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Fostering of innovation within green growth industries: How the Danish national innovation systems affect supply-network enabled innovation

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Abstract

Purpose – This paper aims to analyse how the political, relational and institutional contexts of the offshore wind industry affect supply-network-enabled innovation (SNEI) and to identify significant possibilities for obtaining the overall target of reducing the cost of producing energy based on the offshore wind industry.

Design/methodology/approach – Through an embedded single-case study, the contextual conditions of SNEI within the relatively immature offshore wind energy industry are investigated.

Findings – The national system of innovation only affects product innovation within the industry. Process innovation, which is needed to make the industry grow and mature, seems lesser supported. Different levels of maturity exist among the actors within the industry, which creates barriers for SNEI. To help the offshore wind industry grow, the educational and research system can promote integration of companies by helping the actors to design best practices and manage their business processes according to some generic goals and practices. Additionally, the political system must provide clearer intentions for a sustainable future.

Practical implications – This paper provides insights into how SNEI can be applied within the Danish offshore wind industry to foster competitive advantages against energy recovered based on fossil fuels.

Originality/value – The paper contributes to the rather immature field of research on SNEI with empirical data from a network of companies. Furthermore, it adds to the emerging research area of political-initiated development of renewable energy sources.

Keywords Interviews, Stakeholder meetings, Maturity, Offshore-wind power, Supply-network enabled innovation

Paper type Research paper

1. Introduction

In 2008, the Danish Parliament decided on a fossil fuel-free future in 2050 and instead rely on green energy sources such as offshore wind (The Danish Ministry of Energy, 2012). Despite a tense growth during the past decade, the offshore wind industry is still a relatively immature industry (Heptonstall *et al.*, 2012; Higgins and Foley, 2014; Stentoft *et al.*, 2016). This is reflected in low integration among actors, lack of collaboration, standardisation, transparency in demand and order and inventory processes across the supply-network (SN) (Stentoft *et al.*, 2016).

Commission and installation of offshore wind parks are typically managed by a utility company (UP) managing an SN of wind turbine generator manufacturers (WTG), foundation providers (FP), assembly & installation providers (A&IP), providers of the electrical infrastructure (EIP) and power transmission providers (PTP). From an industry life cycle perspective, the current stage can be classified as a growth phase (Klepper, 1997) focusing on both product and process innovation (Abernathy and Utterback, 1978). Owing

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to the immaturity and the political wish of being independent from fossil fuel, governmental subsidies had initially supported the industry. However, recently, politicians have pressured the sector to become competitive with fossil fuel (European Commission, 2014; Heptonstall *et al.*, 2012). This requires the industry to improve its innovative performance by reducing the cost of producing energy (CoE) (Ortegon *et al.*, 2013; Stentoft *et al.*, 2016). CoE is, according to Greenacre *et al.* (2010, p. 11), high within offshore wind owing to both large capital and operations expenses. This is, e.g., caused by wind farms being established in deeper water further from the shore, larger and more complex foundations, increased grid connections and more challenging installation environments (Heptonstall *et al.*, 2012). However, to gain efficiency through SNEI, scale effects and standardization in turbine size and technology is difficult owing to SN competition and lack of confidence (Heptonstall *et al.*, 2012).

Innovation enabled by the SN is concerned with processes of making changes to products, processes and services resulting in new value creation to the focal firm and its customers by leveraging knowledge efforts of the firm and its SN partners (Narasimhan and Narayanan, 2013). Hence, to achieve innovation within an SN, the processes between a focal firm and its SN need to be managed. Through appropriate management, the innovative performance of all actors can be improved (Dhanaraj and Parkhe, 2006).

Dispersing value-creation activities to firms in an SN, specialised in a particular technology or activity, allows a focal firm to utilise unique capabilities of suppliers to achieve specific innovation needs (Dhanaraj and Parkhe, 2006; Narasimhan and Narayanan, 2013). To become more mature, the value-creating activities within the SN must indeed embrace a shift from competition between technological trajectories within the industry, and development of a dominant design (Bos *et al.*, 2013; Peltoniemi, 2011). Accordingly, the focus needs to be on process innovation (Abernathy and Utterback, 1978). However, engaging in supply-network-enabled innovation (SNEI) requires trust and sharing of information (Hennelly and Wong, 2016), which can be difficult within temporary SNs configured anew each time a park is put on tender (Bygballe *et al.*, 2013; Ekeskär and Rudberg, 2016).

In addition to supply chain management (SCM) and fostering of innovative practices within the company system (CS), SNEI depends on "the wider setting" in which it operates (Koch, 2014; Lundvall, 2007, p. 95). These settings include the R&ES delivering knowledge necessary to transform the industry. Furthermore, SNEI depends on the political system to provide incentives for collaborating and sharing knowledge and technologies (Lundvall, 2007; Stentoft *et al.*, 2016). The political agenda related to the offshore wind industry is recorded in the Energy Agreement (EA). Together, the three systems constitute the context of innovation, called the national innovation system (NIS) (Lundvall, 1992, p. 13). The correlation between the systems included in the NIS – especially involving knowledge of incentives and barriers for engaging in SNEI – is paramount to improve the innovative performance of immature industries (Lundvall, 2007; Stentoft *et al.*, 2016).

The purpose of this paper is to analyse how the political, relational and institutional contexts of the offshore wind industry affect SNEI and to identify possibilities for obtaining the overall target of reducing the CoE within the Danish offshore wind industry.

The rest of the paper is organised as follows: In the next section, a theoretical frame of reference within NIS, SNEI and industry life cycle is provided. Then follows a section describing the applied method. This is followed by an analysis of the empirical data of the incentives and barriers for SNEI in the Danish offshore wind industry based on the political, relational and institutional contexts. The final section concludes the paper.

2. Theoretical frame of reference

This section presents the theoretical frame of reference used to promote SNEI within the Danish offshore wind industry in three subsections. First, the NIS that establishes the context of the offshore wind industry is described. Next, the essence of SNEI is clarified. Finally, the concept of industry life cycle is explained.

