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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 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).

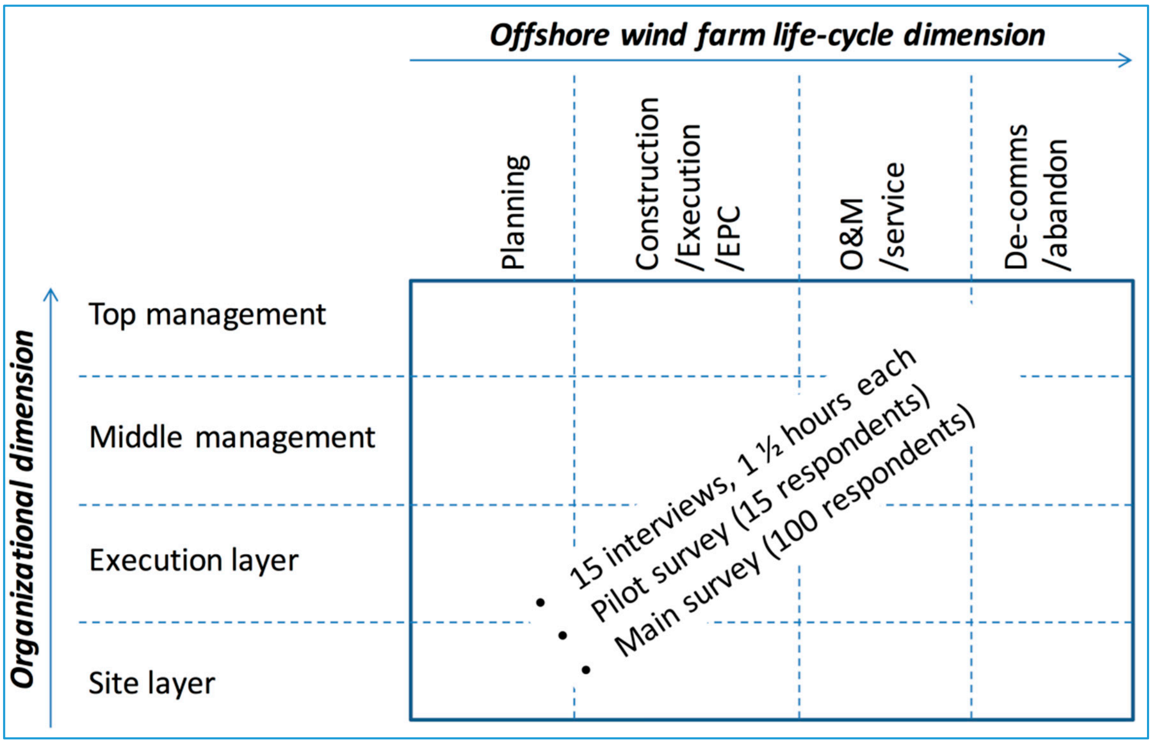

Figure 1. Interview and survey selection matrix.

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).

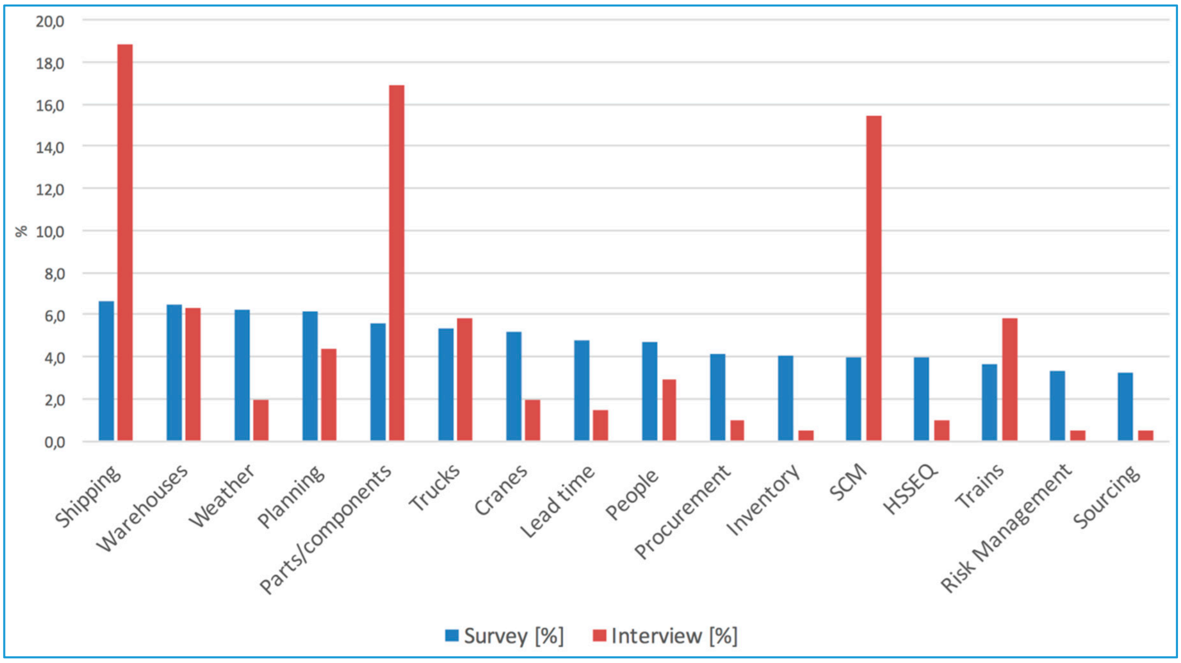

Figure 2. Frequency of terminology used (in %) during interviews and in the survey definition section.

