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Firms’ contribution to the green transition of the Danish national system of innovation – changes in technological specialisation, skills and innovation

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Abstract
In this chapter we analyse the green transition of the Danish national system of innovation with a focus on green patents, green skills and green innovations. We find that green patenting, green skills and green innovations are inter-connected in the green transition. The Danish technological profile has shown an increase in green patents, and green innovation now happens in all parts of Denmark. We find that the education and training system must be adapted if Danish firms are to lead in the green transition. The findings point to challenges, requirements and opportunities created by the transition to a greener economy.

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12.1 Introduction

The Danish system of innovation is facing the challenge of environmental and climate change, which requires a green transition. The green transition entails that both production processes, as well as final goods, evolve towards leaving smaller environmental footprints. This ongoing process has been supported by policies for many years in Denmark, but there is a need for a higher pace in the transition in the coming years. While some green industries like wind turbines and recycling tend to attract the most attention from policymakers, it is important to acknowledge that the green transition is not confined to specific predefined green sectors. It also occurs in many different sectors, including those that are not usually considered to be green (Shapira et al. 2014). In addition, sectors that produce green goods that allow the users to become green might not be green themselves. Therefore, it is necessary to apply a broader perspective of the green transition in analysing the greening of the Danish innovation system.

The public sector, as one of the main actors of the Danish innovation system, plays a significant role in the green transition by controlling the government policy, public investments and public demand. Historically, the Danish environment and energy policy has been critical in promoting certain technologies and industries in the economy (see e.g., Rüdiger 2011). While the role of the public sector is mainly placed on setting the right conditions and environment for making the transition and guiding the direction of the change, the private production system, which constitutes another part of the national innovation system, is the main driving force for realising the transition in the economy. As the Swedish case in the study by Johnson and Jacobsson (2003) has shown, a supportive R&D policy may not be enough for the development of new green industries without active participation of firms in the private sector. Specifically, the production system plays a vital role in the creation and utilisation of knowledge relevant to the green transition. Therefore, this chapter directs focus on Danish firms and how they contribute to the green transition in terms of the development of green technologies, the introduction of environmental innovations, and the demand for skills. While our focus in this chapter lies on the green transition at the national level, we acknowledge that the national innovation system is often influenced by the dynamics at the regional (intra-national) and global level. We will also include relevant regional and global dynamics in relation to the transition of the Danish national innovation system.

Building on the insights gained from the Geography of Nordic Sustainable Transitions (GONST) project which focuses on green transitions in Denmark, Norway, Sweden and Finland, we conduct analyses on technological specialisation, green skills and green innovations of the Danish innovation system. We show that the Danish technological profile in terms of patents has changed considerably during the last 20 years with the increasing share of green patents. This trend can partly be explained by the success of the Danish wind turbine industry, but we see that other patent-intensive industries have also been producing green patents. The analysis of innovations with environmental benefits shows that green innovation happens all over Denmark. It shows which firms undertake green innovation and what requirements this creates for the workforce of such firms, either because these skills are necessary for green innovation, or because they are in demand as a consequence of green innovation. We find that the education and training system in particular, must be adapted if Danish firms are to lead and not just follow in the green transition. Our findings shed light on the challenges and requirements as well as opportunities for the Danish national system of innovation created by the need for making a smooth transition to the greener economy.

The chapter proceeds as follows. In Section 12.2 we discuss previous research on the role of national systems of innovation in shaping the green transition of economies with special focus on the change in technologies, skills and innovations of firms. In Section 12.3, we describe the evolution of patenting towards more green patents in Denmark, showing the technological specialisation of Danish firms in the national system of innovation. In Section 12.4, we present econometric evidence that firms with green innovations often rely on green human capital inputs and create green jobs. Section 12.5 sums up and concludes.

12.2 Green innovations, skills and technologies in the national system of innovation

National systems of innovation can be defined as a narrow concept that focuses on science-based learning and firms' science–technology–innovation (STI) activities, or as a broader concept that also includes doing–using–interacting (DUI) learning in the national economy (Chaminade et al. 2018). The broader definition involves an understanding that knowledge is the most important resource in an economy and that learning is a critical process in creating, diffusing and utilising the knowledge (Chaminade et al. 2018). This definition entails that innovation is an interactive process that involves collaboration between users and producers (Lundvall 2016). Chaminade et al. (2018) argue that the narrow view tends to focus on R&D and radical innovation, while the broader view includes both radical innovation and incremental innovations as well as diffusion of innovations.

We believe that understanding the green transition with a national innovation systems approach entails applying a broader view of the system. The green transition of national innovation systems is not just a question of developing new technologies. Green transition requires a new direction and goal for innovation and learning in the system towards leaving smaller environmental footprints (Lundvall 2016; Schlaile et al. 2017; Fagerberg 2018). Chaminade et al. (2018) argue that national governments play an important role in both enabling and supporting the national innovation systems to generate green innovations and green technologies as well as creating new partnerships and shaping new visions in an emerging phase of a green transition. In later phases, governments become important in providing resources, setting framework conditions and devising policies for the creation of the markets, public procurement and providing incentives for adoption and diffusion of innovations (Chaminade et al. 2018). Similarly, Lundvall (2016) suggests that 'very ambitious combinations of education, life-long learning and labour market policies will be required in order to transform green innovations into wide production and use' (p. 388). However, from the system perspective, the government only constitutes one part of the national innovation system. In order to make the transition happen, the undertakings of the private sector are crucial (Johnson and Jacobsson 2003). Firms in the private sector are often the driving force behind the creation, utilisation and diffusion of knowledge required for making changes towards a greener economy. Therefore, we direct our attention to the commitment of firms in the process of green transition, in terms of the technological transformation, the introduction of green innovations, the demand for green skills and the creation of green jobs.

Seen from the broad innovation system perspective, firms' learning in the process of green transition will involve both DUI and STI modes of learning. In the previous literature, the analyses on the DUI mode of learning have been done through studying innovation processes and skills. In contrast, the analyses on the STI mode of learning focused primarily on R&D and patents activities. Patents represent codified knowledge regarding specific inventions, which may or may not lead to innovation. They contain technological knowledge that could be essential for certain innovations, but analysis on them would only capture limited dynamics of green transition driven by innovation. Our understanding of innovation goes beyond the generation of new technological knowledge. Innovation involves learning in an interactive process from idea to implementation. In addition, innovation does not need to be new to the world. Innovation can also be new to the market, and new to the firm. Thus, it also includes an element of diffusion of knowledge. Knowing how knowledge diffuses through the learning and skills of various actors in the system, including a firm's suppliers, customers and employees, is critical in understanding the green transition of the national innovation system. While we incorporate both the STI and DUI modes of learning in studying the firms in the Danish national innovation system, we do acknowledge that this chapter focuses on specific efforts of firms by focusing on their technologies, skills and innovations.

