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GLOBAL WIND TURBINE SHIPPING & LOGISTICS - A RESEARCH AREA OF THE FUTURE?

Thomas Poulsen, Gang Chen, and Niels G. M. Rytter

Respectively Research Assistant, Assistant Professor, and Associate Professor at Aalborg University, Copenhagen campus, Department of Mechanical and Manufacturing Engineering, A.C. Meyers Vænge 15, 2450 Copenhagen SV, Denmark, emails respectively tp@m-tech.aau.dk, gc@m-tech.aau.dk, and i9nr@m-tech.aau.dk

ABSTRACT

This paper investigates shipping and logistics challenges of the rapidly growing wind turbine industry using an end-to-end supply chain perspective. Wind turbine supply chains execute activities related to inbound logistics, wind turbine production/assembly, outbound logistics, installation, operations/maintenance of active wind farms, and de-commissioning. Such activities are often spread out across countries or regions, and require long-distance transportation of parts, components, or modules. Wind turbines are growing in size and weight, requiring specialized equipment and handling. Each onshore or offshore wind farm project requires tailor-made shipping and logistics solutions as installation sites are unique. Wind turbine manufacturers and/or utility companies owning the wind farms therefore face several practical challenges regarding shipping and logistics activities which also make up significant costs for them while simultaneously posing an increasingly attractive revenue opportunity for shipping and logistics service companies. This paper presents results of an exploratory study including 200+ interviews, site-, and conference visits conducted over 2+ years to uncover current/future shipping and logistics challenges of this particular industry. Basis the exploratory study, the paper outlines a number of research topics of future relevance for researchers within areas of supply chain management and maritime logistics.

Keywords: Wind energy SCM, shipping, logistics, supply chain management

1 INTRODUCTION

Since the 1970's, there has been increasing political focus on replacement of fossil fuels or nuclear power with more sustainable and emission free energy sources all over the world. This has lead to a significant expansion of wind power production capacity and thus tremendous growth rates for the global wind turbine manufacturing industry. Predictions are that power generated by wind energy will grow 10-fold from a total of 285.8 giga-Watt (GW) of globally installed capacity as of end 2012 (BTM Consult a part of Navigant, 2013) to an astonishing 2,541.1 GW by 2030 (Global Wind Energy Council, 2012). This exponential growth will be achieved through the development of many more onshore and offshore wind farms, with offshore wind farms forming the fastest relative growth segment making up a total of only 5.1 GW installed by end 2012. The growing demand for wind turbine capacity and pressure for low cost wind power (as the industry is facing competition from multiple substitute energy sources) have, since the first wind turbine generators (WTGs) were pioneered, been enabled through not only an increasing amount of WTGs but particularly also the constant product innovation and development of WTGs with increasingly higher output.

The first WTG was developed in 1887 and through to the largest present-day onshore Enercon WTG (BTM Consult a part of Navigant, 2013), most research and development (R+D) efforts are currently rendered for offshore WTGs. WTG original equipment manufacturer (OEM) R+D efforts presently include Siemens Wind Power (Siemens), Vestas, the largest Chinese OEMs (Goldwind, Sinovel, and United Power), as well as one South

Korean OEM (Samsung) all working on new 6-10 MW (mega-Watt) offshore WTG designs. In the US, GE is working on a new turbine design expected to produce output of 10-15 MW with support from the US government. In Europe, the European Commission funded the 60-month UpWind research project where in excess of 40 parties concluded that a 20 MW offshore WTG design is feasible (Risø National Laboratory DTU, Aalborg University *et al*, 2011). Based on the ever expanding WTG MW performance and expectations, countries and regions now increasingly measure their wind energy targets in GW.

The chase for higher MW output per WTG poses an increasing challenge not only for the OEMs and their clients operating or owning the onshore or offshore wind farms, but also those whom are responsible for shipping and logistics, whether they are part of the mentioned organizations or operating as independent suppliers to these businesses. Scale and complexity of the shipping and logistics tasks required to transport wind turbine parts/components for assembly or finished modules for installation have increased proportionally with the MW output of the WTGs. As an example, the weight of the Siemens 2.3 MW WTG nacelle is 82 tonnes whereas the REpower 6.15 MW nacelle weighs 325 tonnes and the blade length of those WTGs were 45 respectively 61 meters (BTM Consult a part of Navigant, 2012). Blades continue to get exponentially longer with recent installations at 75 meters for the Siemens 6 MW offshore WTG at the Østerild, Denmark test center and the 83 meter Samsung 7.5 MW offshore WTG test blade shipped from Denmark to Germany (Poulsen, 2012). Such changes in WTG parts/component and module weights/dimensions cause wind transport equipment (TEQ) to continuously require proactive alteration and re-design.

