4) ❑ Claims
(5) ❑ Safety
(6) ❑ Health
(7) ❑ Other (if selected, please give your own example): _____
(8) ❑ I don't understand the question
(9) ❑ I don't know
(10) ❑ Skip

8.5 In your opinion, which of the below processes/operations may produce bottlenecks (supply/demand hindrance)? (please select at least one category)

(1) ❑ Manufacturing
(2) ❑ Landside transport
(3) ❑ Port management
(4) ❑ Ocean transportation
(5) ❑ Installation
(6) ❑ Commissioning
(7) ❑ I have never experienced a logistics related bottleneck
(8) ❑ Other (if selected, please give your own example): _____
(9) ❑ Skip

8.6 How are logistics contracts structured/organized within your area of responsibility? (please select at least one category)

(1) ❑ Frame agreement
(2) ❑ Single project
(3) ❑ Parts of a project
(4) ❑ TCI (Transport, Construction and Installation)
(5) ❑ EPC (Engineering, Procurement and Construction)
(6) ❑ O&M (Operations & Maintenance)
(7) ❑ Service
(8) ❑ Charter party
(9) ❑ Other (if selected, please give your own example): _____
(10) ❑ I don't know
(11) ❑ Skip

8.7 Within your job function, how are the logistics roles and responsibilities organized? (please select at least one category)

(1) ❑ In-house within DONG Energy
(2) ❑ Handled by A2SEA / CT Offshore
(3) ❑ Outsourced to sub-contractors
(4) ❑ Partly controlled by DONG Energy and partly outsourced
(5) ❑ Other (if selected, please give your own example): _____
(6) ❑ I don't know
(7) ❑ Skip

8.8 Within your area of responsibility, how are hand-offs/interfaces between logistics players and processes structured? (please select at least one category)

(1) ❑ Single IT (Information Technology) system provides overview

(2) ❑ Multiple IT systems provide overview
(3) ❑ No IT systems available and managed manually
(4) ❑ Clear operating instructions exist
(5) ❑ Standard Operating Procedures (SOP)
(6) ❑ Service Level Agreements (SLA)
(7) ❑ ISO (International Organization of Standardization) certification and full procedures
(8) ❑ Other (please select at least one category): _____
(9) ❑ I don't know
(10) ❑ Skip

8.9 How do you match planned costs with actual costs as part of your work function? (please select at least one category)

(1) ❑ I can access the cost model to see the planned costs
(2) ❑ I validate all costs against the budget costs
(3) ❑ I have full cost item budget visibility
(4) ❑ I do not have budget visisbility
(5) ❑ I only work with planned budget costs
(6) ❑ I only work with actual costs
(7) ❑ I do not have visibility to planned costs
(8) ❑ I cannot validate actual versus budgeted or planned costs
(9) ❑ Other (please give your own example): _____
(10) ❑ I don't know
(11) ❑ Skip

8.10 How have you experienced logistics to have a negative impact on your work? (please select at least one category)

(1) ❑ Delays/Missed milestones
(2) ❑ Bottlenecks
(3) ❑ Higher costs than planned
(4) ❑ Weather downtime
(5) ❑ Accidents
(6) ❑ Lack of procedures
(7) ❑ Logistics has never had a negative impact on my work
(8) ❑ Other (please give your own example): _____
(9) ❑ Skip

8.11 How have you experienced additional costs resulting from logistics milestone delays? (please select at least one category)

(1) ❑ Extra hire for storage space

(2) ❑ Extra costs for people waiting
(3) ❑ Extra costs for ships on stand-by
(4) ❑ Demurrage/detention
(5) ❑ Delays compared to plans
(6) ❑ Penalties
(7) ❑ I have never experienced extra cost as a result of a logistics milestone delay
(8) ❑ Other (please give your own example): _____
(9) ❑ Skip

