Wind of change

Firm contributions to technological development in development phases

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Abstract

Conflicting theories exist on the contribution to technological development that incumbents and startups have. Previous literature combined contrasting theories by stating that it depends on the industry sector whether incumbents or startups are more innovative, and thus contribute more to technological development. In this research the focus is on the technology level, by looking at what the contribution of different firm types in different stages of the technological development process is. The comparable offshore wind and wave energy sector in Norway, Denmark and Sweden are used to test if there is a difference in the contributions incumbents and startups have in the pre-dominant design, thus R&D, phase and the after-dominant design, thus deployment, phase. A database consisting of the 330 firms that are active in either of those sectors and several of their characteristics is the base of this study. The results show that firm size affects the contribution to technological development that firms have. Smaller firms have a greater contribution to technological development in the pre-dominant design phase, where larger firms have a greater contribution to technological development after the dominant design has been established. Firm age seems to have no effect on a firm's contribution to technological development. Combining the firm characteristics with the development phases shows that no clear difference in the contribution to technological development between startups and incumbents can be identified. These results oppose to existing literature that concluded that the type of industry sector defines if incumbents or startups contribute more to technological development. It implies that policy based on stimulating innovation in both incumbents and startups is necessary if technological development stimulation is wanted. Furthermore, specific policy on the stimulation of wave energy in Norway, Sweden and Denmark can be useful in order to harvest the potential this sector houses.

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1. Introduction

In order to achieve technological development, innovation is key (Macher, 2006; OECD, 2012). A distinction in literature is made between radical and incremental innovations. Incremental innovations are relatively minor changes to existing products (Henderson & Clark, 1990). Innovations that are a breakthrough in the industry because they have a high degree of novelty and are not in line with the status quo are called radical innovations (Henderson & Clark, 1990; Rao, 2007). A technology undergoes several stages in its development process. Initially a technology is in the research and development (R&D) phase (Sagar & van der Zwaan, 2006). No status quo has been established yet, which is why this phase is marked by radical innovation (Anderson & Tushman, 1990; Utterback & Abernathy, 1975). The technology is developed until a new standard is present: the dominant design (Anderson & Tushman, 1990; Suarez, 2004). Once a dominant design is established, the commercial deployment phase is entered (Sagar & van der Zwaan, 2006). In this phase a technology is brought to the market and smaller adjustments are made to the technology, meaning innovations are mostly incremental (Anderson & Tushman, 1990; Milling & Stumpfe, 2000; Utterback & Abernathy, 1975; Utterback & Suárez, 1993).

For firms it is of importance to innovate in order to maintain competitive advantage over other firms and to cultivate firm success (Chandy & Tellis, 2011; Hölttä-Otto, Otto, & Luo, 2013). Various types of firms innovate differently. This is partly due to the fact that each firm type has different innovative potential (Buchmann, 2015). Several theories have been created around the innovative focus and potential of different firm types. Schumpetarian Mark I and II theories stand opposite to each other in stating weather incumbents or startups undertake the most innovative activities, thus contribute to technological development. Large, incumbent firms are often seen as incremental rather than radical innovators (Chandy & Tellis, 2011; Henderson & Clark, 1990; Malerba & Orsenigo, 1995; Schumpeter, 1934). Schumpeter (1934) defined this theory as Mark I. In the face of their technology being replaced by a radically new one, incumbents are known to incrementally improve their product to maintain market share (Geels & Schot, 2007; Henderson & Clark, 1990). Their incentive to innovate radically is therefore small and they have difficulty adapting to large changes (Chandy & Tellis, 2011; Rothaermel, 2001). The same literature strand states that radical innovation is difficult for incumbents due to their previous investments in the established design and their lack of flexibility (Breschi, Malerba, & Orsenigo, 2000; Chandy & Tellis, 2011; Henderson & Clark, 1990; Schumpeter, 1934). They state radical innovation comes from new entrants to the market, the startup firms (Chandy & Tellis, 2011; Henderson & Clark, 1990). Hockerts & Wüstenhagen (2010) found that the Mark I principle also applies in the greenification of sectors: startups are the first to contribute to the sustainable development of sectors, and incumbents follow later.

On the other hand, some scholars tend to see the potential of incumbents to develop radical innovations. They are said to have a key role in radical innovations due to their experience, larger R&D budgets and specialised knowledge base (Malerba & Orsenigo, 1995; Suarez, 2004; Wincent, 1994). In other words: incumbents can pursue new opportunities due to their market capabilities (Chandy & Tellis, 2011; Hannan & Freeman, 1989). Furthermore, Storey & Cressy (1996) and Kelliher & Reinl (2009) state that micro, i.e. very small, firms have the tendency to be more conservative due to the larger uncertainties they face. Therefore they suggest very small firms are more focused on incremental innovation, than larger firms. This strand of literature was developed by Schumpeter and is referred to as Mark II. Malerba & Orsenigo (1995) and Breschi et al. (2000) furthermore state that industries can be divided among Mark I and Mark II theory. This means that the innovativeness of large incumbents is higher than the innovativeness of startups in some industries, and startups have a higher degree of innovativeness in other industries.

Existing research on the innovativeness of firms and technological development is abundant. Technological development is defined by Macher (2006) as a development process in which new knowledge is created: it entails the modification of a technology or the creation of a new technology. Therefore, for an industry's technological development, innovation by the firms in that industry are key (Huergo & Jaumandreu, 2004; Suarez, 2004). Innovative activities, incremental as well as radical, by firms therefore contribute to the technological development process (Macher, 2006). What existing literature has yet to examine closer, is the layer below industry: the different development phases of a technology sector. This means testing if startup firms play a bigger role in one phase of the development process and incumbents in another phase. This study aims to research the possible link between technology development phases and the firm contributions to a technological development, by answering the following research question:

What is the contribution to technological development of startups and incumbents in different development phases?

This study will focus on the cleantech industry. Cleantech is a good case to study the contributions of different firm types, since it is a rapidly growing high-tech industry (Bürer & Wüstenhagen, 2009; Caprotti, 2012; Parad & Youngman, n.d.). This means the industry is developing constantly and active when it comes to innovation (Caprotti, 2012). It is hard to compare the effect startups and incumbents have had in different development phases for a technology sector that is now fully developed. Therefore, two cleantech sectors in different development phases are studied. The study focuses on two sectors with a comparable technological regime: the offshore wind energy sector and the wave energy sector.

Europe is on the forefront of wave energy development, which means several technology designs are being developed and are still in a testing phase. The sector is therefore currently in the R&D phase (Clément et al., 2002; Falcão, 2010; Pérez-Collazo, Greaves, & Iglesias, 2015). Wind energy is the second largest form of power generation on the same continent (BVG Associates, 2017; Falcão, 2010; Wind Europe, 2017). A dominant design has been established and the technology is used for mass production, which means wind energy is currently in a commercial deployment phase (Pérez-Collazo et al., 2015). To make both sectors comparable, this study focuses solely on the offshore subsector of the wind energy sector. This sector faces similar challenges as the wave energy sector, and is therefore a better comparison than the entire wind energy sector.

Especially in Scandinavia cleantech is developing at a rapid pace (Collen & Lindgren, n.d.; Wang, 2015). In order to make the area of focus manageable for this study, three countries within Scandinavia are this study's geographical area of focus: Sweden, Denmark and Norway. The Global Cleantech Innovation Index is published every couple of years, and ranks countries on their cleantech innovativeness based on innovation drivers, cleantech drivers, emerging cleantech innovation and commercialised innovation. In the last two publications, 2014 and 2017, Sweden and Denmark were among the five best performing countries in cleantech, with Norway not far behind (Parad & Youngman, n.d.; Sworder, Salge, & Van Soest, 2017). Furthermore, these countries are among the countries that stimulated wave energy development, meaning a reasonable amount of firms to study should be present (Clément et al., 2002). A database is created to test the linkages between firm and sector characteristics and contribution to technological development via regression analyses. Additionally expert interviews are used to place the findings in context. The upcoming chapters consist of a theory section, methods section, results and a discussion.

2. Theory

This section first gives an overview of technological development. Secondly, Schumpeterian Mark I and Mark II theories are explained. Next, firm types and characteristics are discussed. Thereafter the offshore wind and the wave energy sector are described. Based on these sectors, hypotheses are formulated.

2.1. Technological development

Technology is defined in the Oxford dictionary as “the application of scientific knowledge for practical purposes, especially in industry”. As stated before, technological development is the result of the innovation process, because of the inherent knowledge creation that innovation is (Macher, 2006; OECD, 2012). The definition of technological development used in this study is therefore: adjustments of the practical applications of scientific knowledge. This study focusses on the contribution firms make to the technological development process. More specifically, the contribution different firm types make on technological development. The contributions to the technological development process are made by firms by innovating.

In the early stages of the development process the technology is new and the rate of developments is relatively slow (Christensen, 1997). In this phase of the development process, firms focus on R&D (Sagar & van der Zwaan, 2006; Suarez, 2004; Svensson, 2007). This study will join Svensson (2007) in defining the early stage of the development process as the R&D phase. A dominant design marks a dominant technology that is the new standard in an industry sector (Anderson & Tushman, 1990; Suarez, 2004). After the dominant design occurs, incremental improvements are made to the technology until a new technological discontinuity emerges (Anderson & Tushman, 1990; Milling & Stumpfe, 2000; Utterback & Abernathy, 1975; Utterback & Suárez, 1993). This phase is characterised by commercial deployment (Sagar & van der Zwaan, 2006). This study joins Sagar & van der Zwaan (2006) in defining the second part of the development process as the deployment phase. A major goal for firms in this phase is to capture profits from the investments made in the innovations thus far (Namara, Ryan, Jones, & Noonan, 2015).

2.2. Mark I and Mark II

Early literature describes entrepreneurs as necessary to bring inventions to the market, since they have the technological ease of entering a new industry (Breschi et al., 2000; Malerba & Orsenigo, 1995; Schumpeter, 1934). Entrepreneurs were believed to do things differently due to their new outlook on an existing industry, thus innovating radically. This fundamental theory by Schumpeter (1934) is referred to as Mark I. Schumpeter (1934) developed this theory when studying late nineteenth century European industry. He observed many small firms contributing to fast and industry transforming developments (Malerba & Orsenigo, 1995). Mark I theory states that startup firms rely heavily on their R&D, since they are trying to enter an industry by introducing something new. The R&D departments at incumbent firms are more routinised to focus on incremental improvements of the firm’s current technology (Chandy & Tellis, 2011; Malerba & Orsenigo, 1995; Rothaermel, 2001). Incumbent firms are stated to be better at deploying innovations, due to their experience with the industry and larger funds (Chandy & Tellis, 2011).

In later years Schumpeter moved to the US, focussing his studies on American industry (Malerba & Orsenigo, 1995). He described the key role that larger, older firms have in radical technological innovation, referred to as Mark II. Due to their experience, established firms prevail and create barriers that entrepreneurs face when they try to enter the market (Malerba & Orsenigo, 1995). These barriers are mainly developed by the larger firms’ R&D budgets and thus specialised knowledge base (Breschi et al., 2000; Malerba & Orsenigo, 1995; Wincent, 1994). This theory is supported by Hannan & Freeman (1989), claiming older organisations can pursue new opportunities (Eggers & Kaplan, 2009, p.469). Mark I and Mark II seem opposites; in both theories it seems a different type of firm is most suited to bring radical innovations to the market.

