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Agency in green regional path development: systematic evidence from the Nordic regions

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Abstract

In light of the current climate crisis and pressure on depleted resources, green industrial development is a necessity to improve the sustainability of the environment. Although we have seen a significant increase in the literature dealing with green regional path development, there is still a substantial research gap when it comes to understanding who and what drives different types of the green technological development at the regional level. This article adopts an agency-oriented approach and contributes to the literature by (1) providing a systematic empirical analysis of green regional path development, (2) showing the heterogeneity of green regional path development and (3) the linkages to pre-existing knowledge bases and external knowledge sources, and (4) analyzing the type of inventive actors involved in green regional path development. We use a unique, comprehensive database on green inventors and patent applicants in the Nordic countries. We combine quantitative and qualitative measures to validate an elaborated typology of green regional path development focusing on green path extension, path renewal, path diversification and path creation. Findings reveal that green inventive activity is spatially concentrated in few regions across the Nordic countries characterized by multiple types of path development processes. We find that the majority of green technological development are driven by incumbent firms involved in path extension, renewal and diversification processes, whereas new entrants, although they account for less green inventive activity are mainly involved in path creation processes entailing the largest degree of structural change.

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Abstract

In light of the current climate crisis and pressure on depleted resources, green industrial development is a necessity to improve the sustainability of the environment. Although we have seen a significant increase in the literature dealing with green regional path development, there is still a substantial research gap when it comes to understanding **who** and **what** drives different types of the green technological development at the regional level. This article adopts an agency-oriented approach and contributes to the literature by (1) providing a systematic empirical analysis of green regional path development, (2) showing the heterogeneity of green regional path development and (3) the linkages to pre-existing knowledge bases and external knowledge sources, and (4) analyzing the type of inventive actors involved in green regional path development. We use a unique, comprehensive database on green inventors and patent applicants in the Nordic countries. We combine quantitative and qualitative measures to validate an elaborated typology of green regional path development focusing on green path extension, path renewal, path diversification and path creation. Findings reveal that green inventive activity is spatially concentrated in few regions across the Nordic countries characterized by multiple types of path development processes. We find that the majority of green technological development are driven by incumbent firms involved in path extension, renewal and diversification processes, whereas new entrants, although they account for less green inventive activity are mainly involved in path creation processes entailing the largest degree of structural change.

1 Introduction

The effects of climate changes and the exhaustion of natural resources have increased academics and policy maker's interest in the processes of developing new green industries and/or promoting green shifts in mature industries. Recently, we have seen a rapid surge in the literature dealing with green regional path development (Santoalha and Boschma 2020; Grillitsch and Hansen 2019; Sotarauta et al. 2020; Trippl et al. 2020; Isaksen et al. 2019; Corradini 2019). One key observation derived from this literature is that pre-existing related green and non-green knowledge bases play a role in explaining where green paths develop (Santoalha and Boschma 2020; Corradini 2019; van den Berge, Weterings, and Alkemade 2020; Tanner 2016). Other research (Grillitsch and Hansen 2019; Trippl et al. 2020; Isaksen et al. 2019) has highlighted that green path development is more nuanced and unfolds through various types of path development.

Building on previous typologies of regional path development (Grillitsch, Asheim, and Trippl 2018; Isaksen and Trippl 2016; Martin and Sunley 2006; Isaksen 2015; Tödtling and Trippl 2013) a literature on specific characteristics of green regional path development has emerged. The green path development typology proposes a multifaceted understanding of how green transitions unfold in regional economies distinguishing between four main types of paths: green path extension, path renewal, path diversification, and path creation (Isaksen et al. 2019). Where green path extension and renewal signals some continuity of an existing path present in the region, path diversification and creation involve higher degrees of change of the regional economy¹. However, the vast interest in understanding the structural change in green path development in the literature resulted in limited attention to actors and their actions to create

¹ In this article, we use the term regional path development to capture both processes of continuity, incremental and structural changes of regional economies.

green transitions in the region. Trippel et al. (2020) specifically argue to complement the focus on pre-existing structures with a stronger focus on the agency involved in both reusing existing resources as well as creating (new) or transplanting (non-local) resources.

This article contributes to this stream of literature in three ways. First, we aim to provide more clarity on the type of actors involved in each of the four types of green path development processes. To complement the previous studies on the role of institutional entrepreneurship and system-level agency for green regional path development (Sotarauta et al. 2020; Isaksen et al. 2019), we focus on the actors involved in Schumpeterian patterns of innovation and entrepreneurship and the transition mechanisms that they drive across the four types of paths.

We distinguish between Schumpeter Mark I processes that involves smaller entrepreneurial firms and Schumpeter Mark II processes that involves larger incumbent firms (Breschi, Malerba, and Orsenigo 2000; Neffke et al. 2018). We posit that the green regional path development will be affected by the strategies and capabilities of these actors. Mark I firms will push for a fundamental structural change in the regional path development, while Mark II firms often aim to sustain the existing path or renew or diversify in a green direction based on their existing capabilities.

Second, we systematically assess the degree to which pre-existing knowledge bases are important for different types of green path development. As Boschma (2017) argues, new economic activities tend to draw from both related and unrelated knowledge. We examine the degree of relatedness that characterizes each development path in order to understand when and for which actor relatedness matters for green path development.

Finally, there is a tendency in the literature (e.g., Boschma, Balland, and Kogler 2015; Kogler, Rigby, and Tucker 2013; Tanner 2016) to focus too much on the overall regional technology space as causal determinants of future developments. Thereby, the existing studies overlook

that the direction of technological exploration is often set within the frames of an organization and that these organizations also draw on knowledge from outside the region (Bathelt, Malmberg, and Maskell 2004). Specifically, multinational firms are likely to integrate knowledge from subsidiaries outside the region (Meyer, Mudambi, and Narula 2011). By drawing our attention to the agents and their actions, we are able to analyze the patterns of global orientation at the organizational level, which further characterizes the technological development in the paths we study.