8.12 How has logistics ever made a positive contribution to your work? (please select at least one category)

(1) ❑ Faster than planned
(2) ❑ Safer than expected
(3) ❑ Good health KPI's for our employees
(4) ❑ No delays
(5) ❑ Proactive resolution to potential bottlenecks
(6) ❑ Logistics has never made a positive contribution to my work
(7) ❑ Other (please give your own example): _____
(8) ❑ Skip

9.1 How were the R&D projects you worked on in the past generated? (please select one or more categories)

(1) ❑ I came up with the idea(s)
(2) ❑ A supplier came up with the proposal
(3) ❑ A university approached us
(4) ❑ One of our partners came up with this idea
(5) ❑ The idea came from the Oil & Gas industry
(6) ❑ The idea had been used in the construction industry
(7) ❑ Another wind farm operator was doing things differently
(8) ❑ An industry conference generated the idea
(9) ❑ I haven't been involved with R&D projects
(10) ❑ Other (please give your own example): _____
(11) ❑ I don't know
(12) ❑ Skip

9.2 How do you get R&D project(s) considered within DONG Energy Wind today? (please select one or more categories)

(1) ❑ Through R&D Roadmap 1 Offshore Meteorology
(2) ❑ Through R&D Roadmap 2 Foundation, Geoscience and Marine

(3) ❑ Through R&D Roadmap 3 Electrical Infrastructure
(4) ❑ Through R&D Roadmap 4 WTG O&M
(5) ❑ Through R&D Roadmap 5 Logistics
(6) ❑ I make the decision
(7) ❑ I obtain the necessary approvals
(8) ❑ Dialogue with relevant colleagues via email/phone
(9) ❑ It is hard to get ideas approved
(10) ❑ I generally do not propose new ideas because they generally do not get considered
(11) ❑ Other (please give your own example): _____
(12) ❑ I have never tried to get a proposal approved
(13) ❑ Skip

9.3 How did R&D projects affect your work duties in a positive manner? (please select one or more categories)

(1) ❑ The R&D roadmaps provide structured approach to R&D
(2) ❑ R&D initiatives are generally well thought through
(3) ❑ R&D initiatives are generally well executed
(4) ❑ New ways of doing things have improved my efficiency
(5) ❑ New ways of doing things have improved my effectiveness
(6) ❑ R&D projects have resulted in more uptime
(7) ❑ R&D projects have generated cost savings
(8) ❑ R&D initiatives have generated health improvements
(9) ❑ R&D initiatives have generated greater safety
(10) ❑ Other (please give your own example): _____
(11) ❑ R&D projects have not affected my work in a positive manner
(12) ❑ Skip

9.4 How did you collaborate with learning institutions/universities on R&D projects in the past? (please select one or more categories)

(1) ❑ Learning institutions/universities actively suggest new R&D opportunities
(2) ❑ Learning institutions/universities are asked to provide their thoughts and new ideas as a perquisite to continuing to actively work with DONG Energy Wind Department
(3) ❑ Learning institutions/universities are unable to innovate and be creative
(4) ❑ We never work with learning institutions/universities on R&D matters
(5) ❑ Other (please give your own example): _____
(6) ❑ I have never worked on R&D projects
(7) ❑ Skip

9.5 Which of the following statements describe how you have interfaced with the DONG Energy Wind Power R&D Roadmaps? (please select one or more categories)

(1) ❑ Worked on R&D Roadmap 1 Offshore Meteorology
(2) ❑ Worked on R&D Roadmap 2 Foundation, Geoscience and Marine
(3) ❑ Worked on R&D Roadmap 3 Electrical Infrastructure
(4) ❑ Worked on R&D Roadmap 4 WTG O&M
(5) ❑ Working with R&D Roadmap 5 Logistics
(6) ❑ No interface with R&D Roadmaps
(7) ❑ I have worked on R&D projects outside of the R&D roadmap structure
(8) ❑ Other (please give your own example): _____
(9) ❑ I have never worked on R&D projects
(10) ❑ Skip

10.1 Would you prefer the R&D logistics idea generation process within DONG Energy Wind Power to be anonymous?

(1) ❑ Yes
(2) ❑ No
(3) ❑ Skip

10.2 In your opinion, should there be a reward system towards DONG Energy Wind Power employees for R&D ideas selected for implementation?