Malerba & Orsenigo (1995) discovered that innovative activities of small and large sized firms varied among industry sectors. They state that industry sectors can be divided in Mark I and Mark II categories. The Mark I category is characterised by many small innovative firms and mechanical and traditional sectors, such as mechanical, electrical technologies (Breschi et al., 2000; Malerba & Orsenigo, 1995). The Mark II category is characterised by the technological contributions by large and medium sized firms and chemical and electrical-electronic sectors, such as electronic components (Breschi et al., 2000; Malerba & Orsenigo, 1995). Audretsch (1995) agrees with Malerba & Orsenigo (1995) on the fact that the role of small firms entering a market depends on the industry sector. He states that the likelihood of firm survival differs among industries. Cleantech technologies have comparable purposes to traditional technologies, such as energy production and transportation. The difference is that they are cleaner than their existing substitutes (Basse-Mama, Koch, Bassen, & Bank, 2013). These technologies, such as wind turbines, consist largely of mechanical elements. Therefore this study classifies the cleantech industry in the Mark I category, according to Malerba & Orsenigo (1995).

This study focuses on the role of firm types in different development phases, focusing on a specific technology sector instead of an industry. In early stages of development, I expect startup firms to be more innovative due to low barriers to entry and high uncertainty. This is in line with Mark I theory. In later development stages, I expect incumbents to be a bigger source of innovation, in line with Mark II theory. Incumbents have gathered experience in the sector and can therefore benefit in later development stages. In these stages the barriers of entry are higher and the importance of economies of scale, financial resources, and learning curves is increased. The trend that different firm types have a higher degree of innovativeness in different development stages was touched upon by Malerba & Orsenigo (1995), stating that industry development phases are linked to the innovativeness of firms.

2.3. Firm types

Literature describes several characteristics and criteria that can be used to divide firms in categories. Two criteria that are often combined when it comes to technology related firms, are size and age. The combination of these factors have been deemed significant and consistent when it comes to explaining firm growth, firm performance and firm survival (Almus & Nerlinger, 1999; Ferguson & Olofsson, 2004; Yildiz, Bozkurt, Kalkan, & Ayci, 2013). Since previous studies proved the use of these two firm characteristics useful in defining firms, this study will do the same.

The age of a firm shows how long the firm has been operative in an industry (Huergo & Jaumandreu, 2004). Firms that have been operative in the industry for a longer period of time have gained more experience than new entrants to the industry. Chandler & Hanks (1994) suggest the age of a firm can influence the performance of a firm. The reason to include firm size in combination with firm age, is that firms need to reach a minimum size to assure that they survive (Almus & Nerlinger, 1999; Ferguson & Olofsson, 2004). A commonly used way to measure firm size is measuring the number of employees a firm has (Almeida, Dokko, & Rosenkopf, 2003; Audretsch & Elston, 2002; Wincent, 1994).

Two firm types on the opposite end of the spectrum are identified: startups and incumbents. Startups are defined as “small firms, young firms, entrants or self-employed” (Van Praag & Versloot, 2007, p. 376). When startups enter the market, this leads to business development, possibly endangering the position of existing firms in the market (Van Praag & Versloot, 2007). Since startups are new business endeavours, the chance of failure is quite high. They are relatively new firms that, therefore, have a limited number of employees (Almeida et al., 2003; Audretsch, 1995). Firms that have been operating in the market for a large time period are called incumbents. They are more experienced, larger and older than newly founded firms (Van Praag & Versloot, 2007). Incumbents are large firms that have had time to grow in number of employees (Almeida et al., 2003; Almus & Nerlinger, 1999; Van Praag & Versloot, 2007).

2.4. Sectors

In this study two energy sectors, that are in a different development phase, are taken into account: the offshore wind and the wave energy sector. These are both cleantech sectors that have similar technological opportunities and challenges, appropriability of innovations, cumulativeness of technological advances, and properties of knowledge base (Breschi et al., 2000). Both sectors are concerned with offshore renewable energy and therefore face similar challenges due to operating on sea. Constructing turbines to the sea floor or creating floating power plants is a costly procedure (Bilgili, Yasar, & Simsek, 2011; Dvorak, Archer, & Jacobson, 2010). Furthermore, there are also high costs with deploying, maintaining and testing large prototypes under harsh conditions (Esteban, Diez, López, & Negro, 2011; Falcão, 2010). The biggest challenge for both sectors is therefore to reduce costs in order to make exploitation of the energy source feasible (Pérez-Collazo et al., 2015). Offshore wind and wave energy have a great potential, especially in Europe, with large coastlines with good wave and wind conditions (Pérez-Collazo et al., 2015). Wave energy is created by wind blowing across the oceans, meaning that both offshore wind and wave energy are subject to the whims of the wind and experience energy peaks (Clément et al., 2002).

The Scandinavian offshore wind energy sector has been developing for several decades, thus ensuring a mature sector where a dominant design has been established (Parad & Youngman, n.d.). As a result, most technological developments are happening in the monitoring and control part of the sector and the levelised cost of electricity is declining drastically (Motyk, 2017; Parad & Youngman, n.d.). The sector is currently in a state of deployment in Scandinavia (BVG Associates, 2017; Pérez-Collazo et al., 2015; Toke, Breukers, & Wolsink, 2008). More than a thousand MWs have been installed in Sweden, Norway and Denmark. In contrast, the wave energy sector has been less developed. Several wave energy stimulation programs in the 1990s and 2000s stimulated R&D of wave technologies (Falcão, 2010). In recent years, interest in wave energy has been growing even more (Falcão, 2010). There are still several technologies in development, meaning that the sector has no dominant design in place yet (Falcão, 2010; Henfridsson et al., 2007; Pérez-Collazo et al., 2015).

This study is based on the expectation that startups have a greater contribution to technological development in the early development phase of an industry sector and incumbents have a greater contribution to technological development in a later development phase. The early development phase is depicted by the wave energy sector: a sector that is in the R&D, pre-dominant design, phase. Startup firms are expected to have a greater contribution to technological development in this pre-dominant design phase due to their flexibility and the low barriers to entry. The offshore wind energy sector is the depiction of the deployment phase, where a dominant design has been established. I expect incumbent firms to have a greater contribution to technological development in the phase where a dominant design has been established. The interaction between the technology phase a sector is in and the firm types that are contribute to technological development in that sector, holds a central position in this study. Therefore, I hypothesise the following:

H1: Startup firms have a greater contribution to technological development in the wave energy sector than incumbent firms

H2: Incumbent firms have a greater contribution to technological development in the offshore wind energy sector than startup firms

3. Methodology

3.1. Data

My data, information on firms, patents, and citations, comes from several databases and other online platforms. The database focus is on firms that are based in Norway, Sweden or Denmark. Furthermore, all firms are operational in either the offshore wind energy or the wave energy sector. The names of these firms are obtained by using fifteen existing databases and websites. Firm characteristics - countries in which they are operational, founding year, number of employees, and firm focus - are obtained by searching firm websites, LinkedIn, contacting the firms and other online sources. The databases used are national wind energy databases from Norway, Sweden and Denmark, international wave energy databases, a sustainable energy start-up database, national offshore energy databases and websites that specialise in wind energy or wave energy. For an overview of the websites, see Appendix A. Firms that only focus on onshore wind energy were filtered out.

Firms use various appropriation regimes to protect their knowledge and investments (Spinello, 2007). Patents are believed to be one of the most effective ways of doing so, with a growing number of patent applications over the last decades (Choi & Park, 2008; W. M. Cohen, Nelson, & Walsh, 2000; Crespi, D'Este, Fontana, & Geuna, 2011). Patent data is very consistent over time, due to the fact that each patent request is examined by patent examiners before a patent being granted (Hall, Jaffe, & Trajtenberg, 2001). Therefore, patent analysis is a useful way to indicate technology development (Z. Acs & Audretsch, 1989; Choi & Park, 2008; Jalles, 2010; Pilkington, Dyerson, & Tissier, 2002). In both the offshore wind and the wave energy sector patents seem to be a widely used appropriation regime, with thousands of patents in both sectors and hundreds of applications per year (Falcão, 2010; Johnstone, Haščič, & Popp, 2010). Therefore, this study uses patents as an output measure for contribution to technological development. Often patents cite other patents of which information is used. When a patent receives forward citations, the knowledge contained in the patent is used to further enhance the technological sector. Jaffe & Trajtenberg (1999) state that patents citations offer information about where technological activity originates. Choi & Park (2008) furthermore describe that patent citations are widely used to analysing technological change. When a firm has more citations, its contribution to the development is larger than when it has less citations. Therefore, this study is using patent citations as an additional factor of contribution to technological development.

Patent data is obtained by searching the European Patent Office PATSTAT database, containing more than 90 million patent documents. This database is easy to use when performing patent analysis. When applying for a patent, a firm is assigned a PATSTAT standardised name (psn name) and a corresponding ID (psn id) (EPO, 2016). A firm can have more than one psn id's, for instance due to the fact that different firm departments can apply under a slightly different name than other departments. First the PATSTAT database is searched for each firm name in the study's dataset. These names and id's ae manually added to a list, which was is used to extract the number of patents and patent citations from the PATSTAT database. The dataset does not consist solely of end producers of offshore wind or wave energy technologies. It also contains other firms in the supply chain, such as material producers. Their patents may not be placed in a patent class concerned with renewable energy, which is why firstly all patents are taken into account. Secondly, since this study focuses on renewable energy technologies, it is also interesting to see if the firms in the dataset have specific patents in the field of renewable energy production. Therefore, a patent search in PATSTAT is done with regard to the Y02E10 class, patents regarding 'Energy generation through renewable energy sources' (European Patent Office, 2016; Veefkind, Hurtado-Albir, Angelucci, Karachalios, & Thumm, 2012). There are more specific codes within the Y02E10 category that can be used to search in more specifically defined sectors (Kapoor, Karvonen, Ranaei, & Kässi, 2015; Veefkind et al., 2012). However, wave energy is a diverse technology field: there is a wide variety of technologies and several methods have been proposed to classify wave energy technologies (Falcão, 2010). Therefore, the patent search does not go more in-depth than an overall patent search and a Y02E10 patent search. All the used codes can be found in Appendix B.

Additional qualitative, semi-structured interviews were used to discover how projects are build up and on the motivation firms have behind the choices they make, thus providing context of the quantitative findings (Bryman, 2012). Due to the flexible nature of semi-structured interviews, it is possible to ask pre-determined questions and to elaborate on the topics the interviewee deems important (Bryman, 2012; DiCicco-Bloom & Crabtree, 2006). Therefore, this interview strategy is ideal to create an emerging understanding of the study's context (DiCicco-Bloom & Crabtree, 2006). Interviewee 1 is an expert on business development in Scandinavia. Interviewee 2 is a researcher focusing on wave energy in Denmark.

3.2. Operationalisation

Contribution to technological development

In order to measure the contribution to technological development by firms, several measures are used. The sum of all the patents listed to a firms psn id's is the first measurement of technological contribution. In order to specify to patents in 'energy generation through renewable energy sources', a patent search is done in patent class Y02E10. The sum of all the patents per firm is another measurement of contribution to technological development. Furthermore, the sum of the patent forward citations and patent Y02E10 citations are used as another way to measure firm contribution to technological development (Kapoor et al., 2015). The biggest downside of using forward patent citations in this study is that the number increases over time. This means that firms that have very recent patents are likely to have not obtained many forward citations (Kapoor et al., 2015). Since the wave energy sector has been in development for a shorter period of time, the firms in this sector could lack forward citations that offshore wind energy firm have received on their patents. Therefore, this measurement is used additionally to the total sum of patents and the total sum of Y02E10 patents. By performing analysis on the four dependent variable measurements, various insights can be conceived on the contribution to technological development of different firm types.