Methodologically, this article takes a systematic approach and analyzes different green regional path development processes across eight regions in four Nordic countries (Denmark, Sweden, Norway, and Finland). The eight regions are leading the green technological development measured by green inventive activity in their respective country. Empirically, we analyze the actors' involvement in the green path development proxied by green technology development based on a patent-firm linked dataset and the additional desk-study research of firms' patent documents, webpages, strategies, and annual reports, etc.

We find that the majority of green technological development is driven by incumbent firms involved in green path extension, renewal, and diversification processes. New entrants, although they account for less green inventive activity, are mainly involved in path creation processes entailing the largest degree of structural change.

2 Theory

Recently, the literature on regional path development processes has returned to a theoretical debate on the dual relationship between structure and agency (Boschma 2017; Grillitsch and Sotarauta 2020; Moulaert, Jessop, and Mehmood 2016). The field has arrived at this point based on decades' theoretical advancement aiming to conceptualize regional path development processes.

One stream of literature that has been significantly progressive in dealing with regional restructuring is the field of evolutionary economic geography (EEG). The core argument of EEG is that historically produced regional preconditions (e.g., technological and manufacturing skills) provide greater probabilities for certain future path development than others (Frenken and Boschma 2007). In particular, concepts of relatedness and related variety have become key in explaining regional path development (Frenken, Van Oort, and Verburg 2007; Boschma and Frenken 2011). However, this stream of literature has also gained criticism for overlooking the micro-level processes and mechanisms driving regional path development (Hassink, Isaksen, and Trippel 2019; MacKinnon et al. 2019a; Tanner 2014), which spurred a more fundamental debate on the relationship between structures and actors in regional path development (Grillitsch and Sotarauta 2020; Isaksen et al. 2019; Moulaert, Jessop, and Mehmood 2016; Boschma 2017).

In order to address this critique, it is necessary to unfold how regional industrial development occurs. According to Martin (Martin 2010), regional economies are complex systems composed of individual firms and other actors. Firms show variety across products, market orientation, technologies, skills, routines, business models, and resources, even when they are in the same industry. It is within these defining frames that firms make decisions and predictions regarding the direction of technological exploration (Frenken and Boschma 2007) based on their past experiences and expectations (Garud, Kumaraswamy, and Karnøe 2010; Steen 2016; Grillitsch and Sotarauta 2020).

The composite nature of regional industries entails that changes in one or few firms' orientations may occur without substantial changes to the overall regional industrial path (Martin 2010). However, changes in the orientation may also lead to greater variety through new entries or reconfiguration of existing firms, which result in cumulative changes that ultimately alter the industrial path (Østergaard and Park, 2015; Neffke et al., 2018). Hence, to

understand regional path development, it is necessary to analyze how regional economies “evolve gradually by a changing mix and orientation of lower-level components, that is, firms and their activities” (Martin 2010).

When that is said, pre-existing regional industry structures and initial conditions obviously do influence future path development through the availability and variety of resources, which guide and inspire firms in their technological (re-)orientation. Martin (2010) distinguishes between three phases of local industry evolution: preformation, formation and path development. In the preformation phase, the spurs for new path creation may be latent in pre-existing industries, knowledge and skill bases of a region. The path formation phase is characterized by purposive experimentation, technological development, and competition between actors, where the path development phase reveals the emergence of local increasing returns and network externalities, which reinforce the development of a new local industry.

In sum, it is important to recognize both micro-level agency and structural factors (pre-existing industry) in explanations of regional path development. Furthermore, it is essential to understand how the influence of agency and structure varies across different forms of regional path development.

2.1 Firms as an important source of agency in regional path development

The current study follows the definition of agency as “action or intervention by an actor to produce a particular effect” (Isaksen et al. 2019, p.51). Grillitsch and Sotarauta (2020) identify Schumpeterian innovators (firms) as one of change-agents central to new regional path development processes: Schumpeterian innovators introduce solutions and products based on new knowledge or new combinations of old knowledge. Their accumulated knowledge and decisions on investments in new technology are critical sources of agency in the region.

Following the tradition in evolutionary economics, firms can be categorized as Schumpeterian Mark I and Mark II innovators. The first is usually new entrepreneurial firms, and the latter is large incumbent firms. Some industries are then characterized by being dominated by either Mark I or Mark II dynamics. In the Mark I industries, there is typically low cumulativeness of knowledge and low entry barriers, resulting in a high level of innovative activity among new and small firms. The Mark II industries are characterized by high entry barriers and high cumulativeness of knowledge, which gives an advantage to large incumbents with a high level of R&D spending and accumulated knowledge. Thus Mark I innovators tend to widen the scope of technological development, where Mark II innovators tend to deepen the technological development within existing paths (Breschi et al 2000; Malerba and Orsenigo 2000).

These dynamics have implications for the regional path development since the two types of firms tend to affect path development in different directions. Neffke et al (2018) show that incumbents (Mark II) tend to maintain and reinforce regional economic development along existing paths through their activities. On the other hand, new entities (Mark I) are more inclined to contribute to the development of new paths (Neffke et al. 2018).

2.2 Pre-existing regional conditions

Although different types of agents play out different roles in creating continuity or changes to regional economies, pre-existing economic structures are important for the variety in initial resources for the activities of these agents. Therefore, the type of region also matters, as regional resources differ fundamentally between different types of regions (Todtling and Trippl 2005). Core regions have diverse resources that are important for industries' possibilities to emerge and grow, such as thick labor markets, R&D active firms, and universities, while industries and entrepreneurs in peripheral regions often suffer from thin labor markets and small local markets (Isaksen, 2015).

Moreover, technological relatedness has been confirmed as an underlying principle of many types of regional path development, where relatedness between industries exists when two industries share a common or complementary knowledge base (Makri, Hitt, and Lane 2009; Neffke, Henning, and Boschma 2011). While many quantitative studies have confirmed that relatedness is the prevalent, underlying principle of regional restructuring (see Boschma 2017 for an overview), other contributions have shown that path development can also draw on unrelated knowledge sources (Grillitsch, Asheim, and Tripl 2018; Isaksen and Tripl 2016; Hassink, Isaksen, and Tripl 2019). Thus, a more valuable research strategy is to understand how different forms of regional path development rely on varying degrees of related knowledge.