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.

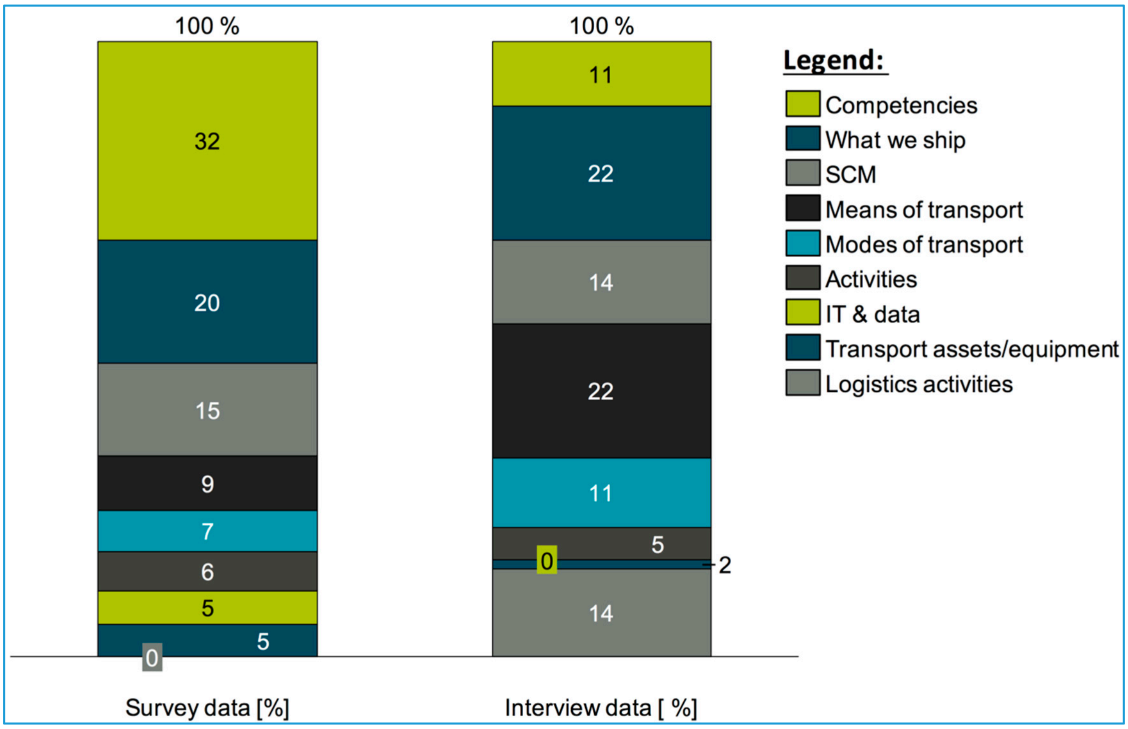

Figure 3. Logistics words frequency (in %) categorized along dimensions from surveys *vs.* interviews.

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.