(1) ❑ Yes
(2) ❑ No
(3) ❑ Skip

10.2 Do you have any ideas for designing the infrastructure/daily operations/mechanics/support process for the RM5 Logistics from idea generation through prioritization and implementation? (feel free to express all your ideas in free text)

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The survey has now been finalized. We would like to sincerely thank you for your participation.

Your answers will be very helpful in our process of creating R&D Roadmap 5: Logistics and hopefully your answers will provide us with the knowledge to best utilize this new opportunity which is the R&D Roadmap 5: Logistics.

Interview guide China case studies

与振华重工集团座谈会议的要点

- 至2020年的海上风电场开发计划
- 了解中国不同省市区域海上风电场的情况
- 振华重工集团风电价值链与合约结构
- 基于SWOT分析对振华重工集团海上风电设备进行讨论
- 了解振华重工集团公司的潜在需求，以及欧洲海上风能行业是否能够提供帮助与支持
- 不同海上风电项目的差异分析
- 在产品、服务、技术、工艺与可发展的能力拓展等方面的“希望清单”
- 对2015年10月13-24日的代表团会面事宜的承诺

Discussion points for ZPMC meeting

- Offshore wind farm pipeline up to 2020
- Different offshore wind farm regions and Provinces of China
- The ZPMC value chain and contract structure
- SWOT analysis discussion ZPMC offshore wind set-up
- Potential areas of need for support from the European offshore wind energy industry
- Specific gap analysis requirements for different offshore wind projects
- ”Wish list” for products, services, skills, technology, and capabilities transfer
- Commitment to meet our delegation on October 13 – 24, 2015

Discussion points for ZPMC meeting
与振华重工集团讨论的议题

1. Offshore wind farm pipeline up to 2020
   至2020年海上风电计划
   - What is the offshore wind farm pipeline for China up to 2020?
     至2020年的海上风电规划是？
   - Of this total China offshore wind market, how many offshore wind farm projects does ZPMC plan to install up to 2020?
     到2020年，振华重工集团的海上风电场的计划安装多少海上风电项目？
   - How big are the different offshore wind farm projects in terms of MW capacity and number of WTG positions?
     海上风电项目计划开发的风场容量和风机数量的区别有多大？
   - What is the range in terms of water depth and distance from shore planned for these offshore wind farms?
     安装位置水深与距陆地的距离范围在？
   - What kind of foundation types will be used?
     风机基础的样式有哪些?
   - How will installation / construction be done?
     如何安装与施工海上风电项目？
   - How will O&M / service be carried out?
     运行维护将如何执行的?

Discussion points for ZPMC meeting
与振华重工集团 讨论的议题

2. Different offshore wind farm regions and Provinces of China
   中国海上风场的地理位置
   - What are the key offshore wind energy regions and Provinces of China?
     海上风场的主要地区和省份有哪些？
   - How are these regions and Provinces different?
     不同地区和省份的差别在哪里？
   - What are the requirements about using locally manufactured parts and local labour?
     对于本地厂商和本地劳动力的要求有哪些？
   - What are the requirements about job creation in these regions and Provencis?
     对于所创造就业机会有哪些要求？
   - How do you organize the legal set-up and infrastructure for each region or Province?
     如何组织每个区域或者省份的法律法规和基础建设？
   - Do you have to organize at a city or municipality level within each Province?
     是否需要在市或者直辖市层面上进行组织和管理？