Finally, exogenous knowledge sources (Tripl, Grillitsch, and Isaksen 2018; Boschma and Iammarino 2009) and linkages to global production networks or global value chains also play a role in understanding regional path development (MacKinnon et al. 2019b). The literature on global pipelines and local buzz (Bathelt, Malmberg, and Maskell 2004) has long challenged the perception of regional economies as self-referential systems (Bathelt 2005). On the contrary, regional path development is influenced by other regional innovation systems through global networks (Binz and Truffer 2017), which transfer non-local knowledge that complements local resources in excelling regional path development.

2.3 Types of green regional path development

There has been increasing scholarly attention to different characteristics of green regional path development (Tripl et al. 2020; Grillitsch and Hansen 2019; Isaksen et al. 2019). While regions share the urgent need to mitigate climate change, how they tackle the challenge of green transition can differ. Common for all regions is that green transition requires a change in

the existing regional path, but who drives the change and through which actions the change occurs can vary.

The green path development typology distinguishes between four main types of paths: path extension, path renewal, path diversification and path creation (Isaksen et al. 2019). The typology aims to describe the degree of restructuring of the regional economy, where green path extension and renewal signals some sort of continuity of an existing path present in the region, path diversification and creation involve higher degrees of change of the regional economy. In the following, each type of path development is discussed with the focus on the actors and the mechanism through which they create change.

Green 'path extension' represents the continued growth of existing green industries along the existing green development path. Extension of existing green paths is characterized by self-reinforcing mechanisms, such as technological interrelatedness, localized externalities, quasi-irreversibility of investments, increasing returns effects, and cognitive and material barriers (Martin 2010; Dosi 1982; Perez 2010). Industrial change in the extension path is incremental and follows the search heuristics within the established technological paradigm (Simmie 2012). We would therefore expect a high degree of technological relatedness in the path development. Green path extension requires the pre-existence of a sizable green industry in the region with an associated high cumulativeness of knowledge. Therefore, incumbents play a prominent role in this type of regional path development. However, other types of actors might also promote path extension. For example, the existence of localized externalities in a specialized green region might attract subsidiaries from incumbents outside the region or through creation of spinoffs from incumbents that also support the existing path.

The second type of path development is green 'path renewal' and captures processes where existing 'non-green' industries renew themselves in a sustainable direction (Trippel et al. 2020;

Grillitsch and Hansen 2019). In path renewal processes, firms from existing industries break with the dominating technological paradigm and adopt new visions and search heuristics (Dosi 1982) as a consequence of a new collectively shared logic of technological development (Perez 2010). The break with the existing technology can have a radical or incremental character. An example of radical renewal is when car producers replace the internal combustion engine (ICE) with an alternative means of propulsion, such as fuel cells or batteries (Tanner 2014; Wesseling et al. 2015). In contrast, an incremental renewal process is when car producers aim to improve the ICE to be less polluting instead of replacing the ICE technology. In incremental renewal, the greening process builds to a higher degree on the existing and, thereby, related knowledge fields and in consequence, will have a less structural impact on the regional economy. In radical renewal processes that involve a shift in the technological paradigm (e.g., from ICE to fuel cells), we would anticipate a higher degree of unrelated knowledge and therefore larger structural impact.

Regional green path renewal is characterized by an internal transformation and greening of existing industries with a focus on supplying similar product-markets and customer needs. In this process, the cumulated capabilities of incumbents play an important role.

The third type is ‘green path diversification’, which entails a high degree of structural change of the regional economy. In contrast to path renewal processes, the industry involved in green diversification is in principle targeting markets and customer needs that are different from existing markets and needs (Tödtling et al. 2014). For example, this is the case when the oil and gas industry diversifies into the offshore wind industry based on technologically related know-how on offshore equipment and operations (Steen and Hansen 2014).

We argue that green path diversification processes can follow two patterns. One pattern is when existing industries diversify into new greener markets and industries by applying existing

related knowledge in new product-markets. Another pattern is through unrelated diversification due to changes in a firm's competitive environment (Arrow 1975) or because of a strategic need to control and align incentives in the value chain (Teece 1986). In related diversification, firms expand their businesses based on economies of scope (Penrose 1959; Breschi, Lissoni, and Malerba 2003) where the scientific principles, routines, and search heuristics are relatively similar (more related) and where firms can capitalize on firm-owned resources. In unrelated diversification from non-green to green product-markets, we anticipate that scientific principles, routines and search heuristics are less similar, hence build on more unrelated knowledge. Consequently, the green diversification of incumbents is thus a question of different degrees of relatedness. The green regional diversification can also occur through the creation of spinoffs or subsidiaries.

The fourth type of green regional path development is path creation, which concerns the emergence of a new industry targeting new markets unrelated to existing activities in the region. Green regional path creation is characterized by structural change, creative destruction, low entry barriers, and low cumulativeness of technological knowledge (Breschi et al., 2003). Here the agents of change are typically startups or firms from outside the region (Trippel et al. 2020). Universities and research institutes can play an important role in creating the foundation of breakthrough inventions (Tanner 2014; Feldman and Lendel 2010). Since path creation builds on breakthrough technologies involving new scientific principles, routines, and search heuristics, we anticipate that the new green activities are more unrelated to the pre-existing knowledge base than the other paths.

The elaboration of the four green path development forms suggests that different types of firms by their actions influence green restructuring of regional economies in different ways. New entrants will push towards green path creation or diversification, while incumbents will be involved in green path extension, renewal, and diversification. Since the incumbents typically

account for a much larger share of the regional industry and have more resources, their actions tend to dominate the overall green path development. However, it should be noted that some incumbents might find the green transition difficult, less imminent, or face a stronger deterioration of their capabilities in relation to becoming green. Therefore, these incumbents affect the type of green regional path development less.

3 Methodological approach

To carry out a systematic analysis of green regional path development processes, we focus on the pattern of green technology development in the regions proxied by inventive activities related to green technological development.

3.1 Green patent data

Using patent statistics has both advantages and disadvantages. On the one hand, patent data is a rich source of information about technological development within very detailed technology classes. In addition, patent data also include information about inventors, applicants, their addresses, and year. Therefore, patent applications provide relatively consistent data for analyzing technological development in regions and actors driving the development with a longitudinal and comparative approach.