Independent variables

Sector

A distinction is made between the offshore wind and the wave energy sector. The activities a firm undertakes are observed by looking at the firm's website and LinkedIn page. Based on these sources, it is judged if a firm is operational in the offshore wind or wave energy sector. Firms operational in both sectors, are removed from the database, since having no double cases in the dataset increases the analysis possibilities. In the case of wind energy firms, the assessment of a firm's activities especially focuses on the distinction between offshore and onshore wind energy. Onshore wind energy faces different challenges and is less costly to generate (Bilgili et al., 2011; Esteban et al., 2011; Zhixin, Chuanwen, Qian, & Chengmin, 2009). Onshore wind energy firms are not included in the dataset.

Firm age

In this study, firm age and size are taken into account to account for firm type. Ferguson & Olofsson (2004) look at firm age in years. This study will follow them by describing the firm age as the numbers of years the firm is old. However, the age of the firms varies between 1 and 257 years old. Therefore, it makes sense to take the log age when performing multiple regression analysis.

Firm size

Firm size is measured in number of employees, in line with Almeida et al. (2003), Audretsch & Elston (2002) and Wincent (1994). The year of measurement that is chosen is 2016, due to the fact that up-to-date information is publicly available of most firms. The firms where a web search does not define how many employees a firm has, were contacted. For several firms, no specific number of employees could be found. Therefore, firm size is a categorical variable with four categories. Several studies have aimed to determine the average amount of employees startup firms have. A commonly used cut-off point between small and medium enterprises (SMEs) and large firms, is 250 employees (Ayyagari, Beck, & Demirguc-Kunt, 2007). Various sources agree with this, dividing enterprises in four size categories: micro, small, medium, and large. With cut-off points 50 and 250 between small, medium and large enterprises (Eurostat, 2016; Wolff & Pett, 2006). Fajnzylber, Maloney, & Montes-Rojas (2011) conducted a study on micro firms and observed at most five paid employees per firms. This study combines the previously mentioned sources and defines a micro firm as a firm with ≤ 5 employees, a small firm as 6-50 employees, a medium firm as 51-250 employees, and a large firm as >250 employees.

Control variables

This study contains several control variables. First, the location where the firms are operative is controlled for. This study focuses on Norway, Denmark and Sweden. Therefore, three binary variables are added. Secondly, a variable is added to control for the main focus on the firm in the supply chain. The dataset consists of turbine producers, material producers, service firms and energy firms. Some firms have more than one focus in the supply chain. In those cases, the main focus of the firm is identified through desktop research.

Table 1: Operationalisation table

Variable	Indicator	Calculation of scores	Measurement
Dependent variable			
Technological development	- Number of patents - Number of citations - Number of patents in renewable energy - Number of renewable energy patents	- Sum patents registered to a firm - Sum of forward citations - Sum patents in class Y02E10 to a firm - Sum of forward citations in class Y02E10	Count
Independent variables			
Sector	Existence of firm in offshore wind or the wave energy sector	1: Wind 0: Wave	Binary
Firm age	Age of the firm	Log age	Continuous
Firm size	Number of employees	Four categories: - Micro: 1-5 - Small: 6-50 - Medium: 51-250 - Large: 251+	Categorical
Control variables			
Location Denmark	Weather firm is operative in Denmark	1: Yes 0: No	Binary
Location Sweden	Weather firm is operative in Sweden	1: Yes 0: No	Binary
Location Norway	Weather firm is operative in Norway	1: Yes 0: No	Binary
Focus	Type work firm mainly focuses on	Four categories: - Turbine producer - Material producer - Service firm - Energy firm	Categorical

3.3. Data analysis

In order to test the created hypotheses and answer the research question, various analyses are performed in statistical software program SPSS. With the dependent variables being count variables, multiple regression analysis is explored as the first step in analysing the data (Grace-Marin, n.d.). However, multiple regression models do not explain contribution to technological development enough, with R Square’s not higher than 2% and no significant effect. This shows the assumptions for multiple regression analysis are violated (J. Cohen, Cohen, West, & Aiken, 2013). As figure 1 shows, the dependent variables are exponentially divided. As an alternative a logistical regression model is used (Hilbe, 2014a). In order to test this model, a categorical dependent variable is created for each of the four dependent variable measurements. In this case, a binary variable is created that indicates weather a firm has patents (1) or not (0), based on the argumentation that a firm that has patents or citations is contributing to technological development, more than a firm that does not have patents or citations. This type of model shows is a good fit with the data with a Nagelkerke R Square value that shows an explained effect of 28.7% at the lowest. The assumptions for using a logistic regression are met: the dependent variable is binary, there are multiple continuous or categorical independent variables and the observations are independent (Hilbe, 2014a). In order to make sure multicollinearity assumptions are not violated, Pearson correlations are used and variance inflation factor (VIF) values are calculated for the models (Kraha, Turner, Nimon, Zientek, & Henson, 2012; Ozdemir, 2011).

Furthermore, the dependent variables 'Patents' and 'Citations' can be called count variables since their values vary between zero to a specified greater number (Hilbe, 2014b). There are several statistical models that have a dependent count variable at its base. The negative binomial model is often used when the dataset is overdispersed due to outliers (Hilbe, 2012, 2014b; Rodríguez, 2013). A negative binomial model has the characteristic that it allows for a far wider range of variability to be modelled than the Poisson model (Hilbe, 2014b). Therefore, this model also seems to be a good fit for the data, and will be used in this study additionally to logistic regression models. Several models are created, the first containing solely the control variables. Secondly, the independent variables are added to the model. Finally, a model is created that contains interaction terms of the firm variables, age and size, and the sector variable. For this purpose, interaction variables are created. The final model is used to test the hypotheses created in the theory section.

Additionally, the interviews with the experts are assessed by transcribing the interviews. The transcriptions of these interviews are later used to put the findings into context. The interviews are also used to assess the societal and theoretical implication of this study. Coding was not used since the purpose of the interviews is just to provide context to the quantitative findings, not to conduct a qualitative research. The interviews can be found in Appendix C.

4. Results

4.1. Descriptive statistics

There are 330 firms in the database that are operational either in the offshore wind or in wave energy sector in Norway, Denmark and Sweden. Of two firms the main focus in the supply chain is a missing value. Approximately 52% of the328 firms of which the supply chain focus in known, is active on the material production side of the sectors (turbine producers and material producers). This percentage shifts when looking at the specific industries: 92% of wave energy firms and 45% of offshore wind firms focuses on the production side of the sector. This may be a result of the age difference of both sectors: since the wave energy sector is in earlier stages of development, there is no demand for service firms yet (see Appendix D for bar charts).

Figure 2 shows that the percentage of firms that have patents on the production side of the sector is greater than on the service side, with approximately 70% of turbine producers and 55% material producers having patents. For service and energy firms these percentages are approximately 35% and 50%. Roughly the same effect is observed when looking at the amount of firms with citations, even though the numbers are lower (see figure 3). Energy firms are the exception, since three out of six energy firms in the dataset have patents as well as citations. Figure 4 shows the focus of firms split by sector and weather a firm has patents or not. However, a higher percentage of wave energy than offshore wind energy firms holds patent, approximately 60% respectively 46%. From these numbers I conclude that service heavy sectors, such as the offshore wind energy sector, have relatively less patent and citations holding firms than producer heavy sectors. In absolute numbers the offshore wind energy sector has more patents, due to the fact that there are more firms operational in this sector. Figure 5 shows that the percentage of Y02E10 patents is 54% for wave energy firms, whereas the percentage of offshore wind energy firms is only approximately 18%. The same trends are observed for 'Citations' and 'Citations Y02E10' (see Appendix E). The large difference between 'Patents' and

‘Patents Y02E10’ within the offshore wind energy sector is caused by the large number of material producers and service firms in that sector. Like described in 3.2., the patents by these types of firms may not necessarily be placed in a patent class concerned with renewable energy.

The amount of firms that are operational in Norway, Denmark and Sweden, is distributed unevenly. The least amount of firms is operational in Norway, which interviewee 1 assigns to the fact that “Norway has the additional disadvantage that we already have almost 100% green electricity [..] thus there is no pressure for Norway to reduce dependency from fossil fuels” (Interviewee 1, Personal Communication, October 10th 2017). Multiple firms are operational in more than one country. The data shows that wave energy firms are mostly located in Norway, while Sweden has the most offshore wind energy firms. The high percentage of wave energy firms focusing on Norway can possibly be linked to the high amount of hydro power plants in Norway (Edenhofer et al., 2011; Norwea, 2016). Of course the large coast line is also a contributing factor to Norway having a relatively large amount of wave energy firms. Expert 2 adds to this, stating that “in the 70s and 80s there [in Norway] was quite a lot going on compared to what was going on on a global scale” (Interviewee 2, Personal Communication, October 4th 2017). It is interesting that Sweden is identified as the country with the most firms in the offshore wind energy sector. In a recent report, commissioned by Norwegian Energy Partners the key offshore wind energy markets are identified. Sweden is not part of these key markets. Denmark, however, is (BVG Associates, 2017). WindEurope, an organisation representing the European wind industry, furthermore states that policy in Sweden currently dejects and delays offshore wind projects by not implementing the cost-reducing auctions scheme that most other European countries have (offshoreWIND.biz, 2017). This is supported by expert 1, who states “Sweden and Norway have much weaker financial incentive schemes” (Interviewee 1, Personal Communication, October 10th 2017). A possible explanation for the high number of offshore wind firms in Sweden can also not be found in the fact that some firms are operational in more than one country. In Sweden approximately 17% of wind firms are also operational in other countries. For Denmark this number is also approximately 17%, while in Norway it is even higher with 36%. Appendix D contains a bar chart of firm distribution per country of operations. Appendix F contains histograms of the other variables.

Table 2 contains the descriptive statistics and correlations of the variables. The first noteworthy observation based on table 2, is that the number of patents and the number of citations have a high standard deviation (SD). Figure 1 shows that the reason for this is a large amount of firms that have zero to a few patents or citations. A few outliers have large amounts of patents and citations, skewing the data. The SD of patents and citations in patent class Y02E10 are lower. This is explained by the fact that these variables have less outliers with no cases with more than 10,000 patents or citations. Therefore, more cases have zero or a few patents or citations. Secondly, I observe positive, significant correlations between the four measurements for the dependent variables. This makes sense, since a firm can only have citations in class Y02E10, if it has patents. Furthermore, firm size has a significant, positive correlation with number of patents, number of Y02E10 patents, and number of Y02E10 citations, with respective coefficients of .116, .145 and .142. Firm size and sector have a positively significant coefficient of .221, indicating that firms in the offshore wind energy sector have a positive correlation with a larger firm size. This is explained by the fact that the offshore wind sector has been developing for a longer time period. Finally, table 2 shows that firm focus correlates negatively significant, -.156 and -.134, with number of Y02E10 patents and citations.