Greening an economy requires either utilisation of existing knowledge in a novel way or creation of new knowledge to mitigate negative environmental impacts. Accordingly, firms often need to develop new knowledge and change their technological profile in the process of introducing green innovations.[1] Recent studies point towards the important role of firms' capabilities in generating green innovation (Kesidou and Demirel 2012; Ketata et al. 2015). Developing green technologies and innovations is a more complex task than developing more conventional technologies and innovations, since firms need to include the environmental impact of their technologies and innovations in the development process (Hall and Vredenburg 2003). Therefore, they often need to draw on several different knowledge bases, which increases complexity (Barbieri et al. 2020). As a result, firms introducing green innovations often invest in R&D, have a higher share of highly educated employees and invest in the training of employees compared to other innovative firms (e.g., Horbach 2008; Cainelli et al. 2015). Besides, firms that introduce green innovation are often more open in their innovation process and collaborate more frequently with external partners than other innovative firms (Horbach 2008; de Marchi 2012; Christensen et al. 2019). Thus, for firms, the green transition means a need for new knowledge in the production process both in terms of the skills of the workforce and the codified knowledge of technologies.

Investments in R&D, patents and employment of highly skilled employees are interlinked. Firms that have high R&D spending often patent to protect their intellectual property and employ many highly skilled employees. Furthermore, firms with high internal spending on R&D typically spend most of their money on wages rather than equipment, which is associated with a relatively high share of high skilled workers in these companies. Employees are key contributors in the innovation process of firms since knowledge as the main input to innovation resides in employees, and learning is also done by employees (Grant 1996). Not only do the employees create internal knowledge vital for innovation, but they also determine the firms' absorptive capacity, i.e., the ability to exploit external knowledge (Cohen and Levinthal 1990).

Recently there has been a line of research focusing on green skills and green jobs.[2] For example, Consoli et al. (2016) find that green occupations in the US often have a higher level of human capital and depend on specific cognitive and interpersonal skills compared to non-green jobs. The study also reports that jobs that are becoming greener require a higher level of formal education, increased on-the-job training and more extended work experience (Consoli et al. 2016). The authors consider 111 out of 905 occupations as green and estimate that 9–11% of all US jobs require green skills.

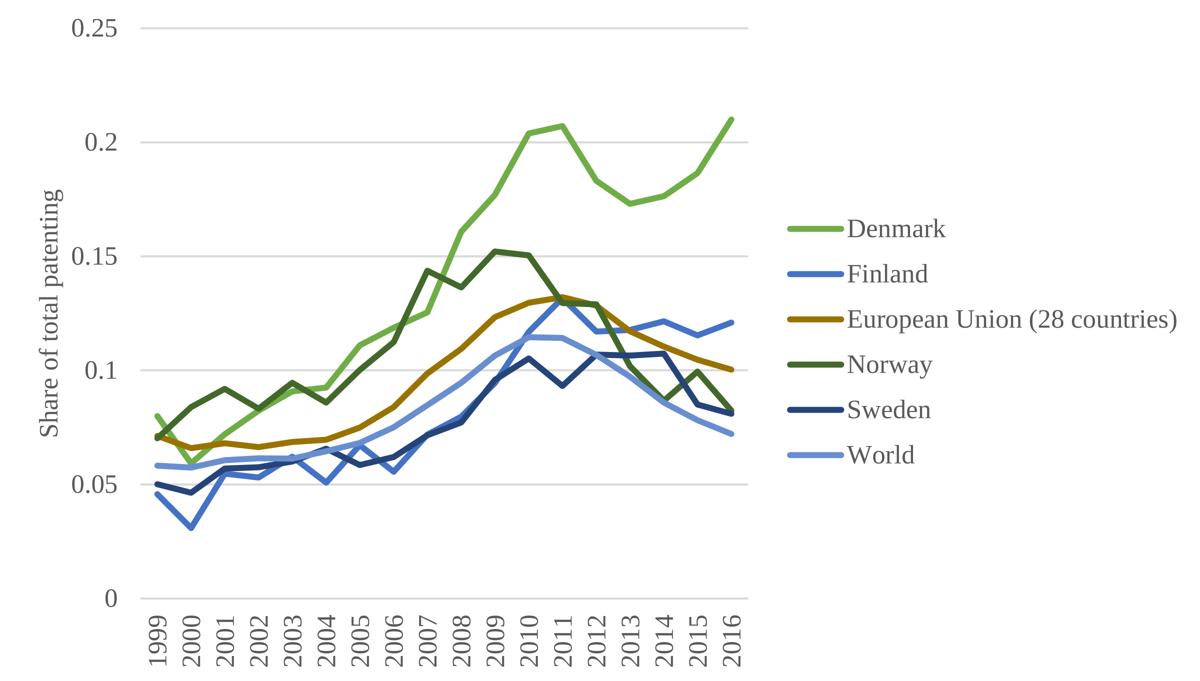
In another study, Østergaard et al. (2019) analyse the extent of green skills based on occupation, education and activity in the economies of the Nordic countries and find a significantly lower level of green skills in these countries compared to the US. The discrepancy in the level of green skills in the two studies may be due to the difficulties in quantifying green skills. Skills depend on several factors such as formal education, work experience and on-the-job training. Nelson and Sidney (1982) define a skill as 'a capability for a smooth sequence of coordinated behaviour that is ordinarily effective relative to its objectives, given the context in which it normally occurs' (Nelson and Winter 1982, p. 73). Thus, skills depend on the match between employees, knowledge and the task content of their work (Autor et al. 2003). Therefore, it might be difficult to identify the extent of green skills, since the match between these factors can change in the process of the green transition. 'Non-green' skills in engineering, for example, might be redirected towards new objectives related to enhancing sustainability. Existing evidence suggests that the green skills might be important for firms engaging in environmental activities (Østergaard et al. 2019), but we need to know more about the changing demand for skills in the process of green transition. That is, if the green transition of the economy leads to a change in firms' demand for particular skills.