On the other hand, patent data also contain some noise (Griliches 1998). First, patents differ greatly with regard to their technical and economic significance (Griliches 1998). Second, patent data are not complete measures of knowledge production and technological development. A lot of knowledge with technical and economic value is not patented. Similarly, inaccuracy can be an issue when comparing inventive activity across technological fields since frequencies and practices of patenting differ hugely across fields and over time (Park, Yoon, and Lee 2005). In consequence, interpretations of absolute numbers should be made with care,

which is why we go a step further and investigate the patents in more detail in the qualitative analysis.

Moreover, delineating green patent activity is not without issues due to their systemic and immature character and difficulties in classifying the greenness of a technology ex-ante (for detailed discussion see Tanner et al. 2019). Although there is no perfect way to overcome the challenges of defining green technologies, it is crucial to work towards a practical and workable classification scheme that can be used for policymaking, firm strategy, as well as for research purposes. Therefore, we use the “Climate Change Mitigation Technologies” (CCMT) developed by European Patent Office (EPO), United Nations Environmental Program, and the International Centre on Trade and Sustainable Development. CCMTs are defined as those “which can be related to a human intervention directed to reduce the sources or enhance the sinks of greenhouse gases” (Veefkind et al., 2012, p. 106).

3.2 Database, sources, and population

To identify green patents in Nordic countries, we went through the following steps:

- a. Identify Patent Families: we identify and extract Nordic Green Patent Families (NGPs) from the PATSTAT dataset (2018b version) using the CCMT classification scheme. We collected data for patents applied for by applicants in, Denmark, Finland, Norway, and Sweden, during 2000-2014 based on the mean patent family application year .
- b. Data preparation: we harmonize and regionalize the target NGPs using standard tools from the OECD and Eurostat. REGPAT database (OECD 2020b) was used to improve the regionalization, and HAN database (OECD 2020a) and EEE-PPAT (EPO 2020) were used during name-harmonization and initial sector allocation.
- c. Entity-recognition: we follow an established string-match approach (Callaert et al. 2011) to match patent applicants with Nordic addresses. Subsequently we matched patent

applicants to Orbis dataset provided by Bureau van Dijk to get additional entity information, such as industry, size, and age. After the matching, country-level firm registries were used to improve accuracy and replenish missing data.

In brief, we focus on a population of European patent families (i) with filings at the EPO, via the PCT in the Nordic countries, and/or at domestic Nordic offices, (ii) with Nordic assignees that are entities (i.e., private individuals are excluded), and (iii) with one or more classes in the CCMT classification system.

The combination of these steps holds several advantages over existing studies of green patenting. First, patchy address information in the patent data was improved to provide a better idea of the location of actors who are engaged in green inventive activities. Second, crucially for this study, the enrichment of the data made it possible to analyze whether green inventive activities are situated in the population of incumbent firms or from ‘new’ entities.

3.3 Method and measures

An initial analysis of green technology development in all regions in the four countries revealed high degrees of spatial concentration. Therefore, we decided to zoom in on the two regions in each country with the highest number of green patents²: East Jutland and Copenhagen suburbs in Denmark, Helsinki-Uusimaa and Ostrobothnia in Finland, Oslo and Rogaland in Norway, and Stockholm and Västra Götaland County in Sweden.

This selection leads to total 6041 unique patent families of green patents, distributed in these eight regions in the following way: 550 in Copenhagen Suburbs, 1139 in East Jutland, 184.5

² The selected regions also have the highest rates of green patents per population except for Västra Götaland County, which had the third highest rate in Sweden.

in Ostrobothnia, 1484.5 in Helsinki, 225.25 in Oslo, 170.75 in Rogaland, 1603 in Stockholm, and 683 in Västra Götaland³.

3.3.1 Green path development types

We classified the types of paths based on two indicators. First, the regional green technological development was analyzed by looking at sub-groups of the CCMT. The CCMTs are divided into nine sub-groups: Y02A (Adaptation to climate change), Y02B (Buildings), Y02C (Capture and storage of greenhouse gases), Y02D (ICT aiming at the reduction of own energy use), Y02E (Production, distribution, and transport of energy), Y02P (Industry and agriculture), Y02T (Transportation), Y02W (Waste and wastewater), and Y04S (Smart grids). We focused on the period 2000-2014, since this is where we see a rapid surge in green inventive activity. The sub-groups Y02C and Y04S was excluded due to the low representation of these patents (<100 in all years) in all Nordic regions. Within each region, we focused mainly on the two largest green technological areas unless the region was very diverse.

Second, we examined the patent applicants driving the green technological development in the region. We divided the agents into incumbents, new entrants (including new entrants, spinoffs, and newly established foreign subsidiaries), and university and research institutes (U&RI). We utilized the ‘PSN sector’ variable from the patent data to distinguish firms from universities and other organizations. We identified new entrants among firms by calculating the year gap between the first filing year of the patent and the incorporation year of the firm. If the year gap is less than ten years and the firm has less than 250 employees, we considered the corresponding patentee as a new entrant. Subsequently, we analyzed how the green technologies relate to the applicants’ existing activities and product-markets (in case of incumbents) and the background and origin of the new activities (in case of new entrants).

³ For regional counts of patent families, we use fractional count.

In addition, we used qualitative data to interpret the type of green path development the identified actors were engaged in. The qualitative data come from desk research of webpages, strategies and annual reports of the main agents. We also screened the patent descriptions of the patentees using Espacenet to enhance our understanding of their green technology development and to decide to what degree it signaled continuity (extension) or different degrees of change (renewal, diversification, or creation).

In order to further substantiate our analysis of the green path development processes, we used measures of 1) diversity of green technologies at the regional level, 2) global orientation in green patenting at both organizational and regional level, and 3) technological relatedness between the green technologies and the pre-existing regional knowledge base.