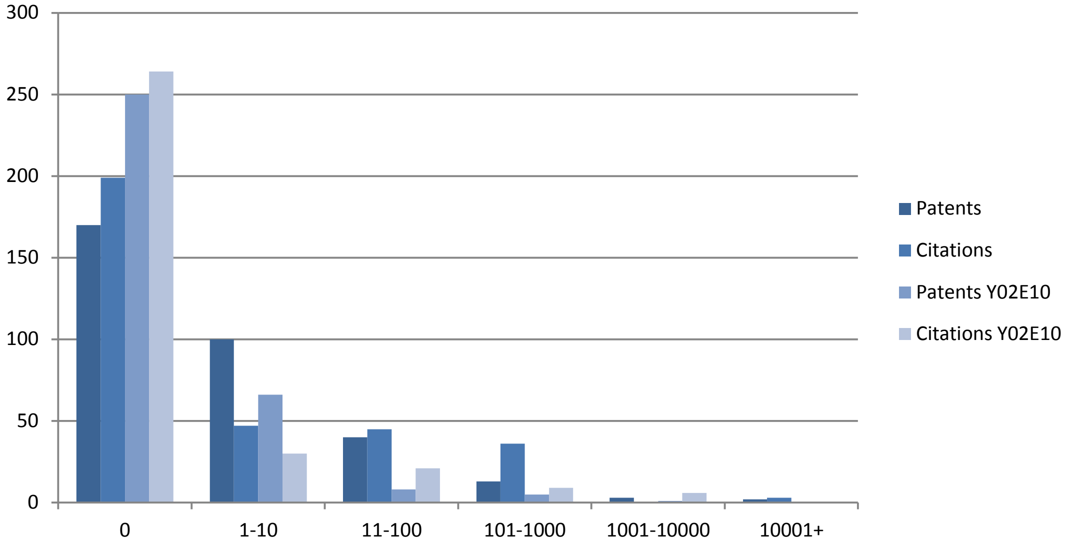

Figure 1: Bar chart of 'Patents', 'Citations', 'Patents Y02E10', and 'Citations Y02E10'

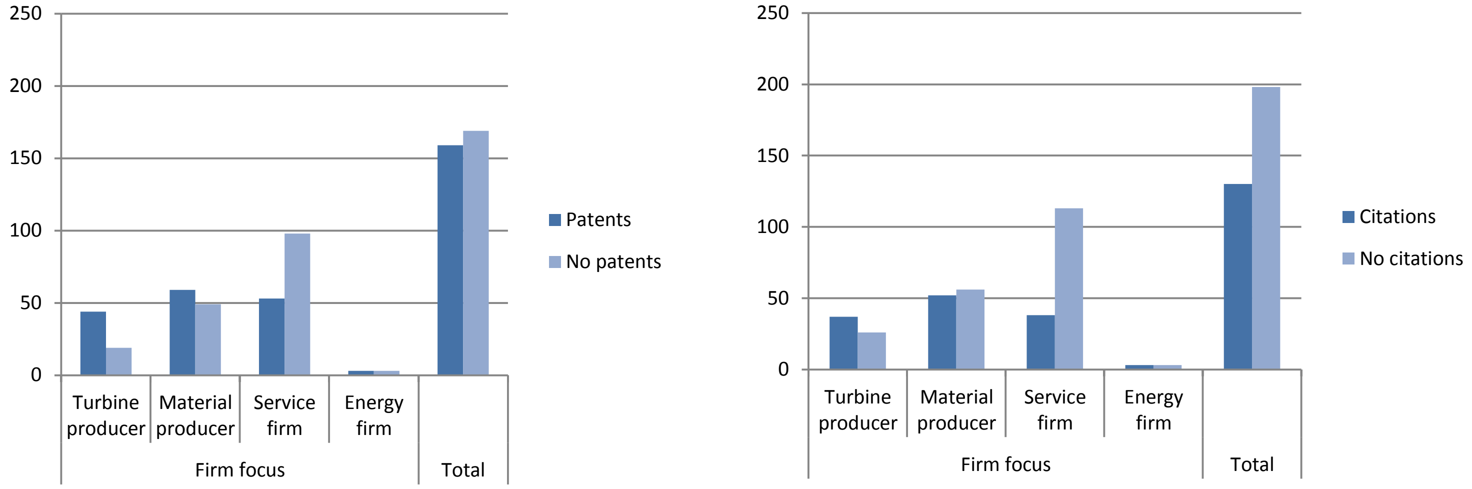

Figure 2 and 3: Bar chart of 'Patents' and 'Patent citations' per firm focus

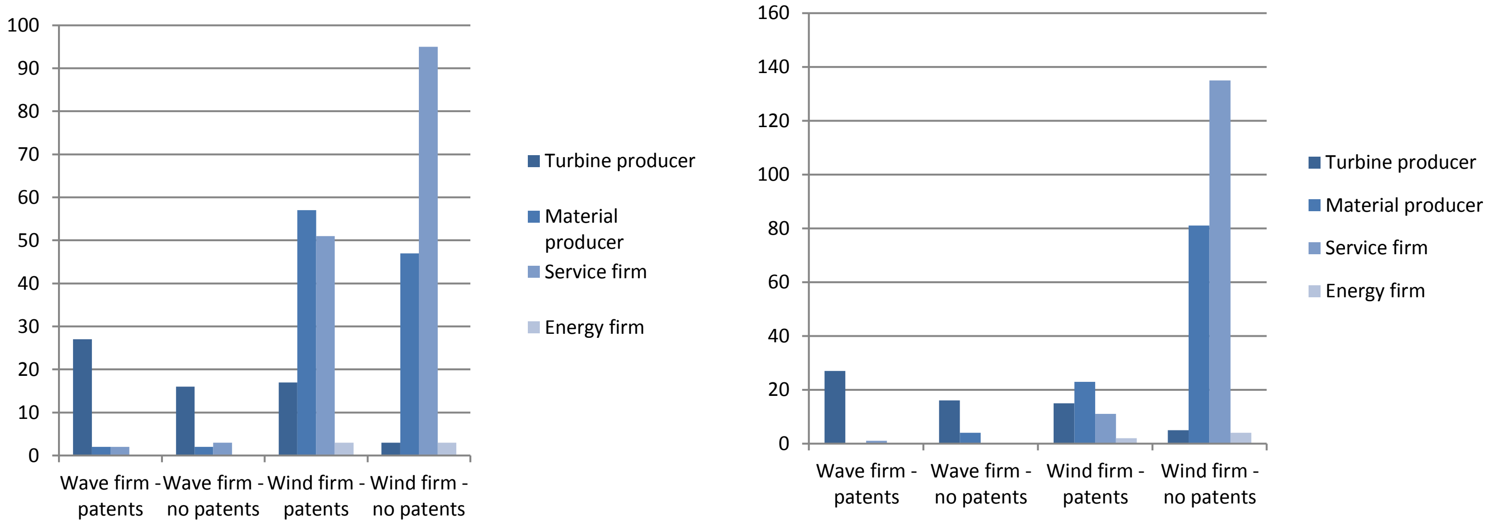

Figure 4 and 5: Bar chart of 'Patents' and 'Patents Y02E10' per sector and firm focus

Table 2: Descriptive statistics and correlations table

	Variable	**Mean**	**SD**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	Number of patents	199.20	2154.84										
2	Number of citations	1999.67	27494.98	0.929**									
3	Number of Y02E10 patents	7.58	61.52	0.257**	0.196**								
4	Number of Y02E10 citations	61.10	517.53	0.398**	0.357**	0.980**							
5	Sector	0.84	0.37	0.039	0.031	0.038	0.042						
6	Firm size	2.78	0.97	0.116*	0.092	0.145*	0.142*	0.221**					
7	Firm age (log)	2.98	1.09	0.100	0.101	0.111	0.127*	0.217*	0.488*				
8	Location Denmark	0.36	0.48	0.043	0.067	0.046	0.060	0.134*	0.183**	0.105			
9	Location Sweden	0.46	0.50	-0.008	-0.038	0.092	0.075	0.166**	0.001	0.081	-0.504**		
10	Location Norway	0.30	0.49	-0.047	-0.039	-0.065	-0.061	-0.247**	-0.042	-0.070	-0.309**	-0.334**	
11	Focus	2.31	0.79	-0.008	-0.020	-0.156**	-0.134**	0.565**	0.182**	0.151**	0.128*	0.151**	-0.198**

*Significance codes: p<0.01 **, p<0.05**

4.2. Model testing

Three models are created with every test: the control model, the independent variable model and the interaction term model. The VIF values of the independent variables are between 1 and 2, the highest being size (VIF=1.466; see Appendix G for all VIF values). Several thresholds for what is an acceptable VIF value are named in literature. Most articles mention an acceptable maximum of 4, 5 or 10 (Hung, Craven, Lin, & Kuo, 2011; Pan & Jackson, 2008; Rogerson, 2001). Since this study´s VIF is below 4, I conclude multicollinearity is not an issue and no variables need to be eliminated (O'Brien, 2007).

The logistic regression models are displayed in table 3 to 6. The Nagelkerke R Square values vary between .287 and .388 for the third model of all the dependent variables. Each of the four tables shows that the model fit increases when more variables are added to the models; the models where the interaction terms are added have the highest model fit. Model 3 of the dependent variable 'Citations Y02E10' has the highest Nagelkerke R Square (.388). The logistic regression models are displayed in table 7 to 10. The Pearson Chi-Square/df values are incredibly lower in all models 2 opposed to all models 1. This shows that the model fit increases from model 1 to model 2, with all four dependent variables, since a lower value means a better model fit (Allison & Waterman, 2002). In most models 3 the Pearson Chi-Square/df value increases slightly compared to model 2. For dependent variable 'Patents' the value increases moderately compared to model 1 and tremendously compared to model 2. This shows the models 2 are a better fit than the models 3, which is also shown by the higher number of variables that have a significant effect in models 2 than in models 3.

'Sector' shows insignificant results in all logistic regression models, meaning there is no proven connection between if a firm has patents or citations and if it is operational in the offshore wind or the wave energy sector. When looking at the negative binomial models, 'Sector' has a significant relationship in model 2 for all dependent variables (p<0.01). When the interaction variables are added to create model 3, this effect increases but is no longer significant. 'Firm size' also shows a positive significant effect in model 2 for all dependent variables (p<0.01). In model 3 this effect increases and stays significant for all dependent variables. This significant effect decreases to p<0.05 for dependent variable 'Patents Y02E10' and stays p<0.01 for the other three dependent variables. This means that larger firms have a greater contribution to technological development than smaller firms, when measured in each of the dependent variables.

‘Firm age’ shows no significant effect in any of the logistic regression models. In the negative binomial models it shows a positive significant connection to all four dependent variables, with p<0.01, before adding the interaction terms. This means when a firm is larger in size, it has a significant higher contribution to technological development, when measured in patents and citations. However, in the complete model 3 no significant relationship between the dependent variables and firm size is observed. With dependent variable ‘Patents Y02E10’ the effect stays positive, for the other three dependent variables the effect turns negative.

The negative binomial tests show a different effect for ‘Firm age’ among the different models. For dependent variables ‘Patents’ and ‘Citations’ a positive significant effect is observed in model 2 and 3 (p<0.01), with an increase in the effect in model 3. This indicates that older firms have a higher technological contribution, when technological contribution is explained in number of patents and number of citations. A small positive effect that is not significant is observed when technological contribution is measured in number of patents in the Y02E10 class. When it is measured in number of citations of Y02E10 patents, the effect is negative and significant in model 2 (p<0.01). However, when interaction terms are added in model 3 the effect is less strong and no longer significant. It seems that patents related to energy generation through renewable energy sources by younger firms are cited more than those patents held by older firms. However, this connection is not significant so no conclusions can be made based on this.