12.3 Changes in the technological landscape of Danish firms

The evolution of the technological landscape is illustrated based on patenting activities in Denmark. For this purpose, we utilise patent data from two different sources. The first source is OECD statistics that provide aggregated data on patent applications under the Patent Cooperation Treaty (PCT)[3] filed at the European Patent Office (EPO) by application year and the inventor's country of residence. The OECD identifies patents in selected environment-related technologies (ENV-TECH), which are further divided into sub-categories (OECD 2009b; Haščič and Migotto 2015). We use this data to show the evolution of the technological landscape in Denmark, focusing on green patents. In addition, we use patent data collected in the GONST project from PATSTAT (2018b version) based on the EPO y-tags (see Tanner et al. 2019).[4] These data, which are not limited to PCT applications, are utilised to analyse firm-level effort in the green transition. The Danish green patents are identified as green patents (y-tag) that have both inventors and applicants located in Denmark. As mentioned, patents as indicators only capture one side of green transition and therefore the results presented here should be understood in combination with the analyses on other indicators presented later in this chapter.

Figure 12.1 presents the evolution in the share of green patents (ENV-TECH) of total patenting in the Nordic countries, EU28, OECD and the world from 1999 to 2016. The green patents are allocated to the country of the inventor(s). In general, there has been an increase in the share of green patents in the world during this time period. Denmark shows a particularly high share of green patents compared to other countries. The share has increased from 6% to 21% over 18 years. During the period, the number of patent applications by inventors in Denmark increased by almost 70% while the number of green patents more than quadrupled. Figure 12.1 clearly shows the ongoing process of green transition in the Danish innovation system. Denmark is specialised in green patents, i.e., it has a higher share of green patents out of total national patents compared to the average share for the world.

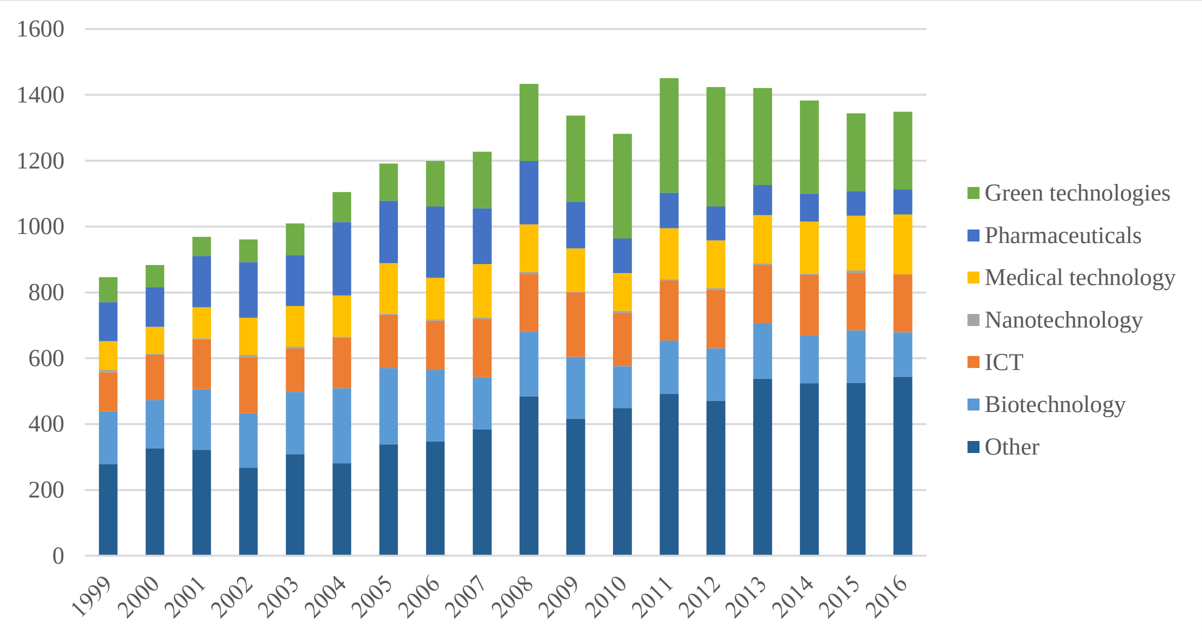
Figure 12.1: Evolution in the share of green patents of total patenting



Source: Patent applications in green patents defined as “selected environment-related technologies” (ENV-TECH) filed under the PCT. Inventor(s)'s country(ies) of residence. OECD.stats.