Discussion points for ZPMC meeting
与振华重工集团讨论的议题

3. The ZPMC value chain and contract structure
   振华重工集团的价值链与合同结构
   - To what extent can you replicate your onshore value chain and contract structure for offshore wind?
     是否直接把陆上风机价值链和合同结构引入海上项目？
   - Which offshore wind farm tasks do you perform in-house and which tasks do you outsource?
     哪些海上风场的任务使用内部资源，哪些为外部资源?
   - Which kind of suppliers do you use for offshore wind?
     海上项目使用的供应商有哪些？
   - Do you have some ”preferred supplier” partners?
     是否有倾向的供应商？
   - What is the average number of contracts you enter into for a typial offshore wind farm project?
     典型海上风电项目的合同平均数量是多少？
   - Which supplier types have the larger contract scopes?
     哪些供应商是大合同供应商？
   - Do you make use of turn-key or full-service scope providers and for which parts of the offshore wind farm projects?
     是否有海上EPC 项目的计划

Discussion points for ZPMC meeting
与振华重工集团 讨论的议题

4. SWOT analysis discussion ZPMC offshore wind set-up
   优劣势、机会风险分析

- If you should make a simple SWOT analysis for offshore wind, please advise what are your:
  - Internal ZPMC company offshore wind Strengths?
    振华重工集团公司内部的优势
    - Strong onshore track-record, wind market experience, etc.陆上风机追踪记录，风电市场经验
  - Internal ZPMC company offshore wind Weaknesses?
    振华重工集团公司内部的劣势
    - Single-market exposure (China), global best practices, etc. 中国海上市场较为单一，国际最佳实践
  - External non-ZPMC offshore wind Opportunities?
    外部非振华重工集团的海上风电机会
    - New 2014 feed-in tariff for offshore wind, faster market development, etc. 2014 新的上网电价政策，快速的市场发展
  - External non-ZPMC offshore wind Threats?
    外部非振华重工集团海上风电的威胁
  - Central government requirements about green energy transition, FIT framework, etc.
    政府对于绿色能源转换的要求

Discussion points for ZPMC meeting
与振华重工集团讨论的议题

5. Specific gap analysis requirements for different offshore wind projects
   不同海上风电项目的差异分析

- What do you perceive to be the main gaps of the China offshore wind market regarding project planning, construction, and O&M/service?
- 中国海上风电市场在开发，建设和运维方面的主要差异
  - Regulatory / legal / procedures 法律法规政策流程
  - Technology (WTG, foundations, cables, offshore sub-station, etc.)
    技术（机组，基础，电缆，海上变电站等）
  - Knowledge / skills / capabilities / know-how 知识/技巧/能力/经验
  - Technical (due to corrosion, water, wind, harsh environment etc.)
    工艺（腐蚀、潮湿，大风，特殊环境）
  - Services (project management, planning, IT support, decision making, logistics, shipping, etc.)
    服务（项目管理，计划，IT支持，决策，物流，航运等）
- Do you have a plan to fill these gaps?
  是否有计划减少这些差距
- Is there a preferred direction forward on this topic?
  对于这个议题是否还有其他的待讨论的问题？

Discussion points for ZPMC meeting
与振华重工集团讨论的议题

6. Potential areas of need for support from the European offshore wind energy industry
欧洲海上风电能提供哪些方面的支持

- Can European companies help you to close some of the gaps discussed?
  欧洲企业能够缩小之前所提到的差异？
- Do you see any particularly weak areas within the China offshore wind set-up and structure?
  中国海上风电配置与架构上是否有明显的不足？
- Do you see any need for support from European companies of a certain kind?
  是否在某方面希望获得欧洲相关公司的支持？
- Do you feel there is sufficient collaboration with European universities about offshore wind?
  与欧洲大学关于海上风电的研究合作是否足够？
- Are there areas of support needed from European governments or wind industry energy associations in terms of offshore wind?
  是否已获得欧洲政府或风能协会的相关支持？

Discussion points for ZPMC meeting
与振华重工集团讨论的议题

7. ”Wish list” for products, services, skills, technology, and capabilities transfer
在产品，服务，技能，技术，能力转移方面有哪些需求