The hypotheses are tested by the interaction effects, since they focus on the different roles of startups and incumbents in the two different sectors. The interaction effects of ‘Sector’ and the firm characteristics ‘Size’ and ‘Age’, show limited significant results in both the logistic regression models and the negative binomial models. The interaction effect of ‘SectorxAge’ has no significant effect to all dependent variables in the logistic regression models. In the negative binomial models, the models including the interaction terms are mostly insignificant. The effect of ‘SectorxAge’ is negatively significant on the dependent variable ‘Patents’ (p<0.1). This indicates that in the wave energy sector older firms have more patents and in the offshore wind energy sector younger firms have more patents. This is not in line with the hypotheses proposed in this study, which means that based on the interaction term of ‘Sector’ and ‘Age’, H1 and H2 are rejected.

‘SectorxSize’ shows a positive significant effect in the logistic regression with dependent variables ‘Patents’ (p<0.1), ‘Citations’ (p<0.05) and ‘Citations Y02E10’ (p<0.05). This means larger firms have a greater contribution to technological development in the offshore wind energy sector and smaller firms have a greater contribution to technological development in the wave energy sector. The same interaction term shows no significant effect in the negative binomial models. Based on the interaction term of ‘Sector’ and ‘Size’, H1 and H2 are therefore partially confirmed. Firm types are identified by the combination of the two firm characteristics: age and size. Since the results of the models with interaction terms ‘SectorxAge’ and ‘SectorxSize’ are not in line with each other and the hypotheses, no complete acceptation or rejection of the hypotheses can be reached.

Table 3, 4, 5 and 6: Logistic regression models for 'Patents', 'Citations', 'Patents Y02E10' and 'Citations Y02E10'

Patents	**Model 1**	**Model 2**	**Model 3**
Constant	1.212***	-0.269	0.196
Sector		0.227	-0.337
Firm size		0.773***	-0.308
Firm age (log)		0.161	0.935
SectorxSize			1.158*
SectorxAge			-0.814
Location Denmark	0.052	-0.371	-0.443
Location Sweden	-0.150	-0.618	-0.637
Location Norway	0.633*	0.477	0.503
Focus	-0.610	-0.993	-0.975
n	328	297	297
Nagelkerke R Square	0.115	0.275	0.287

Citations	**Model 1**	**Model 2**	**Model 3**
Constant	0.853*	-0.914	1.036
Sector		0.321	-2.052
Firm size		0.817***	-0.660
Firm age (log)		0.223	0.715
SectorxSize			1.602**
SectorxAge			-0.514
Location Denmark	0.054	-0.376	-0.475
Location Sweden	-0.010	-0.539	-0.558
Location Norway	0.464	0.267	0.286
Focus	-0.630	-1.071	-1.007
n	328	297	297
Nagelkerke R Square	0.099	0.279	0.302

Patents Y02E10	**Model 1**	**Model 2**	**Model 3**
Constant	1.648***	1.098	1.605
Sector		-0.398	-1.108
Firm size		0.831***	0.120
Firm age (log)		-0.356	0.051
SectorxSize			0.798
SectorxAge			-0.445
Location Denmark	-0.059	-0.088	-0.144
Location Sweden	-0.295	-0.497	-0.505
Location Norway	0.581	0.444	0.460
Focus	-1.360	-1.492	-1.461
n	328	297	297
Nagelkerke R Square	0.302	0.357	0.362

Citations Y02E10	**Model 1**	**Model 2**	**Model 3**
Constant	1.732***	1.376	3.132*
Sector		0.050	-2.831
Firm size		0.814***	-0.836
Firm age (log)		-0.256	0.277
SectorxSize			1.916**
SectorxAge			-0.608
Location Denmark	-0.603	-0.740	-0.914
Location Sweden	-0.362	-0.757	-0.810
Location Norway	0.289	0.098	0.121
Focus	-1.415	-1.653	-1.594
n	328	297	297
Nagelkerke R Square	0.307	0.358	0.388

*Significance codes: p<0.01 ***, p<0.05**, p<0.1**

Table 7, 8, 9 and 10: Negative binomial for ‘Patents’, ‘Citations’, ‘Patents Y02E10’ and ‘Citations Y02E10’

Patents	**Model 1**	**Model 2**	**Model 3**
Intercept	6.168***	-0.696	-2.582***
Sector		1.457***	4.153
Firm size		5.788***	5.979***
Firm age (log)		0.556***	1.371***
SectorxSize			-0.113
SectorxAge			-0.861*
Location Denmark	0.810***	-0.006	-0.068
Location Sweden	0.292	0.479*	0.392
Location Norway	-2.298***	0.414*	0.355
Focus	-4.056***	-5.765***	-6.102***
n	297	297	297
Pearson Chi-Square/df	69.763	2.191	18.930

Citations	**Model 1**	**Model 2**	**Model 3**
Intercept	9.989***	-1.105**	-2.688**
Sector		2.379***	5.079
Firm size		7.544***	8.524***
Firm age (log)		0.700***	1.262***
SectorxSize			-0.423
SectorxAge			-0.593
Location Denmark	-0.287***	-0.246	-0.239
Location Sweden	-1.065	0.294***	0.279
Location Norway	-6.289***	0.362	0.402
Focus	-4.366***	-6.990***	-7.294***
n	297	297	297
Pearson Chi-Square/df	2731.848	22.546	22.157

Patents Y02E10	**Model 1**	**Model 2**	**Model 3**
Intercept	2.814***	0.127	-0.183
Sector		1.069***	1.281
Firm size		4.232***	3.857**
Firm age (log)		0.082	0.274
SectorxSize			0.13
SectorxAge			-0.204
Location Denmark	0.478*	-0.809	-0.808**
Location Sweden	1.180***	-0.115	-0.111
Location Norway	-1.212***	-0.527*	-0.527*
Focus	-3.106***	-4.450***	-4.468***
n	297	297	297
Pearson Chi-Square/df	32.244	10.247	10.319

Citations Y02E10	**Model 1**	**Model 2**	**Model 3**
Intercept	3.902***	0.568	-0.091
Sector		1.347***	1.766
Firm size		7.000***	6.178***
Firm age (log)		-0.664***	-0.259
SectorxSize			0.305
SectorxAge			-0.428
Location Denmark	0.643***	0.197***	0.162
Location Sweden	2.294***	1.137***	1.125***
Location Norway	-0.859***	1.438***	1.412***
Focus	-3.518***	-6.061***	-6.135***
n	297	297	297
Pearson Chi-Square/df	49.429	18.908	19.059

*Significance codes: p<0.01 ***, p<0.05**, p<0.1**

Control variables

The only significant effect observed among the control variables in the logistic regression models, is of ‘Location Norway’ in model 1 with the dependent variable ‘Patents’ (p<0.1). However, this significant effect disappears when the independent variables are added to the model. From this I can conclude that the other variables capture the effect that is described by ‘Location Norway’ in the first model. In the negative binomial models the control variables show multiple significant effects. Model 1, containing solely control variables, shows a significant effect for most location variables and for the firm focus. The significant effect of the location variables mostly decreases in model 2. An exception to this is model 2 with dependent variable ‘Citations’. Where ‘Location Sweden’ has a negative insignificant effect in model 1, it has a positive significant presence in model 2. The complete model only shows a significant effect when looking at the patents and citations in class Y02E10. Firms in Denmark and Norway show to contribute less to technological contribution when looking at patents in class Y02E10 (p< 0.05 resp. p<0.1). This partially clashes with the observations made with regard to citations in class Y02E10. ‘Location Norway’ shows a positive significant effect on this dependent variable (p<0.01), suggesting firms in Norway have a greater contribution to technological development than firms that do not operate in Norway. With regard to citations in class Y02E10 a positive significant effect is also observed for ‘Location Sweden’ (p<0.01). Furthermore, firm focus has a negative significant effect in negative binomial model 3 of all four dependent variables. This indicates that service and energy firms contribute less to technological development than turbine and material producers. This finding is in line with an earlier study on service firms, which found that they are less innovative than manufacturing firms (Tamura, Sheeham, Martínez, & Keorgrach, 2005). Additionally, Tamura et al. (2005) found that innovation in service firms stems more from knowledge acquisition outside the firms, such as collaborations and the purchasing of equipment. This could also be the reason the service firms contribute less to technological development, when this is measured in patents and citations.

5. Discussion

This study aimed to clarify what the technological contribution of different firm types in different development stages of a technology sector is. This study specifically focused on the offshore wind energy sector and the wave energy sector: comparable sectors in different development stages. This study shows that there is a slight difference between the contribution firm types have in comparable sectors in different development phases. Larger firms have a greater contribution in the offshore wind energy sector, a sector in the deployment phase in which a dominant design has been established. Smaller firms have a greater contribution in the wave energy sector, which in the R&D pre-dominant design phase. Firm age does not seem to affect the contribution to technological development different firm types have in different sectors. Therefore, no clear difference between the contribution startups and incumbents have on technological development can be established.

5.1. Theoretical implications

This study adds to the literature on Schumpeterian Mark I and Mark II theories by reflecting these literature strands on different technological development phases. This study confirms there is a difference in the offshore wind energy sector and wave energy sector when it comes to the contribution of firms viewed by firm size. In the offshore wind energy sector larger firms have a greater contribution to technological development than small firms. However, these sectors where chosen due to their comparable technological regime and could thus be studied as one industry. Malerba & Orsenigo (1995) combined the two Schumpeterian literature strands by stating that the type of industry sector defines what contributes most to technological development by innovating. Based on this, one would therefore expect no significant effect between the sector variable and contribution to technological development. Therefore this study’s findings do not agree with Malerba & Orsenigo (1995), on the fact that the type of sector determines whether incumbents or startups are responsible for technological development.

The expectation that startups contribute more in the early phases of a sector and incumbents later on, is also not completely supported by the outcomes of this study. In this study, one of the interactions effects, between sector and firm size, does show a significant effect on the contribution to technological developments. This can be interpreted as that large firms contribute more to technological development than small firms in the deployment phase. However, based on this study there is no effect between sector and firm age, meaning that old firms do not contribute more to technological development in the deployment phase than young firms. A possible explanation for the absence of an effect between sector and firm age is not found in existing literature. Since the combination of the firm characteristics size and age is used to distinguish startups and incumbents, no complete support for the hypotheses is found by this study.

Next, this study shows that the influence that firm size and firm age have on a firm’s contribution to technological development in different development phases is limited. When it comes to firm size, previous literature is not in accordance on whether larger of smaller firms contribute most to technological development (Macher, 2006). Henderson & Clark (1990) found radical innovation mostly comes from new entrants to the market. Chandy & Tellis (2011) also wrote about this, but in the end found that technological developments are more likely to come from incumbents, partially because they have larger R&D departments, and thus have more manpower focused on technological development. Furthermore, Van Praag & Versloot (2007) state that entrepreneurs do not put more effort per employee in R&D than larger firms. Arbussà & Coenders (2007) found in their study that larger firms carry out more R&D than smaller firms in some industries, but in others they do not. This study is mostly in line with the previously mentioned literature in finding that a firm's number of employees influences the contribution to technological development a firm has. What is also in line with previous literature, is the finding that firm age shows to have a significant effect on the number of patents and citations a firm has. Previous literature stated that older firms have the opportunity to pursue new opportunities due to their resources (Eggers & Kaplan, 2009; Hannan & Freeman, 1989). This study focused on testing the influence firm types have on contributing to technological development, while measuring these effects in two different variables. Since the tests do not show significant effects for all of the firm characteristic variables, no unambiguously effect is observed. Therefore, no concrete agreement or contrast with previous literature has been reached.