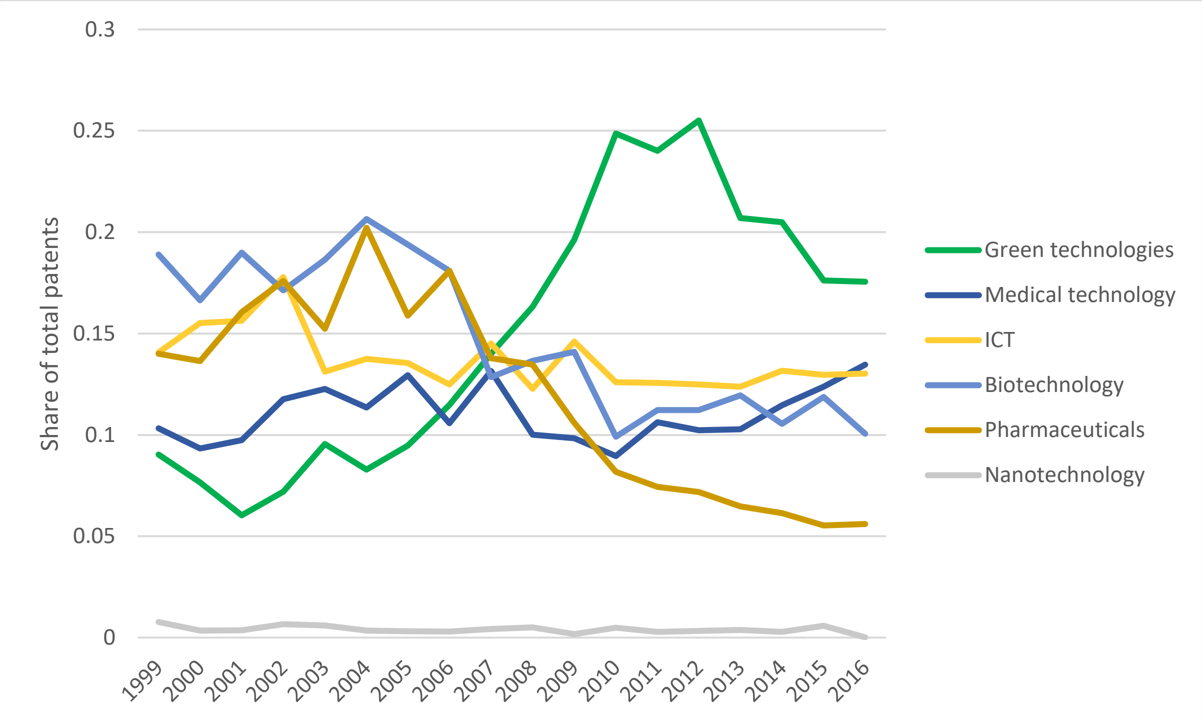
To better understand the technological transformation in Denmark, we visualise the development of green patents in comparison with the development of other technological fields in Danish patents. Figures 12.2 and 12.3 show the same pattern as Figure 12.1: the number and share of green patents by inventors located in Denmark has significantly increased. Other than green patents, the broad medical sector takes up a quite large share of total Danish patenting. The combined share of patents in pharmaceutical, biotechnology and medical technology had accounted for more than 30% of all patents in their highest peak. This is not surprising as the Danish medical sector has for many years shown a particularly strong presence in the Danish innovation system in terms of export, R&D spending and patenting (Møller and Pade 1988; Andersen et al. 2017).[5] However, since 2007, the share of green patents exceeds the share of all other technology fields, including pharmaceuticals, indicating that the technological profile of the Danish economy has become greener in recent years. For most countries the absolute yearly number of green patents applications peak in 2011 and then decline slowly, while the total number of patent application continue to grow. There is no apparent explanation for this decline, but a recent OECD report simply calls for new policies to support development of green technologies (OECD 2019).

Figure 12.2: Evolution in the number of green patents in Denmark 1999-2016



Source: Patent applications filed under the PCT. Inventor(s)'s country(ies) of residence. OECD.stats

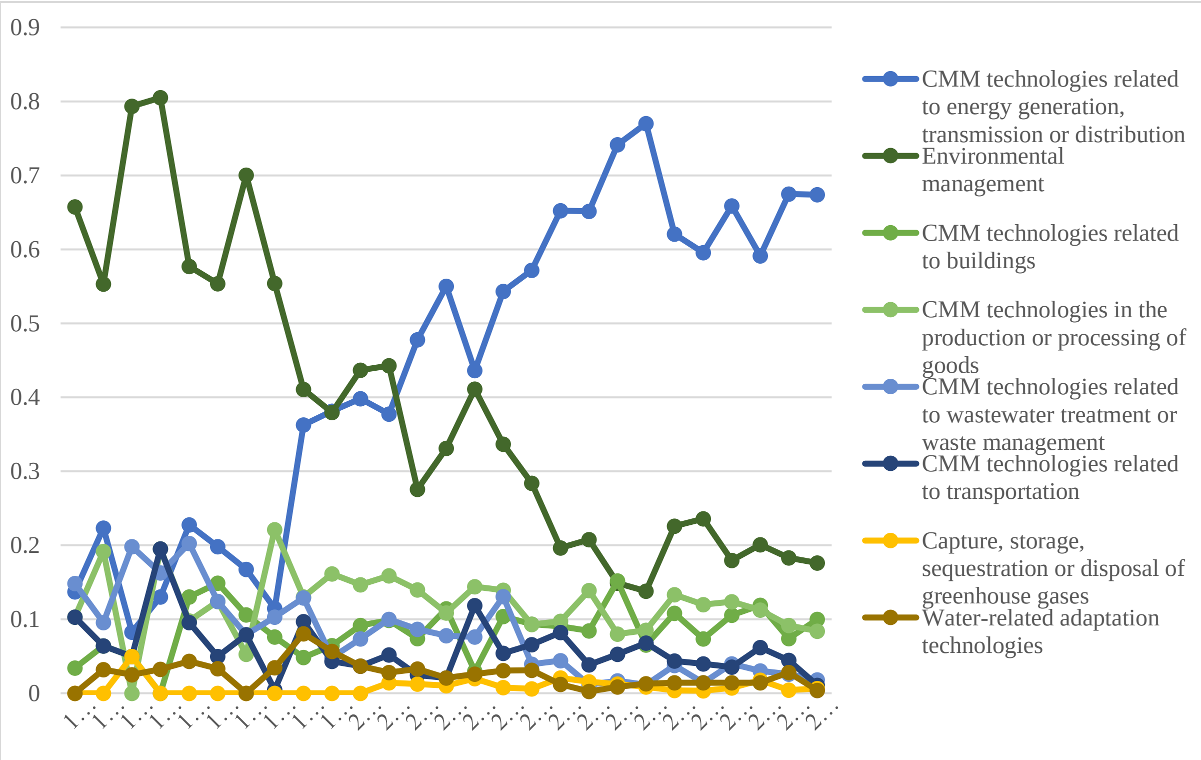
Figure 12.3: Evolution in the share of green patents in Denmark 1999-2016



Source: Patent applications filed under the PCT. Inventor(s)'s country(ies) of residence. OECD.stats

Figure 12.4 shows the green patents distributed across eight subgroups. During the last two decades, most green patents have been generated within climate-mitigating technologies related to energy generation, transmission or distribution, while the share of environmental management patents has declined. In this period the number of green patents has increased by more than a factor of nine, while energy related patents have increased by a factor of 46. Looking into the subcategories of the climate mitigating technologies, Tanner et al. (2019) find that Denmark has a strong specialisation within climate-mitigating technologies related to energy, and that there is also a specialisation in technologies related to production or processing of goods. Since the 1970s energy technology has played an important role in the green transition of the Danish economy and the area has been targeted continuously by different innovation-supporting policies (Borup et al. 2009).