2.1 National innovation system

Key to innovative processes, the flow of technology and information among people, firms and institutions is called the national innovation system (NIS) (Lundvall, 1992, p. 13; OECD, 1997, p. 8). NIS consists of three systems:

(1) the company system (CS);

(2) the research and educational system (R&ES); and

(3) the political system (PS).

NIS contains the interactions between the actors necessary to turn an idea into a process, product or service.

Within the CS, interaction is both technical and informal collaborations among firms sharing technical resources, achieving economies of scale or gaining synergies from complementary human or technical assets. Interaction takes place through informal connections or contacts among firms transferring knowledge (OECD, 1997). Cost minimization is a key driver (Gross *et al.*, 2010), while barriers of SNEI are lack of collaboration, standardization of interfaces (Stentoft and Mikkelsen, 2016) and internal competition (Bygballe *et al.*, 2013; Ekeskär and Rudberg, 2016; Stentoft and Mikkelsen, 2016).

The R&ES consists of public research institutions and research within private firms. OECD (1997, p. 9) acknowledges the interaction between public research infrastructure and industry as "one of the most important national assets for supporting innovation". Government-supported research institutions contribute with generic and applied research (OECD, 1997, p. 9). Increasingly, research is supported by firms collaborating with the public sector on R&D projects where the public research sector functions as the "general source of scientific and technical knowledge". To improve innovation, it is important that firms within the CS have access to knowledge created by the R&ES. This can be achieved through formal and informal technical networks (OECD, 1997). Incentives within the R&ES are related to Denmark maintaining its position as the technological and development hub for wind energy. Barriers are competing technological trajectories (Bos *et al.*, 2013; Peltoniemi, 2011) and costs of R&D and adoption of new technologies (Stentoft and Mikkelsen, 2016).

Finally, the PS is essential in promoting interactions between the systems. The various interactions and knowledge flows can be eased or blocked through framework policies (OECD, 1997). Pertinent to the Danish offshore wind industry, the EA is an important element of the PS in the form of technological "push" and demand "pull" incentives to promote innovation. Technological push is typically enacted as public R&D funding, while demand pull is distributed through market-based instruments to reduce uncertainty of R&D investments through establishing a market and compensating for competitive disadvantage caused by negative external effects (Horbach, 2008; Jaffe *et al.*, 2002). Barriers are related to the industry being born into an established energy market, competing with well-integrated and fully developed industries (Stentoft and Mikkelsen, 2016). The characteristics of interactions within the Danish NIS are illustrated in Table I.

Table I. Characteristics of interactions within the Danish NIS

Characteristics	Company system	Research and educational system	Political system
Actors	Customers Manufacturers Suppliers	Universities (4 of 8 do research related to the offshore wind energy sector) Colleges Sector research institutions Technology communication centre (Offshoreenergy.dk and Danish Wind Energy Association)	The Danish Parliament (Ministry of Energy, Utilities and Climate) EU legislation
Purpose of interaction	Sharing technical resources Achieving economies of scale Gaining synergies Knowledge transfer	Education and training Pure and applied research	Promoting interactions within NIS Promoting innovation within the industry
Type of interaction	Technical Informal	Scientific and technical knowledge	Technological push policies (e.g. public R&D funding) Demand pull policies (e.g. feed-in tariffs, quotas and targets and price-based support)
How interaction take place	Informal collaborations Formal contacts	Research institutions and universities Firms collaborating with the public sector Formal and informal technical networks R&D projects	Framework policies (the EA)

NIS thus constitutes the context of innovation within offshore wind by forming the economic structure and the institutional set-up affecting SNEI (Kuhlmann and Arnold, 2001; Lundvall, 1992, p. 13).

2.2 Supply-network-enabled innovation

SNEI can be defined as:

> [. . .] the process of making changes to products, processes, and services resulting in new value-creation to the organization and its customers by leveraging knowledge efforts of the firm and (or) that of its supply-network partners (Narasimhan and Narayanan, 2013, p. 28).

Related to the EA, new value-creation in the offshore wind industry is associated with reducing the CoE from wind power. SNEI can be unfolded through supply chain innovation that focuses on changes (incremental or radical) within the SN structure, SN business processes or SN technology (or combinations of these) (Arlbjørn *et al.*, 2011). Changes in the SN structure can be related to vertical and horizontal structures of companies and their SN partners where innovations materialise. This includes members of the SN, the structural dimensions or the different process links between the actors (Cooper *et al.*, 1997). Achievement of SNEI within the business processes requires focusing on activities that yield a specific output of value to the customer. These innovation activities can be defined as “a structured, measured set of activities designed to produce a specified output for a particular customer or market” (Davenport, 1993, p. 5). Implementing customer-oriented business processes within and across members of the SN serves the purpose of making transactions more efficient and effective and structures interfirm relationships (Cooper *et al.*, 1997). By applying different SN technologies, either in isolation or in combination with other technologies, it is possible to achieve efficiency in the innovative practices (Arlbjørn *et al.*, 2011). Hence, SNEI allows innovation at the intra-firm, dyadic, chain or network level with the aim of creating value not only for a focal firm but also for other stakeholders.

SNEI has primarily been used to describe innovation dimensions within single firms (Arlbjørn and Paulraj, 2013). In recent years, however, there has been a surge of interest in using SNEI in growth industries through changes in the SN structure (Arlbjørn and Paulraj, 2013), development of relational capabilities through inter-organisational processes (Oke *et al.*, 2013) and diffusion of innovation activities across organisations to increase process innovation (Azadegan and Dooley, 2010). In this paper, SNEI is used as a concept for reducing the CoE of offshore wind energy and for moving the industry towards a mature phase in its industry life cycle (Abernathy and Utterback, 1978; Johnsen *et al.*, 2006) by using a perspective that spans a network of firms.