1) Diversity:

We use the Shannon index to determine the level of diversity on the technology sub-groups introduced above:

$$Diversity = \sum_i^n p_i \left(\ln \frac{1}{p_i} \right)$$

where p is the proportion of patents in technology sub-group i

2) Global orientation:

We use the inventor country location to determine the global orientation of each patent and aggregate the percentage of patents with global connections at the organizational and regional levels. If there is at least one inventor located outside the respective country that the region is located in, we see this patent as a product of global collaboration.

3) Technological relatedness between green technology paths and the pre-existing regional knowledge base:

We use prevalent methods (Tanner 2016) to identify the top-10 co-classified CPC-codes (at class level, 3 digits) to identify related knowledge fields characterizing a given region's engagement in green technology development. We use fractional counts and summarize CPC-classes for the whole period 2000-2014 for each of the green technology sub-groups and for each of the three actor groups: incumbents, new entrants, and U&RI. We follow established methods to calculate revealed comparative advantage (RCA) (Boschma, Balland, and Kogler 2015) of all IPC classes for a region's total inventive activity in a five-year period prior to 2000. To measure the degree of technological relatedness characterizing each region's green technology development, we analyze to what degree the related knowledge fields reflect regional specialization ($RCA > 1$) prior to 2000. We classified relatedness on a scale from low to high depending on the number of knowledge fields with prior regional specialization following this division: 1-3: Low, 4-6: Medium and 7-10: High.

We first analyzed the green path development for each of the eight regions (see supplementary material), before aggregating the patterns of green path development across the regions for each type of regional path development, which is presented in the analysis below.

4 Analysis

In this section, we first show the development of green patenting over time at country and technology level and introduce the eight regions and some general indicators characterizing their green technological development. Thereafter we analyze what characterize the different types of green regional path development in the Nordic countries in terms of agency, technological relatedness and global orientation.

Patterns of green technological development

Green technological development has increased rapidly during the recent years in the Nordic countries. Figure 1 shows the development across the seven technology areas in focus in the four Nordic countries in three 5-year periods covering the period 2000-2014. It is evident that whereas Denmark, Finland and Sweden have shown increasing inventive activity in green technological development, the development in Norway has stagnated at a lower level.

[Insert Figure 1 around here]

Table 1 shows a clear spatial concentration of green technology development in relatively few regions. Nearly all regions have registered some green patenting activities. However, 25 regions accounts for 90 percent of all green patents and only eight regions for 70 percent in the period, indicating high concentration of green technological development. Table 1 also shows that spatial distribution varies across the seven CCMT subgroups. Where inventive activities related to ‘Climate Change Adaptation’ and ‘CCM and waste’ have the highest dispersion with approximately 70 percent patent applications across 11 regions. ‘CCM and ICT’ technologies are the most concentrated technology subclass with 89 percent of 1242 patent applications assigned to only two regions.

[Insert Table 1 around here]

4.1 Eight Nordic Regions

Table 2 list the eight regions leading the green technological development in terms of patenting and some basic regional characteristics, and measures of their green technological development. We use the OECD categorization (OECD 2020c) of urban and rural regions to classify the type of region. Table 3 shows that five of the eight regions are predominantly urban (PU). These are the capital regions Helsinki, Stockholm, Oslo, and Copenhagen and the Västra Götalands County in Sweden. In Finland, Sweden and Norway, it is the capital regions that have the highest number and share of green patenting in the respective country. However, in

Denmark, Copenhagen Suburbs is only the second largest (21 percent) after East Jutland region that accounts for 40 percent of the green patenting activity. The East Jutland and Rogaland regions are characterized as ‘intermediate regions close to a city’ (INC). Finally, the Ostrobothnia region is classified as ‘Predominantly rural region remote’ (PRR). The diversity in types of regions indicate that no regional type is in principle ruled out of playing a role in the green transition.

[Insert Table 2 around here]

The last four columns of Table 2 provide the first insight on the type of green regional path development that takes place in the regions. First, the share of green patents in the region show a huge range from 5.75 to 56 percent. In reality, the PU regions and the Rogaland region (INC) show much similar shares from 5.75 to 14 percent, where the two outliers, Ostrobothnia region (PRR) and East Jutland (INC) has the highest green shares of 55.8 and 39.5 percent, respectively.

Second, the Shannon entropy measure indicates how diverse a region is across the seven technology areas. The PU regions and the Norwegian Rogaland region have the highest scores indicating high green technological diversity, which confirms that core regions are often more economically and technologically diverse. East Jutland and the Ostrobothnia region on the contrary have lower entropy values, because of a high specialization in East Jutland in GHG and Energy (67 percent) and in Ostrobothnia in GHG and Transport (76 percent).

Finally, the share of global patents range from 5 to 35 percent. Where the specialized East Jutland region ranking highest with 35 percent, the diverse Rogaland region has the lowest levels of global connectivity in their green technology development.

[Main agents of green transition in the eight Nordic regions](#)

The degree of contribution of various types of agents (i.e., incumbents, new entrants, and U&RI) in green technology development differs among the eight regions. In all Nordic regions, incumbents are the agents that own the largest share of green patents ranging from 50 (in Oslo) to 96 percent (in Ostrobothnia) (see Table 3). In Oslo and Copenhagen, there is higher levels of activities from other types of agents (respectively new entrants and universities). Typically, the green patenting activities of new entrants are significantly lower than those of incumbents. U&RI have the lowest level of patents in most region, which can be explained by different national institutions for patent ownership. Copenhagen suburb is the only region with active contribution of U&RI, where 22 percent is attributed to a single university.

[Insert Table 3 around here]

Table 3 also shows the two largest patentees across the eight regions. The largest patentees are incumbents like Vestas Wind Systems A/S (Vestas), Novozymes A/S, Nokia Oyj, Equinor Energy ASA (Equinor), LM Ericsson AB, Volvo Lastvagnar AB (Volvo Group), and Wärtsilä Oy. These incumbents have a broad range of industry profiles from green renewable energy to automobile and maritime industry, meaning that some of them are born in ‘green’ industries while others in ‘non-green’ industries. The contribution to the region’s green transition varies among the largest patentees, where Wärtsilä and Vestas, who owns 86 and 78 percent of the green patents clearly dominate the region’s green patenting. The green transition in these regions are highly dependent on the activities and strategies of these incumbents. In contrast, Norsk hydro as the largest patentee in Oslo has merely 14 percent of the region’s green patents. The second largest patentees in the eight regions show a mixture of incumbents, new entrants, and a university.