Figure 12.4: Changes in distribution of green patents across subgroups in Denmark 1990-2016



Source: Patent applications based on patent families filed under the PCT. Inventor(s)'s country(ies) of residence. OECD.stats
Note: Climate change mitigation (CMM). The shares sums to more than 100%

At a more detailed level,[6] the main share of the energy patents is within renewable energy generation, i.e., the majority originating from the Danish wind turbine industry. The contribution of the renewable energy sector is also evident in the list of firms producing green technologies (EPO y-tag) as shown in Table 12.1.

Table 12.1 The top 20 largest holders of green patents in Denmark 2000–2017.

Name		Share of green patents	Share of patents with co-inventors located outside Denmark
VESTAS	687	0.297	0.207
LM GLASFIBER	215	0.093	0.149
NOVOZYMES	104	0.045	0.558
HALDOR TOPSOE	89	0.039	0.191
ENVISION ENERGY (DENMARK)	70	0.030	0.000
MAN DIESEL & TURBO	51	0.022	0.118
GRUNDFOS HOLDING	42	0.018	0.143
DANFOSS	37	0.016	0.135
ROCKWOOL INTERNATIONAL	19	0.008	0.368
INBICON	17	0.007	0.059
KAMSTRUP	17	0.007	0.000
DUPONT NUTRITION BIOSCIENCES APS	16	0.007	0.750
UNION ENGINEERING	15	0.006	0.000
FLSMIDTH	14	0.006	0.071
AMMINEX	14	0.006	0.071
PHARMEXA	12	0.005	0.000
NEG MICON	12	0.005	0.167
PP ENERGY	12	0.005	0.083
VKR HOLDING	11	0.005	0.000
MHI VESTAS OFFSHORE	11	0.005	0.182

A more detailed investigation of the green patents by firms located in Denmark from 2000 to 2017 (see Table 12.1) shows that more than 40% of all green patents in Denmark are owned by firms in the wind energy sector. Vestas, the world-leading wind turbine manufacturer, accounts for almost 30% of the green patents in Denmark. LM Wind Power, which develops and manufactures rotor blades for the wind turbine industry, has 9% of all patents with the second place on the list. Chinese Envision Energy's

R&D centre in Denmark accounts for 3% with the fifth largest share. Other than the firms in the wind energy sector, the list reveals many large multinational engineering and biotechnology firms, which suggests a broader engagement in the greening of the Danish economy. More than 500 companies have patented green technologies, but the top 20 accounts for more than 60%. Moreover, the huge contribution of Vestas to the total green patents in Denmark seems to be of a more recent trend since 2007, when the company's share in total green patents exceeded 30% for the first time. The company's share peaked in 2010, when the company accounted for 47% of total green patents in that year. Although the share of Vestas patents decreased in the following years, it remains in the range 23–41%. This concentration could indicate a potential vulnerability of the Danish innovation system, but patents are only one indicator of performance of the system. The next section takes a broader view on the national innovation system and analyses green innovation and green skills.

Although the patents presented in this table are of Danish origin, generated by at least one inventor located in Denmark and owned by firms in Denmark, the knowledge creation process sometimes involves knowledge that comes from abroad. Table 12.1 also shows the share of patents that involve co-inventors located outside Denmark for each firm. The top three firms that produce the most 'green' patents have relatively high shares of their green patents involving at least one inventor from abroad. Of Vestas' patents 21% have at least one Danish inventor and involve co-inventors located outside Denmark. For the large Danish enzymes firm Novozymes, the share is 56%. The global interaction in patenting can be based on the collaboration between the foreign subsidiaries and the headquarters of Danish firms or the collaboration of Danish firms with other independent partners (firms, universities or research institutes) located abroad. Either way, it suggests that the Danish innovation system is a part of globalised innovation networks and draws on knowledge that resides outside Denmark. More specifically, the green transition of the Danish economy is facilitated by global interaction in the knowledge-creation process.

In terms of technological transformation, Danish firms seem to possess specialisation in green technologies, with an increasing share of green patents in recent years. The technological area in which Denmark seems to have expertise is climate mitigation technologies, particularly renewable energy. We find that large companies within the renewable energy sector possess a huge share of green patents and they often collaborate with actors located abroad in creating new knowledge. Patents represent an STI focus or a narrow view of an innovation system. In order to create new green technologies and make transition towards the greening of the innovation system, companies need employees with knowledge and skills that are relevant for this transition. In the next section, we take a broader view of the Danish innovation system and present analyses on green skills and jobs as well as green innovations in Danish firms.

12.4 Green skills and green innovative firms

In this section, we show some descriptive statistics on green skills in the Danish economy and present results from regression models estimating the relationship between green skills and green innovation in Danish firms. This represents a broader view on the national innovation system and includes DUI types of learning as discussed earlier. While the analyses on patents show the development of technological specialisation in certain green technologies, the analyses on green innovation show patterns of firm innovation related to green transition beyond the boundaries of specific technologies. We note that the analysis of patents is an analysis of inventions during 2000–2017, while the innovation survey data only covers innovations during 2012–2014. Within these timeframes, there are about 570 firms with green patents, while the survey identifies more than 700 green-innovative firms.

12.4.1 Green skills

Table 12.2 is adapted from Østergaard et al. (2019) and shows the share of employees with green skills in each of four Nordic countries in 2014. Three different definitions are used. The first two rely on the job description while the third relies on the description of the employee’s education. The first definition of green jobs (broad) is from Vona et al. (2015) who identify green occupations in the US occupation classifications, SOC, and the result is then transferred to the occupation codes used in the Nordic countries, ISCO. The result is rather broad, encompassing, for example, general managers and economists. The second definition contains only occupations with a green description in the ISCO classifications. This results in a narrower definition of green jobs. The final definition relies instead on the description of the employee's education in the International Standard Classification of Education (ISCED)classification system. See Østergaard et al. (2019) for lists of keywords, and of occupation and education codes identified as green. The number of Danish firms with employees with green skills is much higher: 7.8% of the 271,000 firms in Denmark have employees with green skills according to the broad Green Jobs definition, 0.9% according to the narrower definition and 0.4% according to the Green Education definition.

Table 12.2 Share of green jobs and green education in 2014.

	Employment 2014	Green jobs, broad	Green jobs, narrow	Green education
Denmark	2,619,627	3.7%	0.9%	0.3%
Norway	2,557,624	5.3%	0.3%	0.3%
Sweden	4,593,586	3.5%	0.8%	0.2%
Finland	2,192,654	4.3%	0.3%	2.4%

Adapted from Østergaard et al. (2019).