In terms of shipping and logistics, the wind turbine supply chain management (SCM) market can best be characterized as a cross-over between container shipping, air freight, logistics, port services, offshore, break-bulk, and project cargo in an end-to-end (E2E) multi-modal chain. Parts of the supply chain, such as the inbound shipments of parts/components for nacelle assembly, represent a fairly homogenous and straight-forward supply chain. Other parts of the supply chain are much more complex with offshore wind turbine installation and commissioning involving a very elaborate set-up for land transportation, at the ports involved, and for the vessels as well as crew operating at sea.

Furthermore, wind energy shipping and logistics is a complex SCM discipline as each wind farm project requires tailor-made solutions. This is partly due to the fact that every wind farm installation location is uniquely positioned for example in windy mountainous areas onshore or at deep waters with special waterbed conditions offshore. The complexity is also partly caused by the fact that the wind supply chains are often very extensive, deep, and complex in scope with long lead-times for the different parts of the supply chain and a just-in-time (JIT) requirement back-loaded within the installation phase. Several parts of the wind farms such as offshore foundations are essentially build-to-order (BTO) modules and often, the WTG itself is tailor-made for each project and not "true" serial production. Wind farm shipping and logistics success criteria are many and varied, spanning from costs/lead-time on one hand to complex health-, safety-, environment-, and quality (HSEQ) matters on the other. Many hand-offs in the supply chain between the many different constituencies furthermore require tight coordination between multiple parties in the E2E chain.

Taking the practical challenges related to wind energy shipping and logistics it poses for the wind industry into account as well as the revenue opportunity it poses for logistics and shipping service companies, it is surprising to see how little research has been done on this topic so far. Through a search of literature on this particular topic, we identified only few publications so far. Athanasia *et al* (2012) presents the latest development of the offshore wind power market which determines that the new projects move to deeper waters and further from shore. This new trend requires a strong supply chain covering all the aspects related to wind power. Lange *et al* (2012) developed a simulation tool to test different logistics plans for transporting and installing an offshore wind turbine. Here, investigated scenarios for real wind farms show that disturbances due to weather restrictions can lead to a significant increase in risk and logistics costs. Such a simulation tool is important for developing sustainable logistics concepts and implementing projects within the planned cost and time frames. Schuh & Wienholdt (2011) point out that many companies in the wind power industry have not yet implemented spare parts management strategies and they apply system dynamics simulation methods to support decisions on such implementations for a supply chain. Besides the above studies on logistics challenges, there are also few publications on wind power policy and planning, such as Söderholm & Pettersson (2011) as well as Lema & Lema (2013). Finally, Kaiser & Snyder (2012) explore cost estimation of specialized TEQ.

Due to the limited extend of previous research on the topic, it was decided to launch a mainly exploratory study of wind energy shipping and logistics. This study was conducted by the first author of this paper's research team over a 2+ year period from 2010-2013. The first author has 20+ years of practical and relevant global shipping/logistics/SCM background. The research questions, which have guided the conducted exploratory research task and which are dealt with in this paper presenting results developed so far from the study, are the following:

1) As "a rough estimate", what size is the future market potential for services related to wind turbine shipping and logistics in an E2E wind farm life cycle supply chain perspective?
2) What do various supply chain constituencies perceive to be the key current as well as future challenges of wind turbine shipping/logistics/SCM?
3) Is wind shipping/logistics/SCM an area of research deserving further attention in the coming years and which topics appear immediately relevant to investigate further?

2 MARKET POTENTIAL FOR WIND SHIPPING AND LOGISTICS

2.1 Wind market sizing

The shipping and logistics market for wind energy is a product of the global demand for wind energy, i.e. the number of WTGs to be installed and already in operations. A number of different organizations and research companies publish various estimates for energy in general, the renewable energy portion thereof, and the size of the wind energy market. Most of the estimates stretch out as far as 2020 to 2030 which, for investments in e.g. ports or shipping assets, is usually too short of a time frame for an investment grade business case.

Because of the high degree of subsidies required for the renewable energy sector in general including the wind energy business, wind energy demand projections depend much on political circumstances at a national, regional, and global level. The World Energy Outlook (International Energy Agency, 2012) and the Annual Energy Outlook (US Department of Energy, 2013) are generally fairly conservative 2035 respectively 2040 projections in terms of renewable energy and wind energy's share thereof. Other estimates from well-respected wind industry market intelligence companies (Emerging Energy Research, 2011, and Global Wind Energy Council, 2011) have a more aggressive view of the share of wind energy in the future and projections. From a business case/investment perspective, all estimates do, however, agree that the wind energy sector will grow dramatically up to 2050 (Poulsen, 2012).