2.3 Industry life cycle

Emergence and evolution of industries occur through regular phases from birth till maturity (Klepper, 1997). Generally, industries complete three phases: embryonic, growth and mature (Abernathy and Utterback, 1978; Klepper, 1997). Understanding where the offshore wind industry is in its life cycle might reveal how the SN can exploit knowledge of regularities in the development and evolution of industries to its advantage (Klepper, 1997). According to Jensen and Thoms (2015), the characteristics that change throughout the life cycle of an industry are the industry composition, the market, investment, financing, innovation approach and the SN structure. In the following, the characteristics of each industry life cycle phase are described based on their relevance to SNEI.

In the *embryonic phase*, an industry emerges based on important technological innovation allowing firms to follow a new technological trajectory (Klepper, 1997;

Peltoniemi, 2011). The SN structure is initially characterised by few small, fluid entrepreneurial actors (Agarwal *et al.*, 2002; Abernathy and Utterback, 1978) and frequent entry and exit of actors (Peltoniemi, 2011). The market is difficult to define and predict why a high level of technological uncertainty exists. Competition is intensively based on technological performance of diverse products (Abernathy and Utterback, 1978; Johnsen *et al.*, 2006; Klepper, 1997) and a strong demand for external capital to fund initial investments (Robinson, 2000). Towards the end of the phase, the number of actors increases rapidly as market opportunities become apparent (Johnsen *et al.*, 2006), and both horizontal and vertical linkages increase to mitigate risk and facilitate innovations (Gemser *et al.*, 1996).

During the *growth phase*, the SN structure becomes more permanent with larger and more integrated firms (Agarwal *et al.*, 2002; Klepper, 1997). Simultaneously, with demonstration superiority of a certain technology and emergence of a dominant design, an intense price competition begins to characterise the industry, decreasing the number of actors (Johnsen *et al.*, 2006). The remaining firms experience increased revenues and grow by pursuing economy of scale (EOS) (Abernathy and Utterback, 1978; Klepper, 1997). The focus shifts from radical to incremental product innovation (Abernathy and Utterback, 1978; Klepper, 1997) with increasing focus on process innovation (Johnsen *et al.*, 2006). Still, the industry needs high investments (Jensen and Thoms, 2015). The SN business processes become more formalised (Abernathy and Utterback, 1978), refined and automated with specialised equipment (Bos *et al.*, 2013; Klepper, 1997). The latter results in horizontal de-concentration of business processes, forcing firms to specialise and establish or consolidate existing vertical interfirm linkages (Gemser *et al.*, 1996; Klepper, 1997).

In the *maturity phase*, the SN structure is characterised by established relationships between large-scale producers (Klepper, 1997). As competition shifts towards prices and costs, firms seek EOS and scope through mergers and acquisitions, which decrease the interfirm linkages both horizontally and vertically. To reduce the competitive pressure and rationalise excess capacity, remaining rivals tend to enter into formal or informal agreements and outsource peripheral parts of their business (Gemser *et al.*, 1996). Collaborations are established to achieve technological process innovation and incremental product innovation (Johnsen *et al.*, 2006; Rice and Galvin, 2006). Undifferentiated, standardised products affect the SN business processes, as the industry needs to enhance incremental process innovation through advanced equipment. This leads to refinement of management, manufacturing and marketing processes as well as in formal process designs (Klepper, 1997). Ultimately, SN technologies in the form of highly specialised equipment are needed to achieve highly integrated and dedicated production systems designed rationally for producing specific and standardised products through the remaining vertical and horizontal linkages (Abernathy and Utterback, 1978). The various characteristics of supply chain innovations in relation to different industry life cycle phases are summarised in Table II.

3. Method

The scarce literature on SNEI is mostly conceptual, why an explorative research design is appropriate to generate empirical knowledge of how the political, relational and institutional contexts of the offshore wind industry affect SNEI (Yin, 2014, p. 4). SNEI is considered a phenomenon investigated in a real-life context where the boundaries between the phenomenon and context are not clearly evident (Eisenhardt, 1989; Yin, 2014, p. 4). A single-case study is used with the offshore wind industry representing a common case of a growing industry. The objective is to capture the circumstances and conditions of SNEI in an everyday situation to understand SCM practices related to SNEI and fulfilment of the objectives within the EA (Yin, 2014, p. 52). The advantage of a single-case study is the

	Embryonic phase	Growth phase	Mature phase
Supply-network structure	A few, small entrepreneurial actors At the end of the phase the number of actors increases rapidly	A decreasing number of actors The supply-network structure becomes more permanent with many larger and more integrated firms Vertical interfirm linkages	Established relationships between large-scale producers and customers Mergers and acquisitions of rivals and/or suppliers Decreasing interfirm linkages both horizontally and vertically
Supply-network business processes	Informal process designs and changeable work flows	More formalized Refined and automated with specialized equipment Horizontal de-concentration of business processes	Formal and informal agreements and outsourcing of peripheral parts Refinement of management, manufacturing and marketing processes Formal process design
Supply-network technologies	Interfirm supply-network technologies have not been introduced	Refined and automated specialized equipment	Highly specialized equipment

Source: Own compilation based on presented theory

Table II.
Supply chain innovation across different industry life cycle phases

possibility of greater depth. This is, however, on behalf of limitations related to the generalisability of findings (Yin, 2014, p. 64). According to Flyvbjerg (2006), theory development based on rich information from a single example of a class of phenomena is, however, possible. Flyvbjerg (2006) observed that it is a common misunderstanding that a single-case study cannot contribute to general understanding of a phenomenon. Having access to an extra case would produce a stronger effect in augmenting for external validity. This might, however, result in less depth in each case (Voss *et al.*, 2002). In this study, six embedded units of analysis are investigated (Yin, 2014, p. 50), representing the main actors needed for commission and installation of an offshore wind park. The actors include a UP, a WTG, a FP, an A&IP, an EIP and a PTP.