The four countries have a rather similar distribution of green skills across the different definitions, except for Finland which has a higher share of employees with a green education. This might be explained by the fact that the Finnish national system of innovation is relatively focused on engineering. In general, the low share of employees with a green job or green education in this table suggests problems in quantifying green skills. One issue can be that education and occupation do not always reflect the skills applied or task solved. Moreover, firms might only need a few of these employees with green education or occupation in combination with more generic skills and education in order to become greener. An example is Aalborg CSP, which is a Danish SME that develops and builds solar technological solutions for power plants and district heating. It mainly employs highly skilled engineers with different non-green specialisations and work experience. However, the core of their service, the design of the integrated energy systems and solar solutions, is reliant on a few employees with an engineering degree in energy systems.

Østergaard et al. (2019) show that there is no consistent geographical concentration of the green skills in Denmark except for a higher share in the NUTS region encircling the Copenhagen region. This suggests that the possibilities for firms introducing green innovation are not necessarily limited by the geographical distribution of employees with green skills, but by the general lack of employees with these specialised green skills. It implies that the low number of employees on the labour market with green skills could slow down the green transition of the Danish innovation system, at least to the extent that such skills are a requirement for green innovations. Below we analyse the predictors of green innovation in Danish firms.

12.4.2 Green-innovative firms

In this section we present an econometric analysis of the predictors of green innovation in Danish firms. For this analysis, we use the 2014 edition of the Danish Community Innovation Survey on R&D and Innovation (Danish acronym: FUI) by Statistics Denmark. The 2014 edition was unique as it included a block of questions on innovations with environmental impact. This block of questions was only distributed to firms that had already responded that they had had innovation in the period 2012–2014, and over 90% of firms also responded to the optional module on environmental impact. The share of innovative companies in Denmark is relatively constant at 44% in this period. The share of firms with green innovations is also rather similar to the other Nordic countries in the period (Østergaard et al. 2019).

In the main part of the survey, firms are requested to indicate whether they have introduced 13 different types of innovation (two forms of product/service innovation, three forms of process innovation, three forms of organisational innovation and five forms of marketing innovation). Firms responding negatively to all 13 questions are defined as non-innovative. There are 2217 non-innovative firms in our sample. Firms responding positively to at least one of the 13 questions are then presented to the optional module on environmental impact where they are asked to indicate whether the firm has achieved any of ten environmental impacts on the firm itself or its customers over the period, and, if yes, whether the environmental impact can be attributed to the innovations reported earlier. If the firm's innovations have had any of these ten impacts, then it is classified as green-innovative, and if not, then it is classified as non-green innovative. There are 989 non-green innovative firms and 720 green innovative firms. The total number of observations available for regression analysis is then 3926.

The model predicting innovation activity is a multinomial logistic model[7] (Hilbe 2009). The dependent variable takes three values: 0 for non-innovative firms, 1 for firms that have introduced innovations but not green innovations and 2 for firms with green innovations (green innovators may also have non-green innovations). These three outcomes are indexed by *j*. The multinomial logistic model produces conditional probabilities that firm *i* will belong to category *j* as specified in Equation 12.1.

$$\mathbf{Pr}\left(\boldsymbol{y_i} = \boldsymbol{j} \mid \boldsymbol{x_i}\right) = \frac{\mathbf{exp}\left(\boldsymbol{x_i'\beta_j}\right)}{\sum_{\boldsymbol{j=0}}^{2} \mathbf{exp}\left(\boldsymbol{x_i'\beta_j}\right)} \qquad (12.1)$$

y_i is the dependent variable indicating whether firm *i* is non-innovative, innovative but not green or green-innovative. x_i are the independent variables elaborated in this section, including a 1 for the intercept and the β_j are the vectors of parameters to estimate. $j = 0$ will be used as the reference group meaning that the estimates will be relative to non-innovative firms. Therefore $\beta_0 = 0$, and we report the estimates for the two vectors β_1 and β_2. The advantage of a multinomial logistic model is that it allows for a comparison of the three different outcomes. Non-innovators might become either green innovators or non-green innovators if opportunities emerge. Therefore, it is important to analyse the differences in characteristics simultaneously.

The vector x_i contains controls for firm size measured as log total employment in November 2011 and human capital intensity defined as the share of employment in 2011 with at least tertiary education. In order to account for knowledge inputs to the innovation process, we include the share of employees in 2011 with a green education as identified in the GONST project (Østergaard et al. 2019). The 2014 FUI survey also contains information on firms' R&D expenditures in 2014 which we use in log form as a control for generic inputs to the innovation process, despite this being an imperfect control as it is measured in 2014. x_i also contains controls for the region of the main address of the firm defined at the NUTS2 level and for sectors defined following Eurostat's taxonomies for high-low tech sectors and Knowledge Intensive Business Services with 'other services' and 'primary sector, construction and utilities' added for completeness. We use the 'calibrated weights' supplied by Statistics Denmark and report robust standard errors.

Table 12.3 shows the result of the multinomial logistic regression predicting innovation outcomes 2012–2014. The results show that as firm size increases, the probability that a firm has green innovation compared to no innovation goes up too. R&D is, not surprisingly, positive for both types of innovation, while the share of employees with tertiary education is only positive for non-green innovation, and the share of employees with green education is only positive for green innovation.

Effect coding is used for the categorical variables so that the estimates are relative to the national average and not relative to a reference category. The results show that non-green innovation is predominantly observed in high-tech manufacturing and not in low-tech manufacturing, while green innovation is mostly on primary/construction/utilities and in medium-high-tech manufacturing. It is not surprising that firms in medium-high-tech manufacturing sectors are more likely to be green innovators, since the Danish wind turbine industry, mechanical industry and chemical industry are in this sector. These are also among the most active in green patenting, see Table 12.1. The sector 'primary/construction/utilities' contains agriculture, where organic farming is increasingly important, implementation of building solutions to conserve energy and water and the supply and production of electricity. It is thus not surprising that firms in this sector are relatively more likely to have green innovation rather than no innovation. Firms in the financial knowledge-intensive services are significantly less likely to have green innovation, which could be expected given the type of innovation. However, it could also indicate a lack of focus on green innovations and an untapped potential for improvements. No regional variations in innovation outcomes are found, which also corroborates the even geographical distribution of green patents described earlier.