2.2 Wind energy shipping, logistics, and SCM market segmentation

In order to assess the market size for wind shipping and logistics, the E2E supply chain first has to be broken down into different segments and each segment analyzed/quantified from a process perspective. Because of the fairly young and immature status of the wind industry in general, different points of view exist regarding the steps involved in developing an onshore or offshore wind farm. The UK's Crown Estate (BVG Associates, 2011) works with 5 phases to develop an offshore wind farm, i.e. development & consent, WTG, balance of plant (BOP), installation & commissioning, and operations & maintenance (O&M). Others (BTM Consult a part of Navigant, 2012) use a different terminology and add a 6th de-commissioning phase.

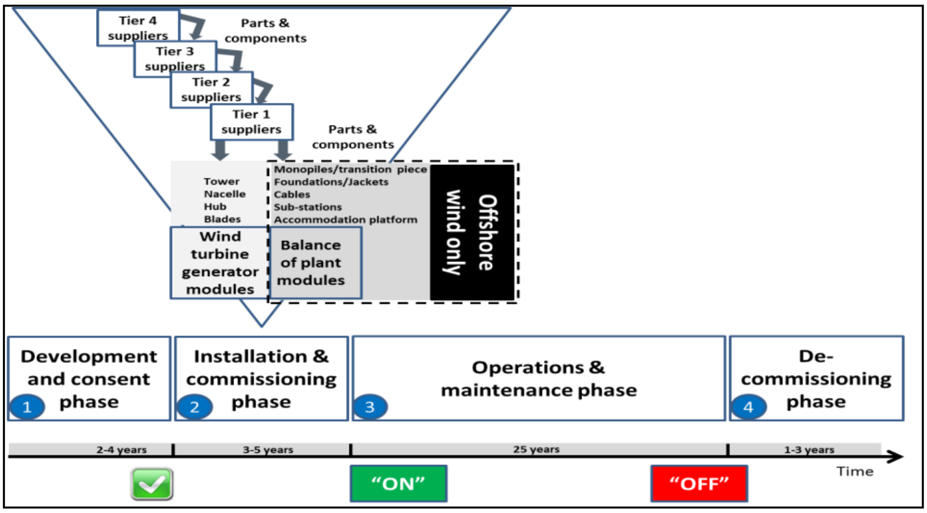

Figure 1. Illustration of different phases of onshore/offshore wind farm life-cycle (Source: Thomas Poulsen research)

In Fig. 1 above, we have outlined our shipping and logistics based overview of the wind farm life cycle. Shipping/logistics/SCM activities occur in every stage of development of the wind farms, starting with the development and consent phase. After the go-ahead for the wind farm has been obtained, construction of the different WTG modules commences and the installation and commissioning phase of the wind farm construction can begin for onshore wind farms. For offshore wind farms, balance of plant (BOP) modules also need to be constructed. Fig. 2 below shows an example of a typical WTG/BOP high level installation process mapping chart for an offshore wind farm. BOP modules such as cables and sub-stations are handled separately whereas for WTGs, foundations/jackets or monopoles/ transition pieces (TP) are installed first, after which wind turbine installation vessels (WTIVs) or simpler heavy-lift crane/tug-barge solutions are deployed offshore for WTG erection.

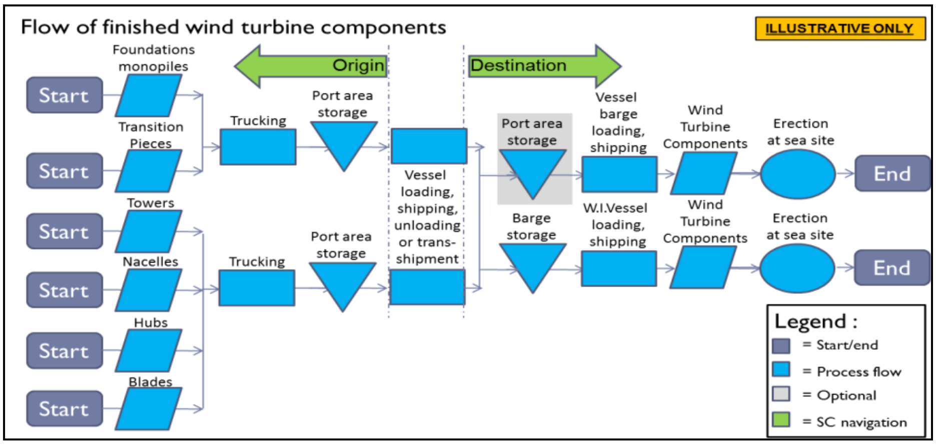

Figure 2. Outbound module supply chain process chart, offshore wind farm (Source: Thomas Poulsen research)

From a process mapping perspective, the installation and commissioning example used in Fig. 2 above example above assumes that:

- Large offshore wind modules manufactured/assembled near coastal areas are shipped from the manufacturing/export port to an intermediary installation port (double-port installation process). At the installation port, components are shifted either on barges in the water and/or onto the installation port area for further assembly prior to installation/ erection at the selected offshore sea site.