3.1 Sampling criteria

The Danish offshore wind industry, represented by six suppliers engaged in commissioning and installing of offshore wind parks, was chosen for its high potential to benefit from SNEI. In extension of this, Lundvall (2007, p. 117) mentioned that to realise additional diffusion and adaptation of new technology within an industry is necessary with an extensive understanding of "what goes on inside and between firms".

Owing to its in-depth knowledge about tendering procedures and selecting of suppliers for offshore wind projects, the UP was selected for this study. The company currently focuses much of its business on offshore wind and tries to initiate SNEI. The WTG was chosen based on its prominent role in manufacturing and because it sources many components and solutions from sub-suppliers, which may give practical insight into how they foster SNEI. The FP was chosen based on its superior skills in both university and industrial cooperation. The A&IP was chosen because it already is integrated in two companies within the industry and thus has experiences in SNEI. The EIP was chosen based on its vast experience in innovation with suppliers within both the offshore wind and oil and gas. Finally, the PTP participated because it has a monopoly on transmission of electricity in Denmark.

CEOs and heads of departments gave interviews. This is in accordance with Dubé and Paré (2003), suggesting executive informants as the principal sources of information to discern important considerations pertaining to the phenomenon studied. The principal objective was to identify the incentives and barriers for SNEI within the industry. The actors chosen are all actively engaged in commissioning and installing offshore wind parks. Although acknowledged that other actors (logistic providers) are part of the SN of the industry, these were excluded from the study, as they are not active in product or process innovation.

3.2 Data collection and analysis

Data were collected through semi-structured interviews during 2015. Informants were contacted personally by phone and explained the objective of the research. If they were positive towards participating, an e-mail was sent with more information about the study. To ensure maximum cooperation from the suppliers, it was highlighted that the research was conducted independently of the UP. When agreeing to participate, meetings for interviews were carried out, each lasting 1-2 h. The interviews contained three main steps:

(1) clarification of processes and critical characteristics of dependencies to other processes in the SN and stimulation of relevant technologies;

(2) incentives and barriers for innovation based on the EA; and

(3) the effectiveness of the NIS on industrial development.

Each interview was conducted in Danish; all were audio-taped and transcribed. The transcripts were returned to the informants for verification of accuracy. To deduce the findings, the write-ups were analysed independently before face-to-face discussions of individual assessments. Before each interview, information was collected through archival data on the companies to construct a platform of knowledge. For this analysis, only subjective measures of the informants' perception of the support and effects of the NIS on SNEI were used.

For analysis and discussion of data, Miles and Huberman's (1984) paper was followed. First, interview data relevant to the research purpose and question were located. Next, data were categorised to compare and explore similarities and differences within the cases and to find explanation patterns that illustrate the diverse incentives and barriers to SNEI. Structuring of the data was approached in line with the predetermined heading from the semi-structured interview guide as well as with new themes found during the process of sorting and analysing the data. The data reduction process focused on illustrating different incentives and barriers to SNEI, aiming to ensure validity of the conclusions drawn from the data.

3.4 Quality of research

Yin's (2014, pp. 45-49) four criteria for judging quality of research are applied to evaluate if the findings were valid and provide an accurate response to the research question. *Construct validity* was sought by clarifying the different concepts used throughout the paper. *Internal validity* is only used in causal (explainable) cases, seeking to establish a relationship whereby certain conditions are believed to lead to other conditions, as distinguished from spurious relationships. This study is exploratory and seeks to provide new knowledge related to fostering of SNEI why *external validity* was established though comparing the results to extant literature on SNEI. Finally, *reliability* was ensured by use of a case study protocol.

4. Analysis of incentives and barriers of supply-network-enabled innovation

Primary data in this paper build on empirical data collected from interviews with six suppliers within the SN of the Danish offshore wind industry (Table III).

The SN is presented in Figure 1 in showing the companies' main function related to commission and installation of offshore wind parks. Each time a new park is decided on, a temporary SN is configured based on competitive tendering to accomplish the wind farm at the lowest possible costs (Informant from UP). This result in separate supply chains involved at different times.

In the following three subsections, data on incentives and barriers of SNEI are analysed with respect to the CS, the R&ES and the PS.

4.1 Incentives and barriers within the company system

In Denmark, the governmental Department of Energy initiates an offshore wind project by putting it on tender. When the UP has won the rights to commission and install the farm, it engages in SNEI through business processes such as product development and selecting and managing different suppliers. The UP's incentives are primarily based on using technologies and capabilities of the SN in "meeting the needs of the market" (UP) and being able to present the best bet to clients, who are often the Danish state. Hence, the UP has a great incentive in making suppliers compete and "feel they have to do a lot of extra to win" (UP). To fulfil their orders to their clients, the UP manages manufacturing flow through a tendering procedure and "very complex contracts on the diverse deliveries of the project". Owing to complexity in supply, SNEI is further encouraged by integrating downstream suppliers in the company and linking others directly to development efforts, which is a mature industry characteristic.

Incentives further down the SN are somewhat different. Opposite to the order fulfilment focus of the UP (engineer-to-order), the sub-suppliers focus on customer service management by assisting the UP in making cost-effective solutions and deliveries related to business processes such as planning, installing and upgrading of the wind turbines in their product development efforts. For instance, the FP stated, "We contribute to faster, more efficient and effectively installing of foundations". Additionally, the suppliers offer technical support before, during and after the UP's purchase of products or capabilities. The PTP described, "We appoint possible locations for future offshore wind power parks [. . .] we just tell where it would be appropriate to lay the cables", and "We help [the UP] by giving directions [of the flow of power] though a very complex data system" (SN technology). The PTP does so by engaging in other SNs and collaborative partnerships. The component manufacturers and the EIP, however, find that the product focus of the UP hampers SNEI and demand a more relationship management approach, stating that:

> [. . .] there has been a tendency among the big players not to share anything, as if they sat in a bell jar (dis-connected supply-network-structure), which made it difficult for the minor players to develop to them, except against a specification without understanding how things might be made even better (integration of business-processes to obtain EOS and scope, characterising a more mature industry).