Finally, the observed influence of the control variable 'Firm focus' indicates that service and energy firms contribute less to technological development than turbine and material producers. This is not in line with previous literature. Previous literature on the knowledge creation in service firms found that appropriation through patents is common practice in science-based service firms (Robertson, Scarbrough, & Swan, 2003). A large share of the service firms in the database are science-based firms, such as computer program developers, non-law based consulting, contractors and installing firms. Based on this strand of literature it is therefore expected that there is no clear distinction between the patenting habits of producing firms and service firms. However, Leiponen & Byma (2009) found that service firms "are somewhat less likely than manufacturing firms to prefer patents" (p. 1486). Following this research means that the contribution to technological development that service firms have, might be influenced by choosing patents as a measure for that contribution.

5.2. Societal implications

The theoretical implications as well as the specific case of offshore wind and wave energy in Scandinavia lead to societal implications. Based on the theoretical implications, this study states that contribution to technological development does not seem to stem from only startups or incumbents. Technological development has an influence on economic development (Rennings, 2000). Therefore, government policy should not necessarily focus on a specific firm type to stimulate economic development. If governments wish to stimulate economic development that originates from firms, this study suggests a combination of measures to stimulate both market entry by startups and incumbents to contribute to technological development.

The database created for this study contains all the firms operational in the offshore wind and wave energy sector in Scandinavia. Based on the data, I conclude that the Norwegian energy policy leads to less firms entering the offshore wind and wave energy sectors. Interviewee 1 says that the offshore wind energy sector holds great industrial opportunity for the country (Interviewee 1, personal communication, October 10th 2017). In order to harvest the potential that the sector houses, stronger government incentives need to be created. Policy makers can stimulate the growth of the offshore wind energy sector for instance by implementing high feed-in tariffs. This will not only lead to more renewable energy but also to a growing industry and the additional employment opportunities (Zhixin et al., 2009).

The wave energy sector is currently in an earlier stage of development than the offshore wind energy sector. This shows by the smaller number of firms that are operational in this sector compared to the offshore wind energy sector, 52 firms compared to 278 firms. According to the business development expert, "wave and tidal energy will mature within the next ten years" (Interviewee 1, personal communication, October 10th 2017).

However, he adds that the technologies in the wave energy sector still need a lot of innovation and R&D “in order to make devices that can withstand the enormous forces in the sea” (Interviewee 1, personal communication, October 10th 2017). He furthermore suggests the wave energy technology developers should learn from the offshore wind, oil and gas industries, since they have gathered experience and have tackled “the challenges related to marine operations for installation, and later for maintenance” (Interviewee 1, personal communication, October 10th 2017). Interviewee 2 adds that obtaining enough (private) funding is the largest bottleneck for wave energy firms to grow into the deployment phase (Interviewee 2, personal communication, October 4th 2017). Deep sea testing is the final testing phase before a wave technology can be deployed (Falcão, 2010). Financial governmental support in the testing phase, like the former Danish Wave Energy Program provided from 1996 to 2002, would help wave technologies take-off on a larger scale. Policy makers should therefore focus on creating financial schemes if they wish to invest in this underdeveloped sector.

5.3. Limitations

This study has a number of limitations that possibly influence the results and generalisability of this study. First of all, the database contains the firms operating in two cleantech sectors in Scandinavia. The population within these sectors is used as the study’s database, which suggests a high external validity (Bryman, 2012). However, it remains unsure if all industries are comparable to the offshore wind and wave energy sectors in Scandinavia, which means the external validity remains unclear. Secondly, firm size is taken into account in the form of a categorical variable. The reason for this is that a web search was used as a way to track down the number of employees a firm has. This often leads to websites defining a firm to have ‘51-200’ employees. Count data on firm size would have let to increasing regression possibilities. Thirdly, a limitation is housed in the relevance of the patents used in the dataset. Two patent searches were done for the firms in the dataset: an overall patent search and a patent search specified on Y02E10. However, it is not guaranteed that the patents included in the patent counts are all related to the offshore wind or wave energy sectors. Due to the large number patents, it was not possible to check if each patent is relevant for this study. Therefore, solely patent counts were used without judging each patent on relevance. Fourthly, the offshore wind and the wave energy sector were compared by the sum of patents and citations they have. This houses one of this study’s methodological limitations. Since the offshore wind energy sector is in a further stage of development, firms in this sector have had more time to create patents. In order to make the two sectors more comparable, patent age can be taken into account, for instance by solely looking at the patents of a certain time period. To put this in perspective, the negative binomial models show that younger firms seem to have more citations in the Y02E10 class. Furthermore, in the period from 1980 to 2010, more than a thousand patents for wave energy technologies had been applied for, with that number increasing in recent years (Falcão, 2010). Even though this minimises the possible unfairness of the measurements used, it might still be of influence and is thus challenging the fairness of the results. Finally, the logistic regression analysis has a limitation in the cut-off point that was chosen. In order to perform the logistic regression analysis, a binary variable was created indicating whether a firm has patents or citations. In this case a firm that has one or more patents or citations is defined as ‘contributing to technological development’. However, the cut-off point between 0 patents and ≥1 patents is chosen arbitrary. The argument used in favour of this cut-off point, is that the act of producing even one patent means a firm is creating knowledge (Nonaka, 2008). However, Basberg (1987) states that patents vary in quality and argues some patents are more import with respect to contributing to technological development. One could also state that a firm that is operational in a sector is also contributing to its development, due to the fact that being operational develops the market.

5.4. Future research

Recommendations for future research can be conducted from this study. Firstly, different measurements of contribution to technological development can be added to the models in order to see if a significant effect between firm types per sector can be observed. This study defined a firm's contribution to technological development by the number of patents and citations the firm has received. This choice was made based on numerous articles and publications. However, not every firm that is involved in a sector holds patents. Other appropriation regimes were not taken into account in this study, due to the fact that other regimes, such as lead time and secrecy, are hard to measure. By solely basing the contribution firms have on technological development on patent related measurements, the results of this study could be skewed (Lanjouw, Pakes, & Putnam, 1998). Other measurements of innovative activity, such as firm revenue and the MWs of the projects firms are involved with, were explored in the data collection phase (Z. J. Acs & Audretsch, 1988). Not enough information on these factors is available, which is why these parameters were not included in the analyses. Future research should include other measurements with regard to contribution to technological development in order to further determine the coherence between firm contribution to technological development by different firm types and technology development phases.

Furthermore, firms operational in both the offshore wind and the wave energy sector were removed from the database in order to increase analysis possibilities. The firms that are removed are mostly large, old firms. One exception to this, is Floating Power Plant, a small firm that develops an offshore foundation that houses both a wind turbine and a wave turbine (Interviewee 2, personal communication, October 4th 2017). This means large firms operative in the wave energy sector as well as a small firm in the offshore wind energy sector are removed from the dataset. Most firms operative in the wave energy sector are small firms with a limited amount of patents, whereas most firms in the offshore wind energy sector are large firms with on average more patents than wave energy firms. Removing the firms that are operative in both thus has the effect that the 'misfits' are removed, which influences the results. Future research should conduct tests containing the firms both operative in the offshore wind energy and wave energy sector to see if the results stay comparable to this study's results.

6. References

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Appendix A: List of the websites used in creating the dataset

National databases	
Windcluster Norway	https://windcluster.no/members/
NORWEA	http://www.norwea.no/om-norwea/medlemmer.aspx
Swedish Wind Energy Database	http://www.windindustry.se/index.php/english/search
Svensk Vindenergi	http://svenskvindenergi.org/
Ocean Energy Sweden	https://oceanenergy-sweden.se/
Offshoreenergy.dk	https://www.offshoreenergy.dk/medlemmer
International databases	
Ocean Energy Europe	https://www.oceanenergy-europe.eu/
Nordic Energy Research	http://www.nordicenergy.org/
OffshoreVäst	http://offshorevast.com/categorized-members-list/
The European Marine Energy Centre	http://www.emec.org.uk/marine-energy/tidal-developers/
4C Offshore	http://www.4coffshore.com/
Ocean Energy Systems	https://www.ocean-energy-systems.org/
Tidal Energy Today	http://tidalenergytoday.com/
North Sea Offshore Service Group	http://www.nsosg.dk/en/members/
NordicGreen - Cleantech Startups	http://www.nordicgreen.net/

Appendix B: Codes used in PATSTAT

Obtaining psn_id and psn_name

```
select distinct psn_id, psn_name from tls206_person
where psn_name like 'firm name %'
```

Obtaining patents

```
alter table Branger alter column psn_id int

select distinct t4.name, t1.docdb_family_id, t1.nb_citing_docdb_fam
into firm_family
from patstat2017a.dbo.tls201_appln as t1
inner join patstat2017a.dbo.tls207_pers_appln as t2
on t1.appln_id = t2.appln_id
inner join patstat2017a.dbo.tls206_person as t3
on t2.person_id = t3.person_id
inner join Branger as t4
on t3.psn_id = t4.psn_id

select docdb_family_id, min(appln_filing_year) as year
into docdb_year
from patstat2017a.dbo.tls201_appln
where docdb_family_id in (select docdb_family_id from firm_family)
group by docdb_family_id

select name, year, count(t1.docdb_family_id) as num, sum(nb_citing_docdb_fam) as num_cit
into firm_year
from firm_family as t1
inner join docdb_year as t2
on t1.docdb_family_id = t2.docdb_family_id
group by name, year
```

Obtaining patents in class Y02E10

```
select distinct t4.name, t1.docdb_family_id, t1.nb_citing_docdb_fam
into firm_family_Y02
from patstat2017a.dbo.tls201_appln as t1
inner join patstat2017a.dbo.tls207_pers_appln as t2
on t1.appln_id = t2.appln_id
inner join patstat2017a.dbo.tls206_person as t3
on t2.person_id = t3.person_id
inner join Branger as t4
on t3.psn_id = t4.psn_id
inner join patstat2017a.dbo.tls224_appln_cpc as t5
on t1.appln_id = t5.appln_id
where t5.cpc_class_symbol like 'Y02E  10%'

select docdb_family_id, min(appln_filing_year) as year
into docdb_year_Y02
from patstat2017a.dbo.tls201_appln
where docdb_family_id in (select docdb_family_id from firm_family_Y02)
group by docdb_family_id

select name, year, count(t1.docdb_family_id) as num, sum(nb_citing_docdb_fam) as num_cit
into firm_year_Y02
from firm_family_Y02 as t1
inner join docdb_year_Y02 as t2
on t1.docdb_family_id = t2.docdb_family_id
group by name, year
```

Appendix C: Interview transcriptions

Two expert interviews were conducted: one via email and one via Skype.

Interview 1: Expert on business development. Management experience in oil and gas supplier industry and offshore wind.

Q: When we first were in contact, you told me that several of GCE Subsea's member companies are diversifying into related markets. Can you tell me a bit more about this trend, e.g. when did this trend start, are it more the bigger firms or (also) smaller firms that are diversifying?