- The offshore installation supply chain utilizes all parts of the supply chain including trucking, rail (in some cases), warehousing, storage, port services, and shipping.
- For very large and heavy modules such as cables, sub-stations, monopoles/TPs, towers, accommodation platforms, and foundations, the near-shore manufacturing plants practically call for the trucking process to make use of self-propelled modular transporters (SPMTs) in most cases due to the heavy weight and short distances involved.
- The size and weight of e.g. nacelles (up to 400 tonnes) and foundations (up to 700 tonnes) put big requirements on the all supply chain constituencies. For example, ports must ensure vast storage areas, sufficient preparation of the ground for heavy loads per square inch (PSI), and that stevedoring/crane/trucking resources are adequately available.

All phases of the wind farm life-cycle can be broken down in a similar manner as what has been done in Fig. 2 above for onshore respectively offshore wind farm projects.

2.3 Market potential

The market potential for wind shipping, logistics, and SCM appears to grow exponentially. A recent study (Poulsen, 2012) estimated that 2012 costs for just the offshore wind installation and commissioning phase amounted to some EUR 2 billion. Using a 2050 Wind Scenario Model (WSM) tool, the study furthermore predicted that the net present value (NPV) of the offshore wind installation and commissioning outbound shipping, logistics, and supply chain market amounts to more than EUR 100 billion. The study used a supply chain process split segregating activities and costs as follows:

- Costs ashore (e.g. for trucking, storage, and cranes)
- Costs in the ports (import/export ports and installation ports)
- Costs at sea (both for transport of modules and offshore wind farm installation activities)
- Costs for intermediaries (e.g. for project managers and project cargo forwarders)

If we compare this bullish market outlook to other parts of the shipping and logistics industry in general, the wind niche presents an attractive alternative (Byrnes, 2010) to the generally depressed shipping and logistics market. This can be evidenced e.g. by the Baltic Dry Index (BDI) which was above 11,500 in 2008 before the global financial crisis. By end February, 2013, the BDI had dropped to approx. 750 (Bloomberg, 2013).

No cost studies have been made for the remaining part of the wind farm installation process and a need exists to expand for example the aforementioned WSM tool to include all stages of wind farm development as depicted in Fig. 1 above. This could be done in both a theoretical model and to the extent possible subsequently be verified with actual and "live" supply chain cost modeling to validate key assumptions and projects in the forecasted numbers up to 2050. Only in this way will the true share of shipping, logistics, and SCM be known for all players in the industry and true market estimations made available to investors and interested parties contemplating investments in TEQ and other supply chain assets going forward.

3 SUPPLY CHAIN CONSTITUENCIES & MULTI-MODAL TRANSPORT SYSTEM

3.1 Wind farm supply chain constituencies

Depending on the contracting terms, a number of supply chain constituencies are involved in a wind farm project. Most often, the wind farm will be commissioned by a utilities company and the utility will then be both wind farm developer and operator. Depending on the skills and experience of the wind farm developer, an engineering, procurement, and construction (EPC) company may be hired as the main project contractor (single contracting) including all shipping/logistics tasks. In other cases, the developer may have sufficient in-house wind farm installation experience to perform all project management functions in-house (multi contracting) and thus contract with all shipping and logistics entities directly. Finally, some wind farms are sold by the OEM's as turn-key projects where the OEM will then need to perform all shipping and logistics activities up to and including installation as well as O&M for the first 3-7 years of operations. Independent wind farm operators also exist and recently, sovereign wealth funds (SWFs) have invested in wind farm development and operations.

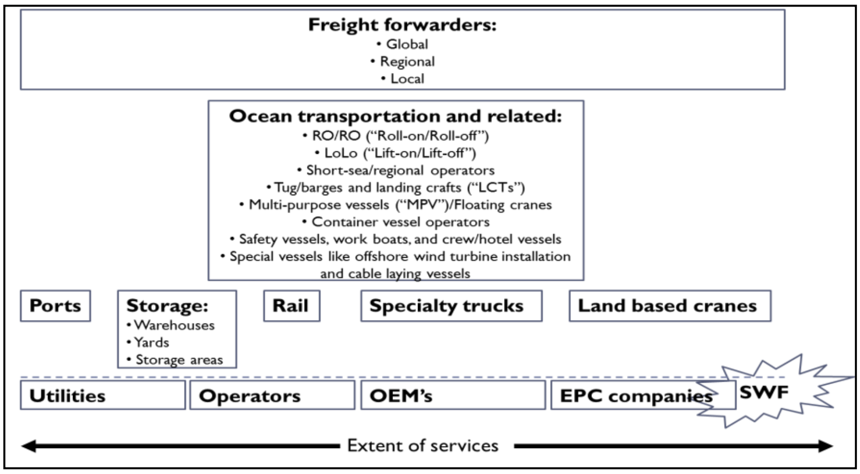

Figure 3. Wind farm SCM constituencies overview (Source: Thomas Poulsen research)