The A&IP is integrated in the UP's operations and therefore experiences cooperation related to collecting, processing, sharing and using of knowledge (close SN links like within mature

Table III. Key facts of the case companies

	UP	WTG	FP	EIP	A&IP	PPT
Information about the case companies						
Relation with UP	–	3 years	14 years	15 years	14 years (UP owns 51% of the firm)	40 years
Employees	+2,000	+ 1,000	70	+1,000	400	552
Focus of innovation	Tender criteria and assessment Cost optimisation	Design, turn-key solutions, production processes	Optimizing cost and processes	Voltage level and turbine capacity Grid interconnections	Pre-assembly of standardized, stackable components Cable installation (quality and protection)	Integration of energy systems (power, heat, and transportation)
Innovative strategy	Co-development after the tender round	In-house R&D, co-opetition, involve sub-contractors and customers	In-house R&D, collaboration with university abroad	Innovation with a steel constructor	Innovation, involve sub-contractor	Innovation with sub-contractors
Information sharing	Collects solution ideas and prices from suppliers	Interface optimizations (when a contract is won) and sourcing	None due to IP concerns. Strategic alliance with a steal contractor	Design and requirements	Number, design and location and installation period	Placement of parks, power generation capacity
Information about informants						
Job function	Manager of Regulatory Affairs and the Head of R&D	Senior Vice President Chief Technology Officer	Business Development Manager	CEO	CEO	Head of R&D
Wind industry experience	20/19 years	15 years	19 years	20 years	32 years	5 years
Duration of interview	1.5 h	1.5 h	1.5 h	1 h	2 h	1 h

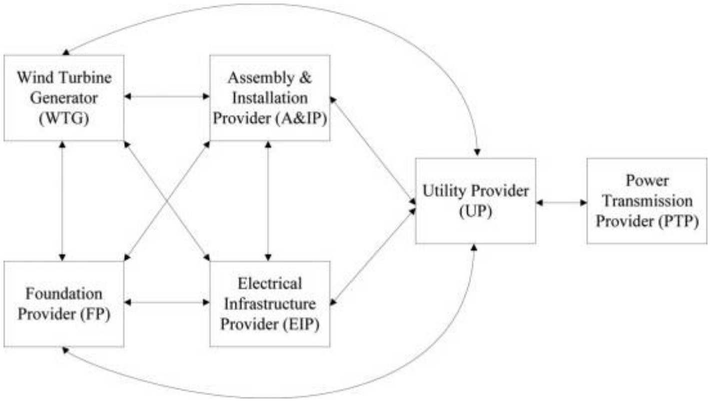

Figure 1.
Supply-network of the offshore wind industry investigated in this study

industries). SNEI between these two firms is thus easier to achieve though scaling and customising to the UP's needs and delivery service (business processes and facilitating supply chain technology). The A&IP stated:

> Now it has become so comprehensive that you are well aware that you cannot just develop a wind-turbine without taking into consideration how actually to carry and install it [. . .] else it'll devour the savings on the components (typical characteristic of mature industries).

The EIP, however, argued that they have two ways of approaching their SN: one when working within Danish SN and one when engaging in foreign SNs. In the first approach, they are not allowed to use their knowledge and design capabilities but only deliver according to precise specifications; components are bought for them, and they just perform electrical installations (immature industry approach). In the latter approach, they just receive some specification regarding MW output and security of supply but make all the calculations and designs themselves. This means that the supplier only engages in SNEI when collaborating within a foreign SN (more mature approach).

The WTG had started a process of engaging suppliers in their innovation efforts:

> We sit together with other suppliers calculating on different loads in order to optimise both deliveries and to find optimal solutions. We give them some data on the turbine to make it possible for them to dimension their cables, transformer stations etc., but it's something they do based on data and data-sheets received from us as a supplier.

To manage the business processes, the manufacturer uses the Production Part Approval Process (SN technology) to "create trust and clarify expectations between them and their suppliers" during the manufacturing process. SNEI is intensified through partnership collaborations (horizontal SN structures) to achieve their common goal of *reducing CoE* mutually beneficial for all suppliers. Additionally, the WTG told that they had "started to source steel in collaboration with their biggest competitor to bring down the costs" (vertical integrations, typical within mature industries).

A perceived large barrier of SNEI within the CS is, according to all the interviewees, primarily associated with the tendering process (SN structure), which inhibits value-creation when making changes to products, processes and services by leveraging the knowledge efforts between the actors in the SN. As the UP stated, "We must drive invitations to tender where all suppliers must be equally judged. We aren't allowed to talk to potential suppliers from an R&D perspective" (integration of product interfaces and business processes); also, "We aren't allowed to brainstorm with WTG, FP or anybody else". Only after the tender has ended, communication can take place. This has resulted in overdesigned turbines that, according to the WTG:

> [...] are overdesigned due to a lack of believing that the turbines can reach the limit (not benefitting from a dominant design). This means that you put them slightly lower and don't exploit the full potential of the production capacity.

Another barrier is lacking maturity and standardisation of components, which inhibits suppliers from using any form of technology to integrate the different processes between them. Further, high concerns related to risk and uncertainties "make the suppliers cautious about sharing their knowledge" (FP, UP, EIP, A&IP and WTG). Despite recognising the necessity of a grid connection to reduce CoE and increase the efficiency of offshore wind power (SN technology), competition caused by the individual importance of winning the next tender deprives suppliers the initiative for or possibility of engaging in product development joint-ventures, as well as from including developers of grid technologies in their businesses to optimise their distribution channels (integration of business processes).