A: A few companies, like VTT Maritime and Norwind took part in the first test park Alpha Ventus as far back as 2008. Later more companies, like Seaproof Solutions and Owec Tower and several of the companies dealing with offshore installation and cable laying (marine operations) (E.g. Nexans and Reach Subsea) entered this market 5-7 years ago. However I think that it was first after the dramatic downturn in oil prices in the fall of 2014 that many more Oil&Gas companies started looking at Offshore Wind as an alternative/complimentary market. First the smaller companies gained interest, while the bigger companies took a waiting stance (Stay true to core business!). But today we see that also the bigger companies are moving into alternative ocean industries like offshore wind, but not only – many are at the same time pursuing opportunities in aquaculture.

Q: Are firms creating spin-off firms to diversify or do they implement the diversifying in their existing firm structure?

A: Norwind was a spin-off from Grieg Logistics, however I am not aware of many spin-offs. I think most companies diversified in their existing firm structure.

Q: One of the measures I use in my research, are the number of patents linked to a firm and the citations these patents have. Do you have any insights on the use of patents in the offshore wind and wave energy sectors? For instance in GCE Subsea's member firms?

A: I do not have much insight in this.

Q: Looking at the position you have within GCE Subsea, what is your view on business development in offshore wind energy in the Nordics?

A: The offshore wind industry has needed a long time to mature, especially in gaining enough experience in tackling all the challenges related to marine operations for installation, and later for maintenance. This they have learned the hard way, with many failures and major cost overruns in the early years. Much of this could probably have been avoided if they had taken more lessons from the offshore Oil&Gas industry. Contract models are still an issue, with some operators preferring an EPC approach, and others preferring a multicontract strategy. Offshore wind has an extreme price focus at CAPEX time, with less emphasis on lifecycle cost, which they may come to regret later on in the lifecycle of the wind parks.

Q: When we were in contact, you told me you are not very much up to speed when it comes to wave energy. However, I am interested to know your view on business development in wave energy in the Nordics?

A:There are quite a number of initiatives, but very few become operational, and then only as pilot projects, so far. The cost for full scale proof of concept is typically very high for wave energy devices, and this is a stage that many developers never make it through (Often called the 'valley of death') However there are also some promising examples:
http://www.havkraft.no/ http://www.hydrowave.no/ https://www.waves4power.com/ http://www.boltwavepower.com/

Q: GCE Subsea is based on Norway. However, my study focuses also on Sweden and Denmark. In your view, is there a difference in the development of renewables such as offshore wind and wave energy between these countries? For instance, is there a difference in governmental support?

A: Very much so. Denmark has aggressive incentives (High feed-in tariffs) and this has led to very expansive offshore wind developments. Sweden and Norway have much weaker financial incentive schemes (Electric certificates), and Norway, even more than Sweden, has the additional disadvantage that we already have almost 100% green electricity due to our hydro power. Thus there is no pressure for Norway to reduce dependency from fossil fuels, as we have no such dependency.

Q: How do you see the future when it comes to business development in the offshore wind and wave energy sectors?

A: For offshore wind it looks very promising in general, but it is a great pity that the Norwegian Government has not put in place stronger incentives, because it would be a large industrial opportunity for our country, as well as representing a future large energy export source, since we have so large ocean space, larger than most companies in the world. Lately the price of offshore wind has come down significantly and is approaching grid parity – so I think we will see offshore wind projects in Norway as well in the not too distant future. I also believe that wave and tidal energy will mature within the next ten years, but it still needs a lot of innovation and research in order to make devices that can withstand the enormous forces in the sea and be able to operate under water without major maintenance for decades, like subsea equipment in the Oil&Gas industry.
If you have any questions for me with regard to this, please let me know. If necessary I could elaborate on the context of these questions via email or telephone.

Interview 2: Expert on wave energy.

Q: As I understand it, you are associate professor at the wave energy research group at Aalborg University. Can you tell me briefly about the wave energy research your department does?

A: We are a part of the Civil Engineering Department. Our approach wave energy field has been from the water side, were others approach it more from the energy electrical side. We started the work in this area because we have wave tanks in our facilities that we traditionally used for harbour structures or offshore structures and so on. But then in the late 90s in Denmark there was an increased interest in utilizing wave energy and there was a specific national support program that was put in place in the late 90s [the Danish Wave Energy Program (DWEP) red. (Kofoed, Frigaard, & Kramer, 2006)]. Through that program is was possible for developers to get a small amount of money to do some initial proof of concept tests. In principle they could do that in different places, but in the end we did quite a lot of these tests in the late 90s and early 2000s. And that program was structured in such a way that it was provoking bottom up type of development, so it was quite easy to get some funds to do those early stage proof of concepts testing. Then there was a staged development, so for the next level, after you have done the prove of concept, you have got some interesting results, then you could get some funding for doing more detailed studies and more detailed laboratory investigations in designs and then further on to doing smaller scale but deep sea testing. And there was also a fourth stage with large scale deep sea testing as well. Within that program there was 20, maybe 25 projects or so in the first stage, maybe a handful second stage and then there was one project that made it to the third stage which was testing in a benign side, but in real sea. That was the Wave Dragon project. That program was stopped when there was a change of government and they decided not to continue the program. So then there was a bit of a stand-by situation for some time. There were some more general programs that supported energy R&D that took on to some extent. There was a number of these projects that had been brought up in the regional program that also continued the work. So there has been a few hands full of projects or concepts under development in Denmark during the years. Wave Dragon was probably the first bigger project and then there was Wave Star, which you might have seen of know about.

Interviewer: Both the Wave Dragon and the Wave Star I came across in my research.

A: Wave Star was also sort of kicked-off during the original program, but they were a little bit later. They also went to test at the same location as where Wave Dragon was testing in the benign side. They went also a step further, to testing larger scale on the West coast of Denmark in Nissum Bredning. They were able to attract also some private funding to a larger extent and went quite far, and they also received a grant for the EU to build a project in Belgium. I do not know if you have heard about that. But they were not able to raise the private funding, so ultimately they actually have more or less closed down their operations at the moment now. They have not completely stopped, but it is back in the hands of the original inventors of the system and basically without any significant funding at the moment.

We as a research group have been always doing our activities in tight connection with developments. That has been the majority of our activities at least. So we do not develop our own technology and such, but we are participating in a number of these projects and assist on modelling, both empirical and experimental. And also participate in real sea test campaigns and so on. But besides that we are also participating, and initiating sometimes also, more generic research, both EU funded projects. FP7 or Horizon2020 and so on. We have also had one large and a few medium sized nationally funded projects, which are more generic in character. Now we have a group of roughly 10-15 people working in this field. The projects that we are mostly engaged with at the moment, we are mainly working with two developments at the moment. One is the floating power plant, which is a combined floating wind and wave energy device.

Interviewer: I ran across that one as well.

A: Ah ok. So we have a close cooperation with them. Both in terms of.. they have been using our lab and we share an employee. And we have a common PhD student as well. And participate in various technology specific projects, for instance one on hydraulic power [?] system that they are using.

Q: What would you say is the current state of the wave energy sector? Because you have said that a lot of research projects are still in a testing phase, or they get to the third stage which is testing in water. What is the current state of the sector? Is it still focusing on R&D mostly or is it already getting linked to more?

A: Well it is in the stage where you can say, most projects are getting to the point where they are ready to go to sea, either in small scale or also larger scale. But they have a lot of challenges in taking the next step because of the costs involved and the need for funding. When you get to that stage, the public funding percentages are getting lower, so the need for private bench marking is getting higher and that is difficult to get. Not only in Denmark I think, that is also the case in other places. A lot of countries, both in Europe and elsewhere, I would say that the political climate at the moment is more favourable. I think that is the situation. I think technology wise there has been quite a lot of development and we do also see quite advanced technologies, and also some that seem to have very good possibilities for commercialisation, but they are typically smaller which have difficulties in getting to the next step and attract the necessary funding.

Q: Yeah, so when you compare it to, for instance, offshore wind energy they are still in an earlier phase because they need more funding and it is difficult to get that funding?

A: Yeah yeah, there is a huge gap. And there is also the big difference that the technology has not converged, so there is still quite different technologies that are being proposed. And I think that is also a part of the reason for the difficulty for attracting the private funding, because of course there is a risk that if you invest in a certain technology, then what if that is not ultimately going to be the dominant design. So yeah. But we are also involved in a project at the moment that is called Weptos, which we just put out a test prototype for in real sea but also it is still at small scale, which really has very promising results. So we hope that we can help them in documenting and attracting attention and funding for going further.

Q: Ok. So I created a database with firms for this thesis, with all the firms I could find that are operative in the Nordic countries in the wave energy sector and offshore wind. Some firms are already starting to commercialise, or at least patent their technologies. Do you think it are more the smaller and new firms that will get patents for the technologies and thus citations? Or do you think larger firms will also hop on at some point?

A: The hope is that there will be bigger companies that will get involved, because I think also one of the necessary next steps is also to, let's say, take a more professional approach to the further development and so on. Because it is very difficult for a very small organisation to be trustworthy, you know, for somebody to go in and put a large amount of money in. And typically if you are going to large scale offshore deployment, it is going to be a multi-million operation, and you need an organisation to support that. And then there is a little bit the hen and the egg, what is going to come first.

Q: But do you expect that the larger firms will already be getting involved soon or will it last for a couple of years where they are still holding off because they are not sure?

A: It is very, very hard to predict, I think. There have been examples of larger companies going into the technology development. But there has also been, let's say, some frightening examples of not getting the outcome of the engagement, which is maybe scaring off some of the bigger companies. The threshold that you need to pass is probably a bit higher now than it was maybe five or ten years ago.

Q: Ok. So as I said I am look at the patents and the citations of the patents the firms have. What do you think of this method as an additional method in my study for the wave energy? Is it useful, or is it maybe not useful yet because wave energy is in an earlier stage?

A: I do not have much experience with how patents are actually used. I am not sure if you will see a lot of use of the patents. Or what is your experience there? Can you see that there is active use of the patents, other than the ones who have taken the patent?

Interviewer: I created the database and have information on how many patents each firm has and how many citations, and what you do see is that of course they have less patents than the average offshore wind firm because you have big firms like Vestas in that sector and you do not have those yet in wave energy. But you see that the patents they do have are already getting cited by other patents, because it is an industry that is evolving. The patents that they do have are pretty new of course, they are applied for in the last couple of years, but they already have some citations, because other developers use these patents as reference for their technologies. So that is interesting to see.

A: I think we are often maybe a little bit reluctant to recommend to put a lot of effort into patents, at least in the early beginnings, because it is quite costly and at the end of the day it seems a little bit like you can almost get a patent on anything with just very small mutations. But on the other hand of course, if you want to get bigger players involved at some point, then it is [?] of course a very important element and something they look at. So it is really a balance, but it is economically a heavy load on many of these small developments, just to get the patents.

Q: Yeah. And lastly I focus my study not only on Denmark, but also on Norway and Sweden. Do you see a difference in wave energy development among these countries?

A: I think there is quite a big difference. There is also difference on what time, how things are being developed in the different countries. But I think in Denmark we have had a more broad bottoms up development compared to most places. Whereas in Sweden there has until a couple of years ago been a very focused technology specific support from the department side. So they have been focusing almost all of their funding towards one specific technology that is coming out of Uppsala University, which I think has not been the right approach, but that is an opinion. I think in Norway it is quite scattered. I mean in the early days, in the 70s and 80s, there was quite a lot going on compared to what was going on on a global scale. Primarily coming out of universities. But then they have not had a lot of focus on the sector during the later years. I do not think they have had coordinated programs and so on. So it has been a little bit more sporadic. We have actually had a few Norwegian developers coming to us to do collaboration and projects.