Table 12.3 Model on characteristics of green innovative firms compared to non-green innovative firms.

	Non-green innovation	S.E.	Green innovation	S.E.
Intercept	−1.072***	0.155	−3.216***	0.254
Size	0.011	0.040	0.254***	0.063
Log(R&D)	0.241***	0.022	0.375***	0.027
Share tertiary education	0.0069***	0.0021	−0.0012	0.0043
Share green edu.	−0.053	0.071	0.130***	0.037
Prim. Constr. Util.	−0.052	0.183	0.782***	0.243
High-tech manufacturing	0.494*	0.266	0.497	0.340
Medium-high-tech manufacturing	0.214	0.195	0.789***	0.215

	Non-green innovation	S.E.	Green innovation	S.E.
Medium-low-tech manufacturing	−0.046	0.180	0.115	0.247
Low-tech manufacturing	−0.524***	0.197	0.129	0.243
High-tech KIS	0.122	0.136	−0.244	0.266
Financial KIS	−0.103	0.239	−1.597***	0.417
Market KIS	−0.086	0.130	0.098	0.230
Other KIS	−0.162	0.287	−0.659	0.678
Other services	0.143	0.102	0.090	0.170
North Jutland	0.010	0.147	−0.310	0.212
Central Denmark	−0.008	0.099	0.135	0.142
South Denmark	−0.055	0.104	0.136	0.142
Capital	0.049	0.086	−0.049	0.145
Zealand	0.005	0.139	0.088	0.186
−2LogL Model	22,977.575			
−2LogL Null	25,157.398			
N	3926			

Multinomial logistic regression with weights. Reference: 'no innovation'. Estimate for linear predictor and S.E. of estimate. *: $p < 0.1$; **: $p < 0.05$; ***: $p < 0.01$. Effect coding used for region and sector. KIS: knowledge intensive services.

The results show that employees with green education make a firm relatively more likely to have green innovation, whereas the same is not true for tertiary education in general. R&D, on the other hand, is an important input to both types of innovation processes. This suggests that the 'green skills' among employees and not the 'generic absorptive capacity' are important for green innovation and for the green transition in Denmark.

12.4.3 Job creation by green-innovative firms

In the previous section, we showed that green skills matter for creating green innovation. Here, we show the type of jobs created by firms with green innovation. Table 12.4 shows the results of five separate ordinary least square regressions estimating the relationship between innovation outcomes and job creation at the firm level.

We measure job growth in five different employee groups, which are four groups by skill: green-skill jobs, low-skill jobs, mid-skill jobs and high-skill jobs, and finally total employment. The definitions of high-, mid- and low-skill jobs follow the literature on job polarisation (Goos et al. 2014). This means that high-skill jobs are managers, professionals, associate professionals and technicians. Mid-skill jobs are clerical jobs, craft and related trades, assemblers and plant and machine operators. Low-skill jobs are service and sales and elementary jobs. For green-skill jobs, we merge the two definitions of green jobs described above in connection with Table 12.2. This allows a broad definition of green jobs which includes both jobs with a narrow green content as well as the more broadly defined jobs that are affected too. g_{ki} is job growth at firm *i* of job group *k* measured as change in employment in the group from 2014 to 2016 relative to the average employment in 2014 and 2016, cf. Equation 12.2.

$$g_{ki} = \frac{\left(l_{ki,2016} - l_{ki,2014}\right)}{\left(l_{ki,2016} + l_{ki,2014}\right)/2} \qquad (12.2)$$

noindent

The five separate regressions then follow the general shape illustrated by Equation 12.3, where z_i is a vector of explanatory variables elaborated below including a 1 for the intercept, α_k are the parameters to estimate and the ϵ_{ki} are classic errors.

$$g_{ki} = z_i^{'}\alpha_k + \epsilon_{ki} \qquad (12.3)$$

The vector z_i contains the same variables as x_i in the multinomial regression models presented earlier with two exceptions. The first is that inputs to the innovation process, i.e., the share of employees with a green education and log (R&D), are replaced by a three-level categorical variable for outputs from the innovation process. The categorical variable takes the value 0 if the firm had no innovation 2012–2014, 1 if the firm had innovation but not green innovation and 2 if the firm had green innovation. The second exception is that we include productivity defined as value-added per full-time equivalent employee in 2014 as a control for firm performance. We again use the 'calibrated weights' supplied by Statistics Denmark and report robust standard errors.

As can be seen in the final column, firms with green innovation 2012–2014 had 6.9% higher growth in total employment 2014–2016 compared to firms with no innovation. Firms with non-green innovation were not significantly different from non-innovative firms. The estimated effect is 0.2% and it is not statistically significant. The first four columns show that the job growth at firms with green innovation was among jobs that require green skills and related jobs in particular. Firms with green innovation are estimated to have had 8.9% higher job growth in such green jobs compared to firms without innovation. No difference is observed with respect to the generic skill level in job creation.

Table 12.4 Job creation by innovative firms 2014–2016.

	Green	High	Mid	Low	Total
Non-green innovation	0.026	−0.019	−0.054	−0.014	0.002
S.E.	0.040	0.042	0.044	0.047	0.025
Green innovation	0.089*	0.069	0.052	0.026	0.069**
S.E.	0.047	0.055	0.061	0.068	0.029
Size	−0.045***	0.017	−0.035**	0.007	0.008
S.E.	0.014	0.017	0.016	0.018	0.009
Share tertiary edu.	0.0004	−0.0001	0.0003	0.0032***	0.0004
S.E.	0.0007	0.0009	0.0010	0.0010	0.0005
Productivity	0.0004	0.0030	0.0139***	−0.0007	0.0017
S.E.	0.0013	0.0031	0.0029	0.0017	0.0018
R2	0.012	0.006	0.009	0.010	0.009
N	3638	3638	3638	3638	3638

Separate OLS regressions with weights. Dependent variables are the growth in green jobs, high-/mid-/low-skill jobs and total jobs. Estimate followed by robust SE. *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$. Models also include an intercept and controls for sector and region.

All five regression models presented in Table 12.4 have low R-squared indicating that they only explain a minor share of firm level job growth. The main take-away from the regressions is thus that there is a statistically significant partial correlation between green innovation and green job growth, and between green innovation and total job growth, while there are no statistically significant correlations between non-green innovation and job growth. Combining the evidence of this section shows that, on average, green innovation processes require green knowledge inputs in terms of the education of the workforce, and green innovations create green jobs broadly defined. Thus, in order to facilitate the green transition, the national system of innovation needs to supply green education, and to facilitate that relatively generic employees in occupations such as management, economics and engineering can adapt and occupy jobs with a more green-task content.