4.2 Incentives and barriers within the educational and research system

The actors within the offshore wind industry only slightly relate to each other or external sources of knowledge creation. The A&IP explained, "It becomes too academic. The part that should be practical-oriented becomes so stiff and poor that it's hard to handle when you are sitting in an operational business". Neither do they use shared supply chain technologies in innovative linkages such as joint research, personal exchange or cross-patenting. Only the WTG explained that they have successfully engaged in common purchase of steel and adaption of products with their largest competitor to achieve incremental process improvements and reduce total costs. This collaboration took form as a co-opetition relationship, where the two WTGs both competed and collaborated (Brandenburger and Nalebuff, 1996). In the FP's efforts to foster innovation by gaining access to external sources of knowledge at the local university, it indicated that a university employee stole their idea and commercialised it together with their largest competitor: "In the meantime, the university has developed a competing product that happens to be a reminiscent of our product – so our confidence in an open collaboration is not quite there". However, the FP is engaged in close collaboration with two other foreign universities. This indicates that the Danish R&ES is less suitable to stimulate SNEI and that the processes among this system and the CS are in an embryonic phase.

In general, the actors in the industry would like to collaborate and share knowledge with research institutions, especially of "practice-related research that they can use right away" (WTG, A&IP). They have found much of the research too academic and hard to apply in their supply chain business processes. The WTG stated, "If we just could make a small verification of the research afterwards and say does it fit together? – if they took it out in reality and it was possible to make just a small model and see if it really applies?". However, the wind industry, associations somehow seem to have been able to establish a coherent morale within the complex network: "I know Offshorewnergy.dk has received funding that force us to collaborate, which we do crisscrossing [...] It's the two Danish wind organisations [offshoreenergy.dk and Vindmølleindustrien] that drive the cooperation" (EIP) (tries to foster SNEI). Currently, research funding is primarily given to innovation in product technologies, and most of the suppliers stated that "there is nothing for them to come for in the EA". The A&IP explained, "The turbines has been optimised through 20 years now and we have in reality reached quite far, so now it must be time to optimise foundations and installation methods" (supply chain business processes and links between the actors).

Still, the suppliers generally are reluctant to share knowledge: "We don't like external funding because we then have to share our knowledge with some of our competitors which we don't like" (UP) (an immature characteristic) and "You might say that the UP delivers something; the WTG delivers something etc., but some [suppliers] are still cautious" (UP). Despite considerable movement of personnel between the actors, knowledge flow (SN links) is limited through that channel:

> [N]ew employees don't dig into databases to update them on how former projects have been handled. Knowledge is [. . .] lost on that account as new employees think it'll be wise to things in a certain way regardless [. . .] that former experience has told the opposite. (A&IP)

Related to hiring, multiple suppliers have had difficulties in attracting qualified workers and have started looking towards other European countries. For instance, the WTG has "started to look towards Spain on how they educate their engineers with both a mechanical and an electro-technical experience" (mature, integrated approach). The WTG admires their tendency to be "excellent productions engineers that can trouble shoot within a factory due to their mechanical, electro-technical-knowledge combined with their engineer-background". The manufacturer has thus recognised that, to achieve SNEI, they need to look towards specialised knowledge centres for access to formal and informal technical networks. Hence, the Danish research institutions might not be efficient developers and diffusers of applied technologies useful to the offshore wind industry. The EIP pointed out the disseminated research institutions in Denmark as inhibitors of SNEI, as the different universities "fight for the scarce funding opportunities" (sign of immaturity). The EIP believed it would be better to allow one university form the core around the different offshore technology-based firms and research institutions to gather a more informal, localised innovation centre or cluster. Additionally, the suppliers have found that "[m]any of the Danish research and universities have a much too narrow Danish focus" (PTP) and that "[i]f we don't begin to talk across the countries, we will never succeed in growing or invent new innovations related to wind turbines" (WTG).

The UP acts as a kind of bridge to link the research institutions more closely to the industry because it sits as a representative for all the big universities in the Danish Research Consortium for Wind Energy (DFFV). Through this public organisation, they influence both independent research at the universities and external research for which funding firms can apply. The DFFV has made industry sector participation obligatory, thus clarifying "both within Denmark but also in the European research community, what [the DFFV] think needs to be investigated, if they wants to achieve funding" (UP). As the UP has an immature life cycle approach to SNEI, this might act as a barrier of obtaining the targets within the EA.

4.3 Incentives and barriers within the political system

Related to the EA, it is primarily the demand pull incentives – "the number and size of the wind turbines" – that matter to the suppliers and their own operations (an immature focus). Because the agreement has no direct incentives for fostering SNEI and because protection of internal intellectual property promotes the chance of winning the next tender round, the policy does not encourage knowledge or technological exchange. Neither are technological push policies in the form of funding opportunities encouraging SNEI. All actors within the industry stated that "there is nothing for them in the EA". Only the UP mentioned that some minor funds might be relevant for them, but "the amount of money that could be achieved are less than the administrative cost associated with applying and adhering to the reporting requirements [. . .] it's not worth the efforts".

Generally, the order-fulfilment focus of the UP is supported by the political context as it "creates a market that makes the whole supply-network react" (but without integrating the supply chain business processes or by use of supply chain technology to promote the processes or the temporary network configurations). However, the customer service management focus of the suppliers is very much affected by fluctuations in the market and competition within Denmark and the EU. Different framework conditions across the EU and requirement of *local content* especially are experienced as barriers of establishing "a steady flow" that could improve further interactions and knowledge flows (business processes) within the SN structure. Overall, the EA is considered decent, as it includes "long-term plans with broad political agreement and thus not so much turmoil around objectives" which "providing a stable environment and a reduced risk for investors and better opportunities for innovation". The EA has thus "created more offshore wind parks which have created a market that makes it a necessity for us to be cost-effective all the time".

However, the tax structure is simultaneously mentioned as blocking SNEI:

> The primary challenge is that electricity is taxed very high even though we want the consumer to use more electricity as it'll benefit the green transition, but electricity is taxed the most while the fossil fuels aren't taxed as high – this makes the incentives in the tax and subsidy structure all wrong (PTP).