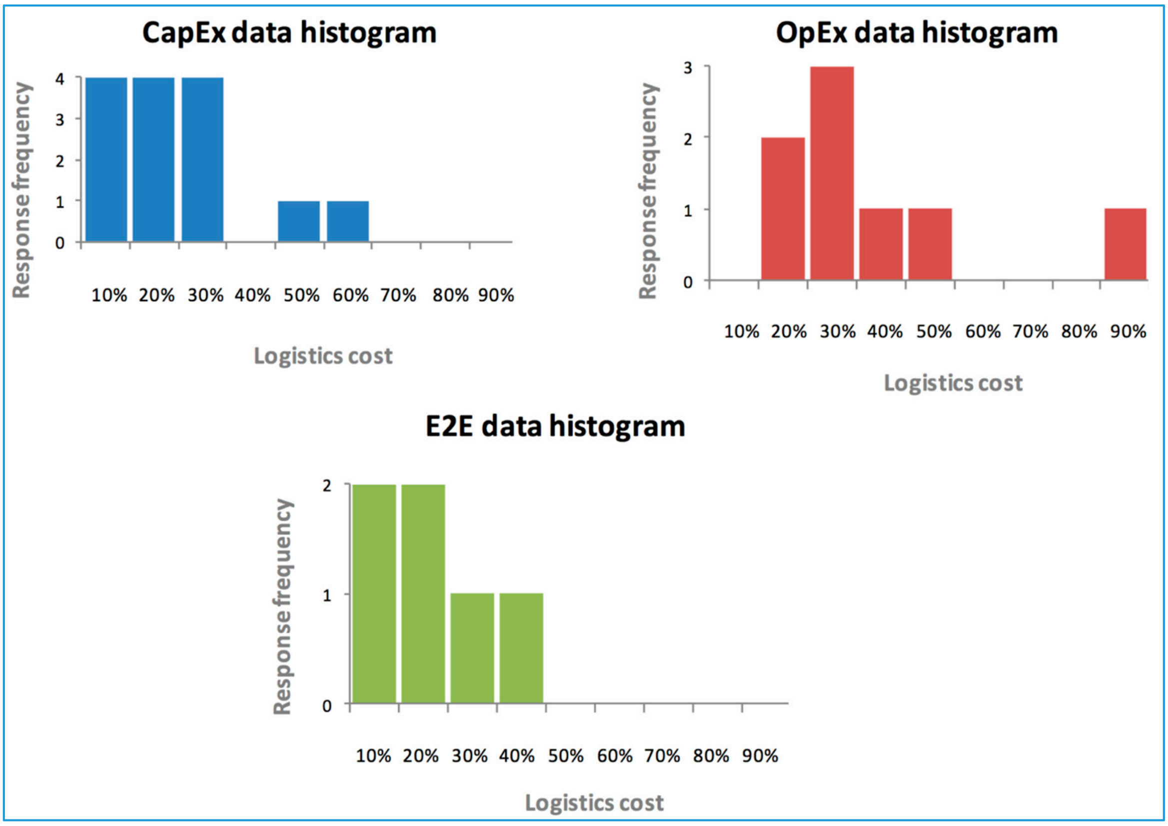

Figure 4. The 28 useful responses about logistics costs (in %) of CapEx, OpEx or LCoE (E2E).

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.

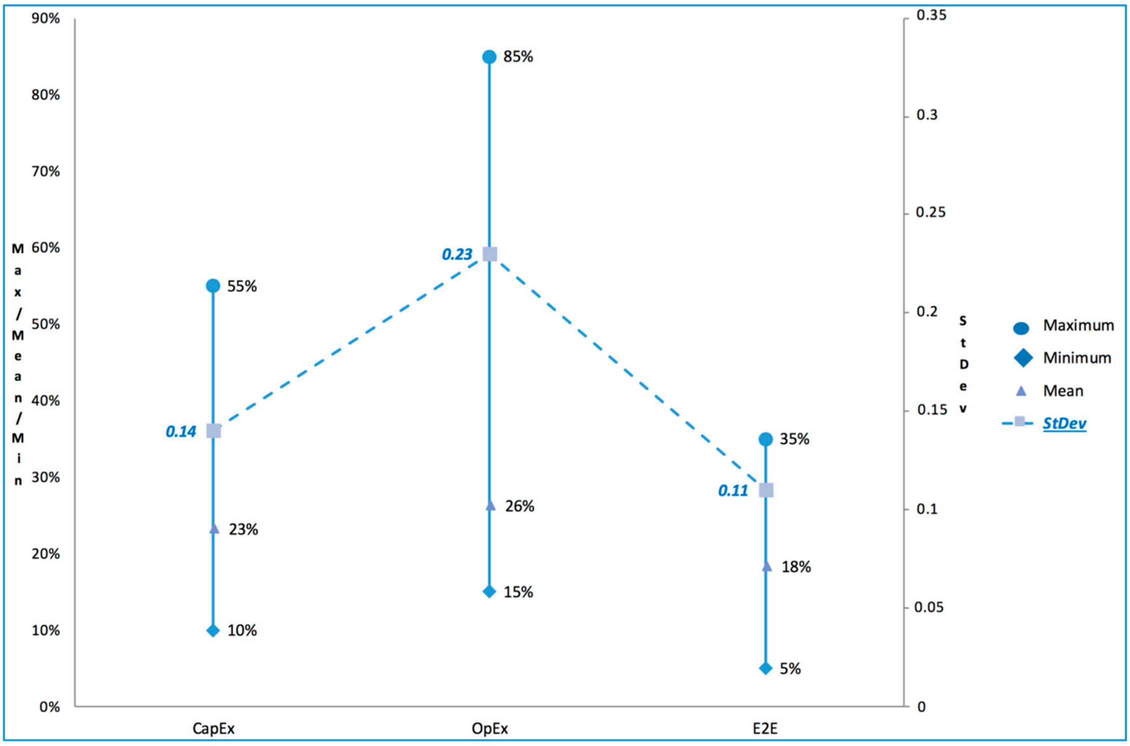

Figure 5. Distribution of responses about logistics costs as a share of total costs.

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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