4.2 Green Path Extension

Green path extension involves continued growth of existing green industries. Path extension takes place in East Jutland, which has been characterized for decades by its pre-existing green path development within the wind power industry. As we would expect, incumbents play a significant role in the continuation of the path. The wind turbine producer, Vestas, is the main driving force as it owns 78.3 percent of all green patents. The second largest incumbent (1.6 percent) is MHI Vestas Offshore Wind A/S (MHI Vestas Offshore), which was a joint venture between Mitsubishi Heavy Industries and Vestas from 2014-2021. Vestas focuses on the onshore wind turbines whereas MHI Vestas Offshore is specialized in offshore wind turbines. Overall, incumbents own 84% of the green patents in the region.

The dominance of the wind power sector in the region is also visible in the pool of patents by new entrants (14%). Envision Energy APS (Envision), a subsidiary of large Chinese wind turbine producer, is the largest patentee among the new entrants and takes up about 6 percent of green patents.

The relatedness analysis reveals high degree of technological relatedness between pre-existing regional knowledge strengths and the continued green inventive activities. In nine out of the top-ten most frequent co-classified CPC-classes, the RCA in East Jutland range between 1.16 and 4.85 in the years 1995-2000. Thus, the green technological development in the region is highly related to the existing knowledge base confirming the interpretation of regional path extension.

However, the continuous growth of the wind power industry is not only locally rooted. The share of global patents shows that the incumbents' green technology development is highly characterized by its global orientation, as 41% of the green patents are the results of cross-border collaboration. This indicates that the East Jutland wind power industry is strongly linked

to other knowledge hubs in the global innovation system of wind power, and that the green transition led by incumbents is supported by active knowledge sourcing from abroad.

4.3 Green Path Renewal

The analysis shows that all regions, except for East Jutland, are involved in green path renewal processes where existing non-green industries renew themselves in a sustainable direction (see supplementary material for comprehensive account). We find that path renewal can have an incremental or a radical character building on medium to high levels of relatedness. We describe two examples of path renewal, Västra Götaland with a radical character and Ostrobothnia with an incremental character.

The analysis confirms that the dominating actors in path renewal processes are the incumbents. In Västra Götaland, path renewal draws on the region's historical strength in automotive and aerospace industries in 'CCM and Transport' (53 percent). Incumbents are the main actor patenting in green transport technologies (97 percent) confirming the path renewal characteristics. The main actors are Volvo Group AB⁴ (50 percent), GKN Aerospace Sweden (17 percent) and Volvo Car AB (12 percent), which all have more than 80 percent of their green patents in the subclass CCM and Transport.

Common for these incumbents is that they focus on existing product-markets and seek to green their existing products by upgrading or replacing their core technology with greener alternatives within their respective transport domain, which is heavy-duty trucks, busses, air transport, or personal vehicles, respectively.

To exemplify, Volvo Group's patent applications mirror their dual strategy that on one hand aims to improve the ICE (F02) involving incremental changes and high relatedness. On the

⁴ Volvo Group AB's largest entity Volvo Lastvagnar AB accounts for 29% of all green patents in Västra Götaland

other hand it involves replacing ICE-technologies with electrical and hybrid technologies (B60L, B60W, H01M) indicating radical renewal processes that are technologically unrelated to the company's core knowledge base on ICE.

The relatedness measure confirms that for the green transport technology path we find a high degree of relatedness to the pre-existing regional knowledge base of Västra Götalands, where seven out of ten technology classes had $RCA > 1$. Interestingly, a qualitative assessment of the co-classified CPC classes without prior regional specialization counts electric power (i.e., H01, H02) and measuring and testing (G01), which are key to the electrification of transport. This confirms that renewal processes do build on a combination of related and unrelated knowledge fields.

The share of global patents of incumbents involved in greening the transport path is noticeably low compared to other incumbents. Volvo Group, has a relatively low level of global orientation (13 percent) and it is even lower for GKN (1.6 percent) and Volvo Car (3.6 percent), indicating that technological development is more locally founded than what we see for other paths.

In Ostrobothnia, the dominating path development process is also path renewal led by incumbents, who owns 96 percent of green patents in the region. Wärtsila is a leading global ship power supplier and provider of decentralised power generation solutions. Wärtsila draws up the main greening of the region with 89 percent of all green patenting, with its main activity in CCM and Transport (86 percent) and minor shares in Energy (9 percent) and Goods (4 percent). Within the transport area, the majority of Wärtsila's green patenting (88 percent) is related to improving ICE, treating exhaust gas, and using alternative fuels in their maritime propulsion systems (F02, F01). Hence, Wärtsila is involved in improving existing non-green technology rather than leading a radical transition towards replacing the core technology. The

relatedness measure corroborates that the green path in Ostrobothnia is highly related to the pre-existing knowledge base with seven out of ten technology classes having RCA measures from 1.1 to 47.7. With the highest specialisation in combustion engines (47.7) and storing or distributing gases (12.7).

The global orientation of the green technology development in Ostrobothnia is relatively low (17 percent), which indicates that knowledge sourcing seems to be more locally bounded.

Green path renewal is not confined to traditional ‘old dirty industries’. Nokia and LM Ericsson are incumbents contributing to path renewal of IT industry in Helsinki and Stockholm respectively. Nokia owns 28% of green patents in Helsinki, where 31% of green patents are in ‘CCM & ICT’. Similarly, LM Ericsson owns 42% of green patents in Stockholm, where 39% of green patents are within ‘CCM & ICT’. Both incumbents are engaged in greening of their existing business areas related to reducing energy consumption in communication networks (Y02D30/00). The relatedness measure, however, reveal medium levels of relatedness (5 out of 10 knowledge fields) indicating that the two green renewal paths draw on a combination of knowledge with and without prior regional specialization.

4.4 Regional path diversification

Green regional path diversification is the process where existing industries diversify into new greener markets by building on existing related knowledge. Two types of agent-based mechanisms characterize path diversification; incumbents diversify their business or startups spin out of existing firms and move into new greener markets based on existing related knowledge. Path diversification is found in four regions with varying degrees of contribution in overall green transition.