In addition, the Danish inhabitants, despite favouring the transition towards sustainability, do not want any turbines in their backyard (the so-called NIMBY [not-in-my-backyard] effect). Owing to the NIMBY effect and a desire to avoid fluctuations in available energy, most of the actors mentioned the missing grid and the possibility to:

> [. . .] place a lot of turbines at, for example the top of the Orkney Irelands where it's blowing 10–12 m/sec 365 days a year, nobody lives and nobody would see them. They would just stand there, but you don't have a grid that can transform all the power produced up there to e.g. London and further down to Paris, Amsterdam etc. Europe needs to decide how they grow their grids between the countries (WTG).

A grid connection could thus be an SN technology that could promote SNEI or a project that could promote development through changes in the SN structures. The findings from the interviews are summarised in Table IV, which are the bases of the further discussion.

5. Discussion

This study discovered that all suppliers are aware that they need to implement changes in products, processes and services to create new value in the form of reduced CoE; however, they do not have a united view across the SN on how to manage the innovative processes to gain competitive advantages. This means that SNEI does not exist within the SN. There are similarities between the actors in terms of the technological uncertainty they experience related to the dominant design of the future energy source in Denmark and the EU. The relatively low market demand, combined with an intensive competition on delivering to the next wind park, has, however, started a process of horizontal and vertical integration. The UP, for example, owns half of the A&IP (the other half is owned by a WTG, but not the WTG of this study), and the WTG has engaged in a strategic alliance with its largest competitor. Additionally, the FP has entered a strategic alliance with a steal contractor. The purpose of the EA is to mitigate risk and facilitate product innovation to improve primarily the technological performance of the turbines. The actors within the CS are, however, not

Table IV.
Identified incentives and barriers within the NIS

	Incentives for supply-network-enabled innovation	Barriers for supply-network-enabled innovation
Company system	Order fulfilment focus of the utility supplier (engineer-to-order) Sub-suppliers focus on customer-service management by assisting the utility company in making cost-effective solutions and deliveries related to planning, installing and upgrading the wind turbines in their product development efforts through partnership collaboration within their own specific area	The tendering process inhibits value-creation when making changes to products, processes and services by leveraging the knowledge efforts between the actors in the supply network, as communication is not allowed until after the process has ended and the suppliers and their solutions have been chosen A lack of maturity and standardisation of components inhibits the suppliers from using any form of technology to integrate the different processes between them High concerns related to risk and uncertainties make suppliers cautious about sharing knowledge Competition is caused by the great individual importance of winning the next tender round
Educational and research system	In general, actors in the offshore wind power industry would like to collaborate and share knowledge with research institutions. They especially demand practice-related research that they can use right away The wind industry associations have been able to establish a coherent morale by attracting funding and forcing suppliers to collaborate The utility provider acts as a bridge linking the research institutions more closely to the industry as the UP represents all the big universities in the Danish Research Consortium for Wind Energy (DFFV) A wish exists for a specialised knowledge centre to gain access to formal and informal technical networks	Bad experience with university employee stealing their idea and commercialising it together with their largest competitor They find much of the research too academic and hard to apply in their practice Research funding is primarily given to innovation in product technologies, and most of the suppliers stated that there is nothing for them to come for in the EA Limited knowledge flow New employees do not update databases to reflect how former projects have been handled Difficulties in attracting qualified workers The research institutions are not efficient as developers and diffusers of applied technologies useful to the offshore wind industry Disseminated research institutions in Denmark

(*continued*)

	Incentives for supply-network-enabled innovation	Barriers for supply-network-enabled innovation
Political system	The number and size of the wind turbines The EA has created a market The EA includes long-term plans with broad political agreement	Does not encourage knowledge or technological exchange All actors within the offshore wind industry stated that there is nothing for them in the EA Though it might be minor relevant funds, the amount of money suppliers are able to attract will be swallowed by the administrative cost of applying and adhering to the reporting requirements Different framework conditions across EU and requirement of local content Incentives in the tax and subsidy structure all wrong Politicians changing opinions and priorities related to offshore wind power

Table IV.

motivated for SNEI based on the EA. Instead of product innovation, they want to focus on process innovation.

The incentives for SNEI differ between the UP and the other actors within the SN. Where the UP has an interest in maintaining intense competition (characterising an immature industry) and does not like to engage in knowledge-sharing activities, the other suppliers are more engaged in formal collaboration with competitors and other actors within the industry to achieving some kind of standardisation and formal process innovation (characterising a growth phase). This indicates that there are different levels of maturity related to the SN business processes within the CS, hampering the overall development of the industry. Further, the statutory tendering procedure is keeping the industry at an immature stage, as operational efficiency and new product development through R&D alliances, for example, are prohibited. According to industry life cycle theory, the industry would benefit from mergers and acquisitions and creation of some large-scale producers focusing on incremental process innovation, formal process innovation and advanced innovation of equipment to reduce CoE.

As the investment opportunities in offshore wind are strong and the demand for external capital is high, the actors are greatly motivated to engage in formal research and engineering with the public sector, competitors and universities on practical R&D projects to standardise the components and formalise inter-organisational business processes to increase the functional product capacity of, for example, foundations and ships. The R&ES, however, only facilitates product innovation through its scientific and technological knowledge production. The suppliers to the UP are highly aware of the necessity of changing the SN business processes by focusing on value-creating activities. They know they need to open-up and implement customer-oriented business processes through formalisation of process design by sharing knowledge and agreeing on a specialisation of tasks. However, concerns related to IP are holding them back; besides, they do not know how to initiate the process. In this regard, the wind associations promote collaboration between the actors and the universities on development of new processes and compositions. What is missing is the creation of valuable skills to make transactions more efficient and effective and structuring of interfirm relationships. Despite good intentions, the collaboration is affected to a very high degree by the low market demand and the competitive context of winning the next tender. Performance improvements based on changes in the SN structure have taken place, but implementation of SN business processes and technologies to foster SNEI is lacking owing to IP concerns and not winning the right to supply the next offshore park put on tender.

