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Is the supply chain ready for the green transformation? The case of offshore wind logistics

Thomas Poulsen[a,*], Rasmus Lema[b]

[a] Department of Mechanical and Manufacturing Engineering, Aalborg University, A C Meyers Vænge 15, 2450 Copenhagen SV, Denmark
[b] Department of Business and Management, Aalborg University, Frederikskaj 10, 2450 Copenhagen SV, Denmark

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ABSTRACT

The transition from fossil fuel-based energy systems to renewable energy systems is a cornerstone of the green transformation to decarbonize our economic systems and mitigate climate change. Given the urgency of effective climate change mitigation, renewable energy diffusion needs to accelerate drastically. Among the many constraints to renewable energy diffusion, the important role of the supply chain is often overlooked. Therefore, this article addresses the role of the supply chain in the renewable energy diffusion process. Using the offshore wind energy sector as a case, this article presents an analysis of supply chain readiness to ascertain the role of the supply chain in the green transformation. Examining Europe and China mainly within offshore wind logistics, the research findings show that this segment of the supply chain constitutes a key bottleneck for accelerated deployment. For Europe, the key findings indicate that legislation for offshore wind beyond 2020 is necessary to ensure the implementation of the required investments in logistics assets, transport equipment, and personnel. In China, the key findings indicate that the Chinese supply chain of wind energy is mainly organized around onshore wind. Key bottlenecks exist, predominantly in logistics, and this article identifies specific areas of the supply chain where international collaboration and knowledge transfer may speed up deployment.

1. Introduction

There is growing consensus that a green transformation of our economy is necessary in order to avoid significant reduction in human wellbeing resulting from multiple environmental stresses including pollution, biodiversity loss, and climate change [1–4]. Climate change mitigation is a cornerstone in the green transformation and depends on a sweeping process of 'creative destruction' in which new renewable energy sources replace old fossil fuel-based sources. Reaching the targets for renewable energy will hinge on both technological change and massive public and private investments [5,6]. Diffusion, so far, has been varied in different geographies [7–10]. This article analyzes an often overlooked - yet crucially important - element in the transition to renewable energy systems: The ability of the supply chain to support precipitous growth and rapid technological change. This is not a trivial issue. Deployment numbers need to be exponential rather than linear. To reach current targets, the renewable energy industry would need to double its capacity every seven years for the next seventy years [11]. Such an expansion of capacity at the sector level is unprecedented in history. The challenge is grand but a mitigating factor is that the doubling of renewable energy capacity is not equal to a doubling of the numbers of workers and factories in the renewable energy industries. This is because of technological change where the energy generation capacity of each unit produced and installed is gradually increased. Yet, the technological changes pose their own challenges to the supply chain. Nowhere is this clearer than in the offshore wind power industry, the focus of this article.

Whereas wind energy has been used for electricity production at an industrial scale since the 1980s [12], the advance in offshore wind energy production is much more recent. It was not until the mid-2000s that governments and energy firms started to move from experimental pilot projects to full-fledged deployment [6,13,14]. Offshore wind is projected to play an important role in the future energy mix of many countries as further onshore wind opportunities are becoming constrained and because offshore wind provides better wind speeds as well as more area for installing larger farms which enable electricity production at scale [15]. While crucially important to future climate change mitigation efforts, offshore wind depends on a transformation of supply chains. The offshore segment differs from the onshore segment as it tends to use larger wind turbines and because the installation process at sea depends on entirely different technologies and skillsets. In particular, the offshore wind segment depends on

* Corresponding author.

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challenging shipping and logistics processes which are entirely novel or which at least are new to the main constituencies who have hitherto been involved in electricity production [16]. That is why this article is particularly focused on shipping and logistics as a case study within the overall supply chain for offshore wind power.

Our research sets out to answer the following questions:

a) How ready is the supply chain for the exponential expansion of offshore wind?
b) What are the key barriers, bottlenecks, and/or constraints to offshore wind diffusion?
c) Are there differences between Europe and China as the largest markets in this regard?
d) How can the diffusion challenges be addressed with new solutions?
e) Where will the solutions come from?

The main contributions of this article are as follows:

First, we bring the supply chain perspective into the debate about renewable energy technologies in the context of climate change. Most discussions focus on the availability of different technologies to mitigate climate change or the availability of finance [17–20]. The crucial question of whether the supply chain is ready to buttress widespread deployment tends to be overlooked. The offshore wind industry provides an exemplary case of supply chain readiness for diffusion of renewables.