Fig. 3 above displays some of the key players involved in the supply chain for wind farms:

- Port operators provide facilities for linkage of the ocean based supply chain and the land based chain. This includes ample storage areas, berths, cranes, and easy access
- Storage providers make warehouses, yards, and storage areas available for storage of both TEQ and wind turbine parts, components, and modules
- Rail operators - especially in North America and also to some extent in Europe - provide specialized rail transport TEQ options for WTG blades and parts/components/modules
- Specialty trucks along with land based cranes are required to move WTG modules such as blades and nacelles on land from e.g. place of manufacture or assembly to ship out port
- At sea, a range of ocean transportation providers are involved and for offshore wind farms, the scope/extent of ocean going vessels is much larger than onshore installations
- Freight forwarders (project forwarders) "glue together" a number of supply chain processes and take responsibility for service quality, safety, and supply chain hand-offs.

3.2 Complex multi-modal transport system

The transport system for WTG's is truly multi-modal and consists of all known modes of transport. From a process mapping perspective, the inbound assembly parts/component flow for key parts required to produce the nacelle demonstrates the multi-modal set-up as follows:

- The parts are sourced from various global locations into the assembly plant. Parts are e.g. produced by German and Danish companies in Europe or China. When larger components or sub-modules are created, the value added manufacturing is often done in China and as such, sub-flows exist from Germany/Denmark to China and then back from China to the nacelle assembly plant in Denmark, Spain, the US, or Germany
- Some parts and components have dimensions and weights that allow for homogenous transport using ocean bound containers or occasionally, in case of urgent shipments, air freight. Larger components like the canopy ("casing"/nacelle "house") are so big/heavy that break-bulk shipments using multi-purpose project (MPP/MPV) vessels are involved

- For the inbound assembly parts/component flow, the transport system includes trucking, rail (in some cases), warehousing, storage, and port services besides the shipping by sea or air. Links and hand-offs in the supply chain are carefully orchestrated and coordinated

4 RESEARCH DESIGN FOR THE EXPLORATORY STUDY

A number of practical and cost optimization challenges exist in the area of wind energy shipping and logistics now and in the future. To get an overview of these challenges, an exploratory study of the wind shipping and logistics market was carried out by the first author of this paper from 2010 until present. A total of 200+ data collection encounters such as interviews, site visits, and conference/seminar attendances (combined referred to as encounters) were conducted during more than 60 trips involving in excess of 300 interviewees and the findings were duly recorded (as per Brinkmann & Kvale, 2009). Tab. 1 presents an overview of the encounters and interviewees.

Table 1. Exploratory study 2010-2013 wind shipping and logistics industry

Encounters				
Total number of encounters				246
Total number of trips				65
Number of encounters	2010	2011	2012	2013
	4	123	48	71
	1,6%	50,0%	19,5%	28,9%
Split of encounters by type	Site visits	Conferences	Interview meetings	
	35	27	184	
	14,2%	11,0%	74,8%	
Regional split	Europe	Asia	Americas	
	195	17	34	
	79,3%	6,9%	13,8%	

Interviewees						
Total number of interviewees						318
Positions of interviewees	CxO	VP	Professor	Manager	Analyst	Student
	55	88	16	124	21	14
	17,3%	27,7%	5,0%	39,0%	6,6%	4,4%
Interviewee by supply chain constituency type	Utilities	Operators	EPC	OEM's	Suppliers	
	15	0	1	29	7	
	4,7%	0,0%	0,3%	9,1%	2,2%	
	Politicians	Education	Shipping companies	Freight forwarders	Ports	
	9	31	92	67	21	
	2,8%	9,7%	28,9%	21,1%	6,6%	
	Warehouse /storage	Rail operators	Truckers	Crane providers	Market research	Others
	3	2	3	0	23	15
	0,9%	0,6%	0,9%	0,0%	7,2%	4,7%

Source: Thomas Poulsen research

75 per cent of the encounters were meetings with interviews of two or more participants and conversely, 14 respectively 11 per cent were encounters done during site visits and conferences. Interview meetings enabled in-depth conversations of relevant industry respondents and the 35 site visits included useful field study trips providing better practical understanding of matters at hand. Finally, industry conferences were an efficient data collection opportunity as it was possible to reach out to a larger number of relevant stakeholders and conduct many shorter conversations on relevant conference topics.