Several of the SN actors have difficulties in hiring qualified employees and have claimed that the disseminated research institutions in Denmark, along with a too narrow domestic focus related to education and research, are inhibiting SNEI. The UP has the possibility to influence both education and the areas of research. The question is to what extent focusing separately on single areas that need to be explored can foster SNEI. It might be necessary to strictly consider a wide-ranging integration of the knowledge creation and what its application will mean for the actors and the wider SN. At least, suppliers will find foreign employees who, with more holistic educations, are more capable of engaging in product and process development as a basis for SNEI. To foster progress to the next phase in the industry's life cycle, creating alliances between and within the CS and the R&ES is recommended to develop best practices. Alliances should address development activities emphasising all products and processes necessary to commission and install the final wind farm, including automated productions equipment and new development and integration of grid technologies.

Related to SNEI, the PS in form of the EA has created a market for offshore wind technologies. The transition to the next maturity phase depends on increasing global demand, thus raising the importance of politicians fosters security for the future demand. Besides, it is necessary for politicians to agree on a united European approach. Until the SNs feel secure that offshore wind power has a future, no strong investment in SN technologies to improve efficiency of the innovative business processes will take place. Additionally, it is important that the Danish actors compete on the same conditions across Europe and do not feel they have a competitive disadvantage. To promote SNEI, it necessary that politicians agree on localisation of turbines to avoid planned parks being dropped owing to residential dissatisfaction, increasing the perceived risk within the network. Additionally, the PS needs must incentivise creation of the abovementioned research alliances. These alliances must agree on a dominant design to foster innovation in SN business processes. In the process of specialisation, it might be necessary to decrease the number of actors competing within the industry. For SNEI to take place within an immature industry, the PS must also simultaneously focus on creating stimulating conditions for the suppliers, optimising of SN business processes and using SN technologies that promote collaboration.

Delivering single components based on specific criteria according to a fixed contract does not foster SNEI. This is, however, what the current political framework is promoting, in terms of the tendering procedure. Overall, the PS is sending divergent signals such as the tax structure on electricity or lack of economic punishment for polluting companies. Indeed, the suppliers experience much instability from politicians' changing opinions and priorities related to offshore wind power. This affects SNEI negatively in terms of concerns related to risk and uncertainties.

6. Conclusion and implications for future research

So far, SNEI has primarily been discussed within successful, mature industries, focusing on describing various dimensions to improve competitive advantages. This study is distinct, as it involves an immature industry that initially had received government subsidisation to develop but is now facing subsidy expiration and needs quickly to become more competitive. Previous studies often have compared SNEI from a dyadic perspective only, but the network perspective has allowed an understanding of the pooled incentives and barriers for SNEI within a network.

Additionally, this study extends previous studies of SNEI by revealing how NIS affects SN structure, SN business processes and application of SN technologies in the innovative efforts. Particularly, it is discovered how different levels of maturity in SN business processes affect SNEI. Significant possibilities for improving the innovative performance through development of best practices that address development activities related to overall commissioning and installing of wind farms are identified. Although NIS should form the economic structure and the institutional set-up affecting innovation positively, it is found that only product innovation is supported. Instead of making changes to processes and services that increase value-creation, NIS promotes intercompany competition that makes SNEI difficult on an industrial level. Only optimisations of single components are fostered, not process innovation, as sharing of knowledge within the network would make suppliers vulnerable. Applying theory of SNEI to an immature industry highlights the necessity of reducing the numbers of actors within the industry through both horizontal and vertical integrations within the SN structure. This would make it possible for the SN to focus on incremental innovation of the business processes and implementation of SN technology to promote collaboration and achievement of efficiency in the innovative practices. Such changes within SN business processes must be based on standardisation of the turbine design and defined commissioning and installation processes. It is a complex area, but we suggest that a good starting point would be to let the educational and research system initiate the process by promoting this development. This could be done by supporting determination and description of the diverse SN business processes linked to industry-decided best practices. Additionally, the educational and research system could facilitate training for process improvement based on the maturity level of each actor. As a neutral partner, the R&ES could avert the internal competition within the SN. A uniform process maturity level will additionally facilitate CoE through SNEI [The Software Engineering Institute (SEI), 2010]. Furthermore, the PS must agree on localisation of turbines to create incentives for forming research alliances across the R&ES and the CSs. Finally, the industry requires more consensuses between the political goals of a fossil fuel future, the tax structure and tolerance towards high-polluting companies acting against the incentives of the EA. The biggest challenge for SNEI in the NIS is the requirement of putting the different deliveries on tender. However, this requirement is subject to EU legislation and might be hard to change, so developing the offshore wind industry within the given framework must be emphasised.

Limitations of the study might be related to the trajectory of the UP and its approach to SNEI. Selection of another EPC company might have represented another perspective to engaging in SNEI with foreign utilities, as experienced by the EIP, for example. There is always a chance that the identity and backgrounds of interviewees and their experience, knowledge and personal agenda might affect findings.

6.1 Implications for future research and practice

This paper has focused on how SNEI contributes to CoE reduction, which constitutes some theoretical areas of CoE framework developed by Stentoft *et al.* (2016). Further research needs to explore how other SCM practices constitute to CoE in the context of NIS. Furthermore, to grow offshore wind or other immature industries, it would be interesting to investigate SNEI within more mature industries to agree on and collaborate in accordance with some generic goals and practices. What kinds of management approaches have industries used to align the elements of SNEI? In addition, as technological trajectories are determined by historical patterns of knowledge accumulation, resolute to institutional factors and interactions within the NIS, it would be exciting to examine how past NIS have supported innovation in development and diffusion of innovations within successful industries. Owing to trajectories, many prejudices related to change in underlying business processes might exist within the actors of an industry. In addition, future research could focus on how each of the systems within NIS can possibly contribute to SNEI. Hence, for practice, it would be worth researching how other industries have succeeded in redefining themselves and their offerings to match a changed mind-set within an industry. Additionally, this would give insight into how NIS affects SNEI and how to appropriately design a supporting NIS for industrial development.

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