In Rogaland, that is known for its large oil industry, the incumbent oil company Equinor has taken out 44% of all green patents in the region, followed by the Equinor subsidiary Hywind

AS (3.5%). Equinor is highly diversified across the seven green technology areas with its largest shares in CCS & GHG and GHG and Energy. A detailed investigation of Equinor's patent portfolio shows that one part is focusing on greening existing activities (i.e. green path renewal) other parts clearly follows green path diversification in terms of applying their technology of drilling and injection technology to a new market for CO₂ capture. The relatedness analysis for the GHG & CCS-technology path in Rogaland reveals medium levels of relatedness with four knowledge fields with regional strengths prior to 2000 ('earth and rock drilling; mining' (E21), 'handling technical gases' (C10), 'conveying through pipes or tubes' (B65), 'ships or other waterborne vessels' (B63)). In consequence, moving into CCS involves firm diversification combining existing knowledge strengths with knowledge that is new to the region.

Hywind is example of path diversification in Rogaland. Hywind's technology is focused on floating offshore wind turbine installations and is part of an emerging energy path that make up 30 percent of the region's green inventive activity. Other new entrants in green energy counts Energreen Company focusing on clean energy from pressure in a fluid process system and Wave Energy AS patenting on wave energy. The relatedness analysis reveal an emerging path with low degree of relatedness to pre-existing regional knowledge strengths. Only two knowledge fields' ships or other waterborne vessels' (B63) and 'engineering elements related to gearing (F16H) were specialized knowledge fields prior to 2000. The green energy path is thus constituted by mix of firm diversification and startups that is only to a very low degree related to pre-existing knowledge in Rogaland.

Moreover, Rogaland has the lowest shares of global patents (5 percent) in their green development activities.

Another example of green path diversification is led by the incumbent company SKF AB in Västra Götalands County. SKF has 60 percent of their green patents in ‘GHG & Energy’ and the remaining in ‘CCM & Goods’ (23 percent) and ‘CCM and Transport’ (14 percent). The SKF AB has used their century long business strength in roller bearings to diversify into the wind power industry and patented their first invention related to wind (Y02E10/72) in 2001. This development signals path diversification process where competitive strength and knowledge about roller bearings are used in new market segments in wind power. The relatedness measure is medium for the incumbent driven green energy path drawing on four knowledge fields with specialization measures over one prior to 2000. The global connectivity measure for SKF AB is one of the highest, with 83 percent of their patents developed with global connection. This indicates that a diversification of the knowledge base as a result of SKF’s diversification into new markets draw to a high degree on extra-regional knowledge sources.

Green path diversification also characterize parts of the development in Copenhagen Suburbs. One example is the spinoff-firm Novozymes A/S focusing on enzymes for bioenergy production and enzymatic and probiotic animal feed. Novozymes became an independent company in 2000 when it was separated from the insulin-producer Novo Nordisk A/S. Novozymes diversified even further with Novozymes Bioag in 2007, which focuses on microbes and biopesticides for the agricultural sector. Novozymes green inventive activity constitute half of all patenting in the GHG & Energy path in Copenhagen suburbs. Although these new companies target new markets through new industrial application of technologies, the GHG & Energy path in Copenhagen Suburbs is strongly related to the pre-existing knowledge base with eight out of ten knowledge fields having specialization measures between 1.1 and 3.6. The high relatedness level may be because the technological development that led

to the spinout of Novozymes began in the 1980s and therefore form part of the existing regional knowledge base.

Another example of path diversification is the Oslo region where large Norwegian multinational company Norsk Hydro ASA is the main patentee (14 percent). A detailed investigation of Norsk Hydro's patents shows a rather broad engagement in green technology development across electro chemical processes, solar, floating offshore wind turbine installations, geophysical measuring and CCS. Another incumbent in the region is Yara International focusing on greening of fertilizers that was demerged from Norsk Hydro in 2003. The relatedness measure for all incumbents' green activities in the region shows low degree of relatedness with only three out of ten knowledge fields with specialization measures over one. In terms of global orientation, the Oslo region has the second highest share (33 percent) of patents developed from international collaboration, with the individual companies, Norsk Hydro and Yara Int., have 24 and 42 percent of their patents with global inventor teams respectively.

4.5 Green Regional Path Creation

Green regional path creation involves the development of new industries targeting new applications and markets. We see potential of path creation in all of the eight regions as our dataset has uncovered a large number of new entrants within each region within a wide range of green technologies. However, the magnitude and durability of the new entrants' technological development varies, which makes it difficult to analyze to what extent we see actual path creation in the eight regions. One consistent trend is that path creation tends to develop based on breakthrough knowledge developed at universities or research institutes and used in establishing new firms.

Copenhagen Suburbs distinguishes itself from the other regions by having a large share of university-based green inventive activity (24 percent), with the Technical University of Denmark (DTU) as the main actor. The relatedness analysis shows that DTU's green inventive activity are to a high degree unrelated to existing knowledge strengths of the region. Only three knowledge fields out of ten was characterized by specialization measures over one in the years prior to 2000.

A further analysis of the new entrants in Copenhagen Suburbs reveals many university spinouts from DTU. Within the CC Adaptation path these count Amminex Emissions Technology A/S (Amminex), Windar Photonics A/S, and Aquaporin A/S. Amminex was founded in 2005 with the aim to explore technology to remove toxic exhaust from diesel engines. Windar Photonics, founded in 2008, provides sensors to optimize wind turbines, and Aquaporin A/S, founded in 2005, focuses on cleaning of wastewater . Common for the new entrants within the path Adaptation is that they only to a limited degree build on regional specialization (3 out of 10 knowledge fields: F01, C01 and C12).