From a geographical perspective, Tab. 1 illustrates that Europe dominated the exploratory study efforts with some 75+ per cent of all interviews. With more than 30 encounters in the Americas and more than 15 in Asia, regional differences and company/cultural differences have been catered for through an acceptable encounter mass. In terms of supply chain point of view, the interviewees' position and experience affect the scope and nature of the encounter. Tab. 1 reveals that the study involved many respondents on top management positions as the Board/owner/CEO/CCO/COO/CIO/CHRO (CxO), Vice President (VP), as well as professor level – both making up 50 per cent of persons interviewed. The other half of the respondents reached out to, were operational staff (managers, analysts, and students) included to capture a practical or "hands-on" perspective on industry challenges as part of the exploratory study. Tab. 1 furthermore displays that a wide range of supply chain constituencies were consulted during the exploratory study including respondents from shipping companies, freight forwarders, OEMs, and port operators. Operators, EPCs, suppliers, and some other important supply chain constituencies have not been part of this round of exploratory research to the extent we would have liked, however, in our continued research we will focus on them also.

5. WIND ENERGY SHIPPING AND LOGISTICS CHALLENGES

5.1 Major industry challenges

Basis the exploratory study coupled with relevant academic literature, several themes emerged as what can be categorized as "critical industry challenges".

Table 2. Catalogue of global wind energy shipping and logistics "critical industry challenges"

Seq.	What	Challenge to which supply chain constituencies?	Comments
	Macro economy and policy		
1	2050 forecasting models	Utilities, operators, shipping and logistics companies	Present models only up to 2030-2040
2	Regional policy updates	Utilities, operators	Only European Union (EU) and People's Republic of China (PRC) have goals by law
3	Country forecasts	Utilities, operators, shipping and logistics companies	Each country has own approach
4	Shipping/logistics contribution to Cost of Energy (CoE) reduction targets	Utilities, operators, OEMs, ports, shipping and logistics companies	Total CoE reduction targets and total shipping costs unclear
5	Development plans of sovereign wealth (SWFs) funds, utilities, and operators	Utilities, operators, OEMs, ports, shipping and logistics companies	SWFs from Norway/UAE/China and utilities from EU/China lead, operators depend on policies
6	OEM forecasts	Ports, shipping and logistics companies	OEMs compete by market and R+D is critical
7	Government dependencies and subsidies makes shipping/logistics less desirable	Ports, shipping and logistics companies	Perception making "usual shipping and logistics company suspects" reluctant to invest
8	Wind energy sector is immature	Ports, shipping and logistics companies	Supporting shipping and logistics business equally immature
	Supply chain economics		
9	Public Private Partnership analysis	Regions, countries, ports, shipping and logistics companies	Roads, ports, and rail in Europe; state-owned companies in China
10	Risk management in investment models	Ports, shipping and logistics companies	Changes in transport equipment (TEQ) requirements, asset retirement options, HSEQ
11	Pay-back modeling using accurate	Ports, shipping and logistics companies	Critical for investment decisions
12	Supply chain component/mode of transport cost split	Utilities, operators, OEMs, ports, shipping and logistics companies	Ability to break-down supply chain to understand costs and analyze costs by transport mode
13	Assignment of responsibilities within the supply chain	Utilities, operators, OEMs, ports, shipping and logistics companies	Who is responsible under what terms and how to obtain proper insurance
14	Desire to focus on core business	Utilities, operators, OEMs	Non-shipping players divestiture of shipping/logistics assets when market matures
15	Longer term contracts	Ports, shipping and logistics companies	As TEQ is acquired and trust emerges between players, contracts can be optimized
16	Actual wind turbine parts, components, and module freight movement analysis	Utilities, operators, OEMs, ports, shipping and logistics companies	Basis HTS numbers and using historic development for global research
	Supply chain facilities and transport equipment		
17	Location mapping of key manufacturing sites	Utilities, operators, OEMs, ports, shipping and logistics companies	Larger modules should be manufactured/assembled near coastal areas/ports
18	Port master plans by region/country	Utilities, operators, OEMs, ports, shipping and logistics companies	To eliminate waste, master plans should be developed for key install markets
19	Inter-regional and intra-regional flow forecasting	OEMs, ports, shipping and logistics companies	Historic, present, and future flow mapping between and within regions
20	WTG MW output size/weight conversion model	OEMs, ports, shipping and logistics companies	Historic, present, and future mapping of relation between WTG MW output and TEQ
21	TEQ design overview for land, ports, and ocean	Utilities, operators, OEMs, ports, shipping and logistics companies	What TEQ is used in which wind shipping and logistics supply chains - past/present/future
22	TEQ and asset retirement options review	Utilities, OEMs, ports, shipping and logistics companies	Different assets and TEQ can be deployed in other parts of the world or other industries
23	Port construction guidelines	Regions, countries, ports, shipping and logistics companies	Procedures for export/import, manufacturing, installation, and other WTG related ports
	Supply chain operations		
24	Value chain roles and responsibilities	Utilities, operators, OEMs, ports, shipping and logistics companies	Who are involved and what is their role
25	Detailed process mapping all parts of wind farm construction process	Utilities, operators, OEMs, ports, shipping and logistics companies	Buying term conversions inbound from DAP to FOB/FCA/EXW, case studies, modeling
26	Multi-modal hand-off studies	Utilities, operators, OEMs, ports, shipping and logistics companies	Procedures, insurance, roles and responsibilities
27	Operations for different parts of the wind supply chain	Utilities, operators, OEMs, ports, shipping and logistics companies	Detailed studies of actual operational procedures for entire wind farm construction
28	Knowledge gathering and storage	Utilities, operators, OEMs, ports, shipping and logistics companies	Assembly of global best practices for knowledge sharing and transfer
29	Supply chain health, safety, environment, quality (HSEQ) mapping	Utilities, operators, OEMs, ports, shipping and logistics companies	HSEQ maping for people, environment, and products involved in shipping and logistics
30	Human resource management (HRM) in the wind supply chain	Utilities, operators, OEMs, ports, shipping and logistics companies	Strategic overview of HRM needs now and in future