Second, the analysis is based on conceptual advances supplemented by our case study work in mainly Europe and China. Most articles have discussed basic value and supply chains mainly in the context of the onshore segment [21–23], or have reviewed supply-chain trends without a fine-grained analysis of the many steps involved in deployment [24–26]. This article decomposes the supply chain for offshore wind to make an analysis of sub-supply chains per life-cycle stage of offshore wind farms.

Third, this article provides a cross-continental comparison of shipping and logistics capabilities for offshore wind power. Prior comparative work has focused on policies and innovation systems [27] or has researched broader technological trajectories [28]. This article provides an in-depth analysis of the offshore segment in order to identify specific leverage points for future deployment.

This article is organized in five sections. Section 2 provides background and framing for the empirical analysis. In Section 3, we identify the main barriers, bottlenecks, and constraints challenging offshore wind diffusion and analyze to what extent and how supply chain readiness differs between Europe and Asia. Section 4 discusses ways forward by reviewing solutions for each of the main challenges for diffusion. Section 5 brings together the insights and conclusions.

2. Renewable energy systems: The role of the supply chain

Current scientific scenarios for reducing carbon emissions to avoid climate change [29] are far more demanding than the current political targets.[1] According to climate change scientists, the current political targets for carbon emissions reductions are not ambitious enough to avoid a two degree Celsius rise in the global average temperatures [20,30,31]. However, even the political goals far exceed the transformative capacity of the key sectors involved in the green transformation. The transformative capacity for renewable energy is limited by a number of barriers, bottlenecks, and constraints which we will look at in the next subsection.

2.1. Barriers, bottlenecks, and constraints

Within this article, these terms will be used as follows:

- *Barriers* are elements in the supply chain that slow down, hinder, or block the diffusion of offshore wind and renewable energy. Academically, barriers to diffusion can be traced back to the medical sciences, veterinary sciences, and physics. The opposite of a barrier are factors that facilitate or enable the diffusion of offshore wind and renewable energy.
- *Bottlenecks* are imbalances in the supply chain where the supply chain capacity is smaller than the demand. Traditional mathematical, statistical, and economic approaches to bottlenecks include capacity planning, queuing theory, calculations of optimal supply/demand balances, and simulations of the equilibrium. Goldratt and Cox [32:139] define a bottleneck as "…any resource whose capacity is equal to or less than the demand placed upon it."
- *Constraints* are challenges faced by certain resources in the supply chain that cause the capacity to be less than optimal compared to demand. Within math or engineering, constraints equal conditions that must be satisfied by the solution in question. The theory of constraints [33] outlines that for a broad definition of a system "…at least one constraint exists that limits the ability of the system to achieve higher levels of performance relative to its goal".

In the case of wind energy, the output is estimated to be 372 gigaWatt ("GW") of installed capacity per annum as of end, 2014 [13,34]. The output surpassed 400 GW during 2015 [35] with China as the world's largest market for wind energy. Using scenarios for 2050, the wind energy output required will be between 1600–4000 GW per annum [36]. There is a massive shortfall in current industrial capacity to meet an output of this scale. There are many well-known bottlenecks when it comes to producing and installing wind energy technology on an adequate scale to support the green transformation. These include:

- Scarcity of sites for new turbine installations[2] [15]
- Technologies for dealing with intermittency [13]
- Financial resources [17–19]
- Government policies [19,37–40]
- Subsidies and tariffs [18,41,42]
- Human capital and skills [43]
- Storage capacity for wind energy after production [34]
- Grid expansion and interconnection [44–46]

Acknowledging constraints in all of these areas, this article is focused on a particular set of constraints – those found in the supply chain. In order to provide a framing for the analysis, the next subsection starts by outlining the role of wind power in climate change mitigation.

2.2. Diffusion of wind power for climate change mitigation

Wind power is a central technology when it comes keeping global temperature increases below two degrees Celsius by ensuring that carbon-dioxide emissions peak and then decline before 2020 as e.g. observed in the European Union ("EU") 20-20-20 policy to reduce dependency on fossil fuels by 2020 [47]. During recent years, a boom in global wind power supply has been witnessed taking wind power output from 17 GW in the year 2000 to 372 GW in 2014 [13,34]. In a 'moderate scenario' according to Global Wind Energy Council [36], this output number will grow to 1480 GW in 2030 while in an 'advanced scenario' it will grow to 1934 GW. This latter scenario expresses a best

[1] Such as EU's 20–2020 regime; China's 12th Five Year Plan, and international agreements within the UNFCCC.

[2] Arising from local opposition, referred to as the NIMBY "not in my back yard" movement and decreasing returns on investment as the best sites are taken.