- Do you have any offshore wind energy topics that make you unable to sleep at night because you worry about how to resolve them?
  是否有亟待解决的问题？
- Do you have any wishes about offshore wind support from some European countries?
  是否有意向从欧洲国家获得相关支持？
- Have you defined some requirements in terms of any particular products, services, skills, technology, or capabilities?
  在上述提到的方面是否已有明确的需求？
- Do you have any recommendations about knowledge transfer or best practices to your suppliers or their sub-suppliers?
  关于知识转移是否有建议，或是已有的实例提供给供应商参考？

Discussion points for ZPMC meeting
与振华重工集团讨论的议题

8. Commitment to meet our delegation on October 13 – 24, 2015

商议2015年10月13日至24日的代表团来访事宜

- Do you wish to meet our delegation of companies and organizations from Poland, Germany, Denmark, and Norway in October?

  是否有意向会面来自波兰，德国，丹麦和挪威的代表团？
- Do you prefer meetings during China Wind Power conference in Beijing on October 14, 15, 16?

  是否愿意在10月14-16日的中国风能展上会面？
- Do you prefer a workshop meeting with all the companies?

  是否倾向于工作坊的会议形式?
- Do you prefer a ”catalogue” of companies and capabilities to choose from and make individual 1-on-1 meetings?

  是否倾向于提供分类的公司名录并选择有意向的进行单独会面？
- Do you prefer that we assemble all companies for example in Beijing and Shanghai for you to meet and discuss with?
- 是否倾向于在北京和上海同时会见所有相关公司？

APPENDIX 5: EMPIRICAL DATA COLLECTION EFFORTS

Empirical data collection activity	Timing	Semi-structured interviews	Formal inter-views	Participant observa-tion site visits / conference attendance	Usable survey responses
MBA thesis (Poulsen, 2011)	July 2010 - July 2011	99		25	
LogMS 2013 conference paper (Poulsen, et al., 2013a) *1	2010 - June 2013	184		62	
Anholt EAWE conference paper (Poulsen, et al., 2013b)	March - August 2013		8	2	
Contextual paper framing this PhD thesis (Poulsen, 2015) *2	February 2013 - May 2014	160		28	
Ørsted case study (Poulsen & Hasager, 2016)	July 2014 - September 2015		15	2	38
O&M logistics case study (Poulsen, et al., 2017)	August 2014 - April 2016	18		6	
China market case study (Poulsen & Hasager, 2017)	May 2013 - March 2016	47+41	15	40	
(Poulsen & Lema, 2017) *3	May 2013 - April 2016	65+41	30	48	38
Reference Group	August 2013 - March 2017			15	

Note *1: The first conference paper of this project (not forming part of this PhD thesis) included empirical data collected during the MBA

Note *2: The contextual paper framing this PhD thesis was partly based on empirical data collected as part of the prior two conference papers not forming part of this PhD thesis (Poulsen, et al., 2013a; Poulsen, et al., 2013b)

Note *3: The cross-case paper forming part of this PhD thesis was based on the three primary case studies of this PhD thesis

SUMMARY

Based on gaps in academic literature, this PhD thesis has used the case study method to collect empirical data and perform different types of qualitative as well as quantitative analysis.

The findings in the form of seven key theoretical contributions have been presented based on the five peer-reviewed and published academic papers forming part of this research:

- An academic definition of logistics in offshore wind has been proposed
- A furthering of the understanding of logistics costs in offshore wind has been generated as seen in relation to offshore wind farm capital expenditure, operating expenditure, and levelized cost of energy
- The high logistics costs as a share of total costs for offshore wind suggest that logistics be treated as a separate discipline of great importance by academia as well as industry
- Levelized cost of energy studies and cost models seem to possibly be biased
- Logistics costs do not appear to be not properly defined and accounted for in major cost studies
- Analysis of China, as a representative emerging market for offshore wind, indicated that logistics characteristics are different there compared to mature markets
- Using logistics as the lens, it was found that the offshore wind supply chain does not seem ready for the planned government diffusion plans of the future

This research presents several ideas for how academia may further the studies of logistics in offshore wind.

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