12.5 Conclusion

The purpose of this chapter was to analyse the green transition of the Danish economy with a special focus on green patents, green skills and green innovations of firms. The evolution in the Danish technological specialisation through patent analyses shows a rather drastic change towards green technologies. Green patents have had a high growth since the 2000s, and the data from 2016 shows that green patents account for almost 18% of all Danish patents. This is partly driven by the success of the Danish wind turbine industry, which contributes to more than 40% of green patenting in Denmark. Technologically, the greening of Danish innovation system seems to be concentrated in certain sectors and firms. This suggests that there are some sectoral and technological innovation systems related to green technologies within the Danish national innovation system. Borup et al. (2009) identify five different technological innovation systems within energy technology in the Danish innovation system. These have different properties and challenges, but they have also interdependencies as a part of the Danish national innovation system. Malerba (2002) also argues that it is necessary to complement the analysis of national innovation systems with the analysis of sectoral innovation systems since growth and changes at the national level are often determined by leading sectors located in particular regions in the country. This is also relevant to the greening of the Danish innovation system, as the wind turbine industry concentrated in the central Jutland region is driving the transformation.

When it comes to the geographical aspect of the green transition, it is also essential to consider the global interaction of firms in the national innovation system. As is shown by the extent of global connectivity in the patenting of the large green firms in Table 12.1, the success of these firms also depends on their ability to collaborate with inventors outside Denmark. Thus, the green transition in terms of patenting also relies on the absorptive capacity of the Danish firms. As noted by Lundvall (2016), the traditional national innovation systems literature has somehow neglected these globalised knowledge flows, and the analysis of national innovation systems needs to include the learning from knowledge flowing through global value chains and distributed innovation.

We also showed that green patenting, green innovations and green employment are interconnected in the effort of firms making the green transition. In order to conduct green R&D and make green inventions, firms need to hire highly educated employees with green skills. Our regression analysis shows that firms with employees with green skills are more likely to introduce green innovations. While the analysis of patents revealed a concentration in particular sectors and firms, the analysis of firms' likelihood to do green innovation shows a broader trend of the green transition. The medium-high-tech manufacturing sector, high R&D spenders and large firms were more likely to do green innovations compared to other types of innovation. But the traditionally low-innovative industries like construction, utilities and primary industry were also more likely to develop green innovations. There were also no signs of a geographical concentration of green innovators within Denmark. However, the broader scope of transition in terms of green innovation compared to green technologies could be from how these concepts are identified and measured in our analysis. Innovations with environmental impact per definition can be generated across a wide range of technologies and sectors.

Furthermore, we find that green innovators have higher employment growth than other innovative firms and also a higher growth of green jobs. This suggests that the green transition of the Danish economy can be self-reinforcing, as increased green innovation creates more green jobs thus increasing the scope for further green innovation in terms of incremental shop floor innovations, increased absorptive capacity for green innovations and thus increased demand and increased potential for diffusing green innovations in export markets. The positive effect of green jobs and education for the likelihood for green innovation opens the possibilities for supportive innovation policy in terms of increasing and diversifying the supply of green education and training. It could be worrying that the green patenting in Denmark is highly reliant on a few firms within the wind turbine industry and that R&D spending is concentrated in few large firms, which makes the green transition of the Danish economy somewhat vulnerable. Furthermore, the apparent low level of green innovations in the service industry, which accounts for the majority of employment in the Danish economy, calls for further research.

As pointed out earlier, firms are an important part of the national innovation system as well as different regional, technological and sectoral innovation systems. They are highly dependent on institutional frameworks in these systems, including the role of demand, financial system, government, public sector, political system, broader knowledge infrastructure and other actors (Fagerberg 2018). Considering the pattern of the green transition of firms in Denmark shown in these analyses, developing policy instruments that encompass different levels of innovation systems to deal with balanced development of technologies, skills and sectors would be necessary.

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[1] Our definition of green innovation follows how the Community Innovation Survey (2014) defines 'environmental innovation'. We see green innovation as innovation with environmental benefits within the firm or for users or both. While green patents are defined as patents in environmental-related technologies (OECD 2009b), green innovations are not necessarily associated with specific technologies and industries. This definition does not require that the environmental benefits were the main objective of innovation.
[2] The International Labour Office (ILO) defines green jobs as: 'they reduce the consumption of energy and raw materials, limit greenhouse gas emissions, minimise waste and pollution, protect and restore ecosystems and enable enterprises and communities to adapt to climate change' (ILO 2018, p. 53), while skills are 'defined as the ability to carry out the tasks and duties of a given job' (ILO 2012, p. 11).
[3] The PCT procedure allows applicants the possibility to seek rights in multiple countries with one international application at a single (receiving) patent office. In 2006, the share of PCT application was 62% at the EPO, and since the early 2000s this share keeps increasing (OECD 2009a).
[4] Both ENV-TECH and EPO y-tags have in common that both systems identify sets of technologies that are environment-related. However, these are two independent classification systems and there may be deviation in the patents identified by the two systems. See Tanner et al. (2019) for a detailed explanation on the different coverage of the two systems.
[5] According to the recent EU Industrial R&D Investment Scoreboard 2019, Denmark has 45 companies on the top 1000 list of R&D spenders, of which 12 are within the pharmaceutical and biotechnology sector. Their total R&D spending accounts for 56% of the total. The large Danish wind turbine company Vestas is fifth on the list, and its joint venture with Mitsubishi is 22nd.
[6] The detailed level is not shown in Figure 12.3 but is available from the authors upon request or at OECD stats.
[7] The advantage of a multinominal model is that it allows for a comparison of the three different outcomes. Non-innovators might later become either green innovators or non-green innovators. Therefore, it is important to analyse the differences in characteristics simultaneously. A Heckman selection model could also be used to control for unobserved differences between non-innovators and innovators in a sense that some non-innovators might not innovate because they do not want to innovate. However, this represents a rather linear innovation thinking. Demand from customers or regulation or technologies from suppliers might present a company with unexpected opportunities for innovation – regardless of the initial innovation strategy.