Source: Thomas Poulsen research

A catalogue of 30 such challenge themes has been assembled in Tab. 2 above. The challenges have been reviewed based on different supply chain stakeholder vantage points. Most critically, the wind industry is quite immature with R+D being considered as extremely

OEM centric, confidential, and very proprietary. This means that across the industry, no global best practices sharing or shared ways of working exist to any significant extent. The supply chain complexity coupled with internal organizational fragmentation observed among the interviewees result in a myopic and silo-based approach to costs. This in turn generates an apparent lack of overview when it comes to total E2E costs leading to an evident lack of even average industry transparency when it comes to shipping, logistics, and SCM costs. This is further compounded by the additional complexities when involving different cost pictures and operational set-ups of different regions, between regions, or even business models of supply chain constituencies based in different geographies. The operating models and cost awareness for an onshore wind farm appear to be connected with a greater degree of certainty in terms of answers by the interviewees. Conversely, offshore wind farm development very much seems to be a very new and unexplored area of business where shipping, logistics, and SCM costs are very significant for all phases of a project and where operations practices vary greatly. As a consequence, no answer can be provided to the simple question of "How much do shipping, logistics, and SCM costs make up of a wind farm from cradle to grave?"

The critical industry challenges have been segmented into 4 categories discussed below.

5.2.1 Macro economy and policy

A significant catalogue grouping has to do with macro-economic issues and policy matters. Macro-economic factors have been analysed at various levels and political resolve as well as action called for in order to save the planet from a climate-economical perspective. Various abatement options call for countries to spend up to 2 per cent of GDP (Stern, 2007) on measures to avoid greenhouse gasses.

Similarly, the political side has also been subjected to debate and analysis leading to a very broad public reach (Gore, 2009) as well as a fairly deep understanding and personal involvement among citizens of many countries. This has led to political, financial, and sometimes legally binding initiatives at global, regional, country, as well city level across the globe. Legally binding initiatives include the EU 20-20-20 plan as well as China's 12^{th} 5 Year Plan. These and other initiatives include the promotion of renewable energy sources with government subsidies as alternatives to especially nuclear and heavily polluting fossil fuels.

However, especially the fact that the renewable energy industry in general - and therefore also the wind energy sector – is driven largely by political resolve and based on government subsidies to be viable, is a cause for great concern among many players within the sometimes rather conservative shipping and logistics industry. Competitive, self-sustaining cost of energy (CoE) coupled with market transparency is therefore macro-economic factors of critical importance to activate the shipping and logistics industry players within the wind energy sector (Lynch, 2009).

5.2.2 Supply chain economics

The catalogue grouping representing the economics of the supply chain and its' different components is vital for investments in assets, personnel, IT systems, and/or knowledge by all supply chain constituencies. Proper process mapping and ensuing cost modelling understanding is therefore vital for companies and organizations to develop as the costs associated with WTG manufacturing, assembly, installation, O&M, and decommissioning: These costs equal the revenue opportunities for shipping and logistics supply chain constituencies interested in investing in this market. Strategy setting in shipping and logistics companies largely depends on CxO/VP level decision makers having the right information available about historic, present, as well as future market developments. Traditionally, the shipping and logistics markets are well researched and documented (Stopford, 2009) and the wind energy market ought not to be different in that respect.

When making investment decisions in a corporate finance perspective (Allen *et al*, 2008), companies/organizations wish to understand the market dynamics, economics, and forecasts at the time of investment decision. Similarly, a clear competitive overview (Porter, 2000) must be available. These factors are not completely clear in the wind energy shipping and logistics market as a number of rather “untraditional players” such as utility companies, EPC companies, SWFs, and OEMs described in section 3 (see Fig. 3) above are currently actively involved with own personnel and TEQ. This clouds the market place and discourages investment from the more “traditional players”. A divestment/demerger strategy may be expected on the part of the untraditional players (De Wit *et al*, 2004) as the industry matures.