Q: These were all the questions from my end. Do you have any questions for me, or anything else to add?

A: Not immediately. If you write a report on it, I would be interested to see that.

Appendix D: Bar charts of firm focus and country of operation

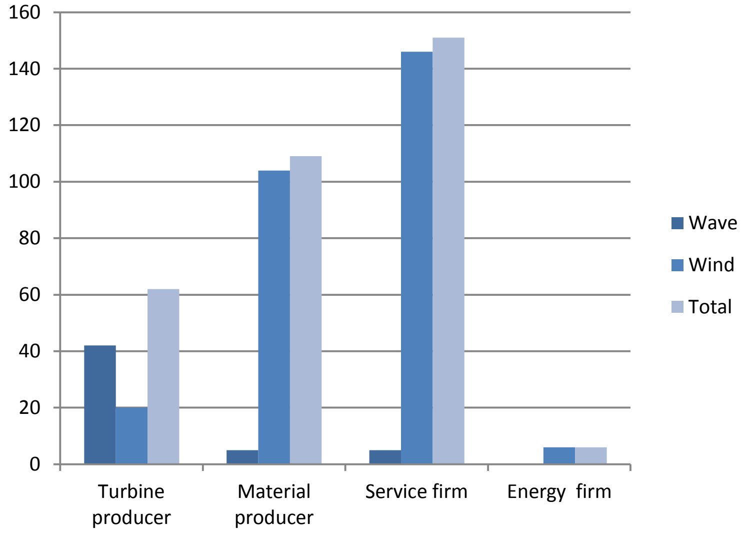

Figure 6: Bar charts of 'Firm focus'

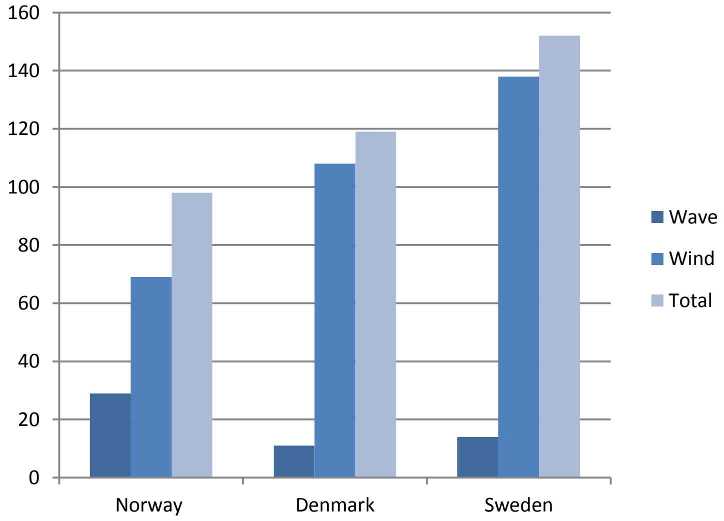

Figure 7: Bar charts of country of operation

Appendix E: Additional bar charts

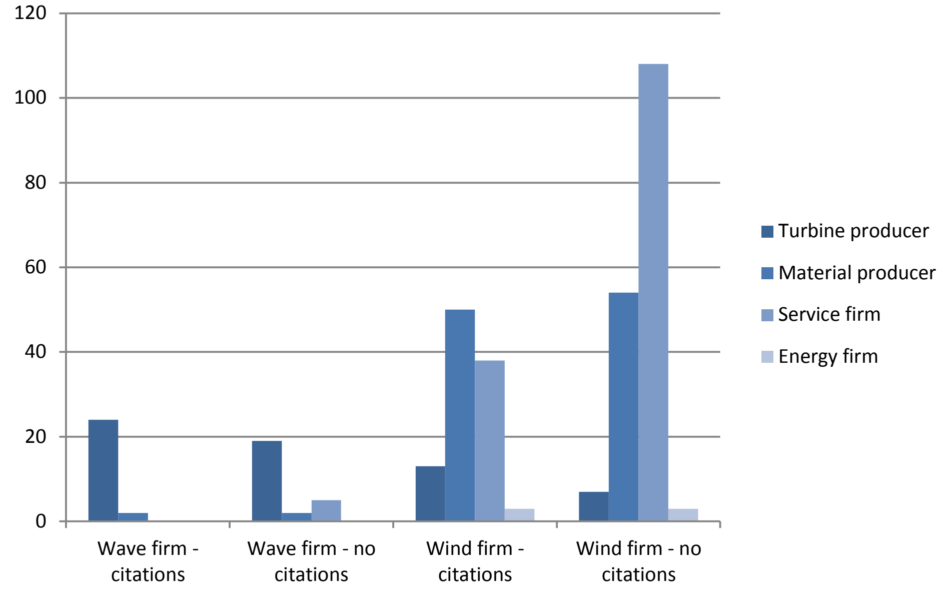

Figure 8: Bar chart of 'Citations' per sector and firm focus

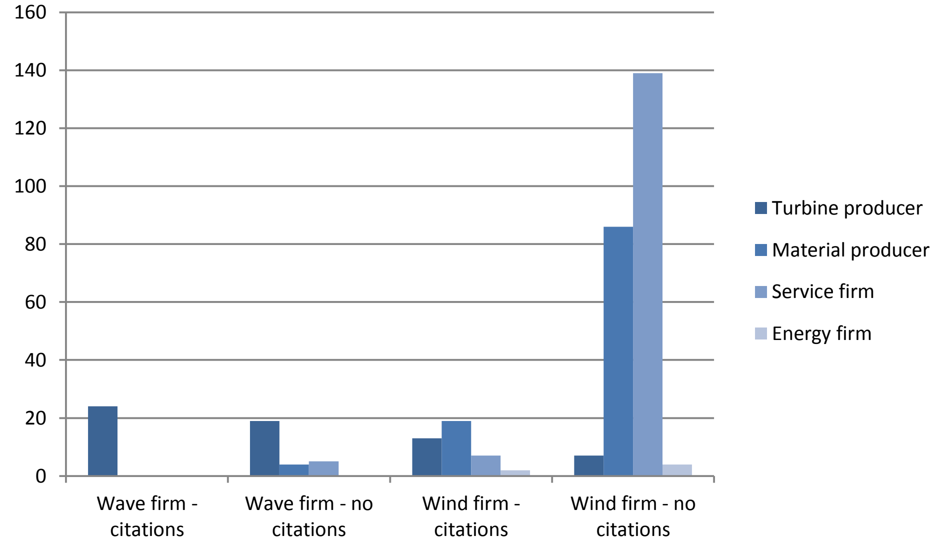

Figure 9: Bar chart of 'Citations Y02E10' per sector and firm focus

Appendix F: Independent variables histograms

Independent variables

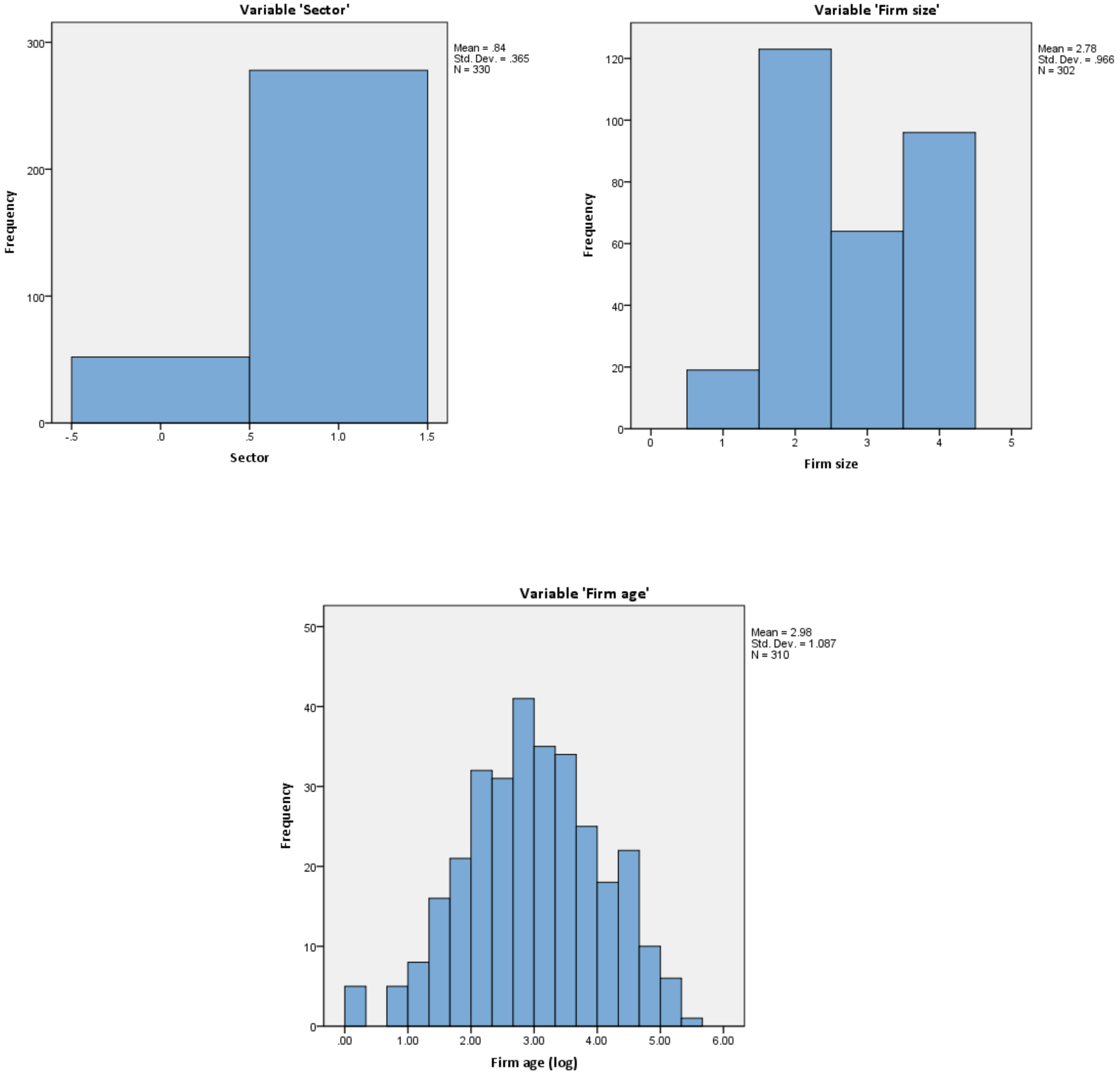

Figure 10, 11 and 12: Histograms of the independent variables

Appendix G: VIF scores

	Dependent variable			
Variable	**Patents**	**Citations**	**Patents Y02E10**	**Citations Y02E10**
Number of patents		2.671	7.740	7.790
Number of citations	3.987		7.467	7.578
Number of Y02 patents	91.148	58.925		1.202
Number of Y02 citations	98.894	64.459	1.295	
Sector	1.457	1.452	1.447	1.449
Firm size	1.466	1.462	1.413	1.418
Firm age (log)	1.358	1.358	1.342	1.341
Location Denmark	2.139	2.146	2.141	2.138
Location Sweden	2.148	2.147	2.148	2.147
Location Norway	1.161	1.608	1.596	1.595
Focus	1.520	1.478	1.427	1.448