5.2.3 Supply chain facilities and TEQ

The different supply chains for e.g. nacelle assembly, BOP module construction, offshore wind farm installation, O&M operations onshore as well as offshore all require more or less complex and elaborate multi-modal connectivity supply chain facilities and TEQ to operate. Linking such modes of transport across multi-modal chains on a global basis is a complex undertaking (Christopher, 2010) which requires significant investments in facilities, TEQ, people, IT systems, and knowledge management. As discussed above, the fast-paced R+D efforts within the wind energy business itself to increase WTG MW output causes weight as well as dimensions of the parts, components, and modules to be transported to change frequently. The supply chains, related facilities, and TEQ are therefore very fluid, changing, and dynamic and cause significant complexity again requiring tight procedures, close practical monitoring, and hands-on management in the field (Christopher, 2010).

Faster depreciation/amortization modelling as well as alternative asset retirement strategies become critical components for investors in the wind energy shipping and logistics industry. Not all markets in the world install the same WTGs and MW requirements vary by market based on maturity and investment appetite. Some assets may therefore be obsolete in one market but at the same time be required in another region or market. Similarly, some assets may be constructed in such a way that they can serve dual purposes, like for example offshore wind installation as well as offshore wind O&M.

5.2.4 Supply chain operations

Seen from the perspective of the catalogue grouping referred to as supply chain operations, process mapping (Slack *et al*, 2010) is critical to generate an overall supply chain composition understanding. Only by breaking down the supply chain into different sub-processes and modes of transport can the true cost composition be understood, measured, and/or simulated. In comparing supply chains within regions as well as across different regions, similarities and differences exist from a cultural and company/organizational perspective (Christopher, 2011). By using detailed mapping and comparison techniques, global wind energy supply chain operations could be described in order to derive best practices for the industry at large to learn from. This would include the vital HSEQ parameters critical to timely and sustainable supply chain solutions executed without the loss of human life. Operational challenges can be better resolved after best practices have been established and comparisons made. Detailed process understanding reveals bottlenecks, improvement opportunities, waste, and other types of inefficiencies to be eliminated.

6 IMPLICATIONS FOR SCM/MARITIME LOGISTICS RESEARCH

The industry challenges in the wind shipping and logistics market introduced in section 5 above demand extensive research efforts from both industry-based R&D and academia-based studies. However, in our literature review in section 1 above, we only identified a limited number of academic studies done with this area. When parsing these academic studies into the challenge areas included in Tab. 2 above, we can only identify that 4 out of the 30 main industry challenges have been addressed by academic publications or contributions so far:

- Category 1 - topic number 3: Söderholm & Pettersson (2011)
- Category 1 - topic number 8: Athanasia *et al*, (2012)
- Category 2 - topic number 11: Kaiser & Snyder (2012)
- Category 4 - topic number 27: Lange et al, (2012); Schuh & Wienholdt (2011)

On this basis, a significant mass of additional topics are open and ready for future research within all 4 research categories identified. This calls for further research also cutting across classical research disciplines and levels. Due to the global and complex nature of this market and related research topic, good research studies should follow some principles as follows:

- As the wind shipping and logistics market is becoming increasingly more global, a truly global point of view is important along with in-depth knowledge of regional as well as national requirements and other pre-requisites for competition.
- Studying current business models, practices, and SCM solutions for wind energy shipping and logistics can potentially lead to producing conclusions and recommendations not relevant for the future. This is a risk for researchers because simultaneously monitoring possible future technological developments and their impact on the still immature wind industry is critical for successful research outcomes.
- There is a need for balancing a high level overview of global E2E wind turbine supply chain setups with narrow focus on particular industry challenges and sub-topics of interest. It is necessary to looks across different geographies, supply chain disciplines, business models, and the different stages of wind farm development in order to identify the main industry challenges/inefficiencies while simultaneously performing in-depth studies able to produce relevant recommendations for optimizing the future supply chains.

7 CONCLUSION

The market for wind energy shipping and logistics is expanding despite the global financial crisis and the generally depressed transport and supply chain market. Whether seen from a transportation policy-making or shipping/logistics company/organization point of view, a great need exists for more transparent and comprehensive wind energy shipping and logistics research. Basis the findings from a 2010-2013 exploratory study with more than 200 data gathering encounters involving more than 300 interviewees, we have outlined 30 sub-topics, within 4 main categories that pose significant practical and business challenges for the industry constituencies already today and in the future. Comparing these challenges to the limited amount of academic research done so far within the area, the authors therefore suggest peers to pursue the research opportunities which the area of global wind energy shipping and logistics offers for SCM and maritime logistics related academic researchers going forward.

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