Another distinctive path is developed around GHG and Energy with contribution of DTU spinoffs, such as Biogasol APS that develops 2nd generation biorefinery equipment and technology. Biogasol later (2012) spun off another green startup, Estibio APS, focusing on bioethanol through fermentation technology. Topsøe Fuel cell can also be considered as a DTU spinoff as the company acquired DTU-developed technology and signed licensing agreements for over 40 patents taken by DTU. The close collaboration with Haldor Topsoe, the parent company, involved training of Topsoe Fuel cell staff at DTU. The GHG and Energy path also counts other startups such as Wave Star A/S (wave energy) and Logima APS (offshore wind installation vessels). The co-occurrence analysis confirms that new entrants within the path of GHG and Energy only to some extent build directly on regional strengths (four out of ten

knowledge fields: C12, C01, C10, C22). This analysis supports that new green transition paths are created by new entrants and universities in the region of Copenhagen Suburbs.

5 Discussion

Through the systematic analysis of eight Nordic regions, the paper shed light on the four main types of development paths observed in the regions and how different agents are involved in green transition in the early stage of path formation. It is important to notice that the analysis primarily covers emerging experimentation and green technological development characterizing the path formation stage, which potentially may lead to local increasing returns and network externalities supporting the materialization of new regional path development (Martin 2010; Njøs et al. 2020).

The analysis on the agents driving the green transition revealed that incumbents are key actors in driving green technology development in almost all regions. While the contribution of the incumbents varies among the regions, it clearly shows that incumbents do not only pursue continuity, but also drive change with regards to regional industrial development. Contrary to the conventional view on incumbents as the agents maintaining and reinforcing the existing economic structure (Neffke et al., 2018), some incumbents like Wärtsilä, Volvo, and Equinor show signs of breaking from potential ‘lock-in’ to non-green technological paradigms. Incumbents matter for understanding the substantial part of green transition patterns in Nordic regions.

A closer look at the green path development by incumbents shows that they are involved in diverse development paths. For example, Vestas drives path extension based on a clear green path that has existed in the region for decades. In this case, the incumbents are deepening the technological knowledge that is well-established in the region. On the other hand, firms like Volvo, Wärtsilä, and Equinor find themselves in ‘dirty’ industries, where regulations become

tighter to reduce the damage to the environment. These firms are, to a higher degree, pressured to pursue green technologies to meet the current market's demand or to explore new markets arising from green demand. As the literature suggests, the Nordic incumbents are most likely to engage in path extension, -renewal, and -diversification, where the firms build upon varying degrees of existing technology competences in developing green technologies.

As expected, path extension is characterized by high levels of relatedness, whereas green path renewal shows relatedness levels between medium and high. Relatedness measures for green diversification paths cover a wider spectrum from low to high depending on the timing of the diversification. The high relatedness measure for the diversification path in Copenhagen suburbs may be because the technological development involved in the green diversification was initiated in Novo Nordisk before 2000, which results in prior specialization in the related knowledge fields. The remaining diversification paths and green path creation show relatedness measures between low and medium, which indicates that these technology paths involve knowledge that is not a prior strength in the region.

In many cases, large incumbents active in green technology development show a high level of global connectivity in their innovation activities. These incumbents represent large multinational enterprises that own foreign subsidiaries in knowledge hotspots. The operations of MNEs facilitate knowledge transfer within and across the organizational and national boundaries (Ghoshal and Bartlett 1990; Kogut and Zander 1993) and create global knowledge pipelines for the regions (Bathelt, Malmberg, and Maskell 2004). MNE's subsidiaries are not only part of the intra-organizational network but are also engaged in extra-organizational networks in the local host environment (Meyer, Mudambi, and Narula 2011). These global networks provide a diverse source of knowledge as valuable input for new green technologies.

In the context of green innovation, the multinational firms' exposure to various institutional settings around the world would also stimulate the effort to develop new technologies to address climate change.

Compared to incumbents, new entrants like startups, spinoffs, foreign subsidiaries tend to contribute to the regional green transition to a lower extent. It is rather difficult to identify a distinctive path creation by new entrants due to a lack of scale and directionality of activities by these actors. Many new entrants developed 1-2 patents during the 15 years, and some disappeared shortly after they developed new technologies. However, when they develop green technologies, they are more likely to engage in path diversification and -creation. The new entrants tend to follow Schumpeterian Mark I dynamics through which firms are likely to widen the scope of technological development with stronger orientation to address new market demand (Breschi, Malerba, and Orsenigo 2000; Malerba 2000). The exception is newly-established foreign subsidiaries, as they enter the foreign location to reap the benefit of regional technological profile and are therefore likely to extend the current technological path. Envision in East Jutland is an excellent example of this case.

What is also noticeable in the case of new entrants are spinoffs, both from universities and incumbents, engaged in path diversification and -creation. This path development is most evident in the Copenhagen region, where university spinoffs from DTU and parent spinoffs from incumbents contribute to the green transition to a higher degree than in other regions. Universities provide breakthrough innovations that can potentially lead to new path creation through the establishment of spinoff firms. Parent spinoffs from incumbents are more likely to engage in path diversification, exploring new market opportunities with technologies related to the parent firm's technological competences (Klepper, 2010).

6 Conclusion

In most regions, multiple types of path development co-existed with various degrees of dominance in the respective regions. By directing attention to the agents driving the transition, our analysis shed light on the multiplicity and complexity of transition paths, partly driven by organizational-level strategies. . Two important messages can be derived from this observation. Firstly, regional paths may emerge and evolve through various phases of development. Identifying and supporting activities at the path formation phase characterized by experimentation and technological development, could potentially lead to a distinctive path development. Secondly, the green transition path development at the regional level should be understood in the light of organizational-level transition. These are valuable insights to keep in mind in fostering green transition movements in the regions.

This study focuses on firm level agency in understanding the regional transition by identifying actors conducting Schumpeterian Mark I and II types of innovations. As Isaksen et al. (2019) asserts, new growth paths require both firm level agency and system level agency that transforms the system settings to support the structural change of the region. Our results suggest that system level agents should be alert to multiple paths that co-exist in the region and provide suitable system conditions to facilitate the transition effort by various types of firms engaged in structural change.

While our analysis on patent data provides an in-depth understanding of the green transition from the technological perspective, it does not capture all aspects of green transition in the regions. We need to be cautious in interpreting the results from the study as green transition efforts can be made outside the technological sphere. It should also be noted that technologies documented in patents and owned by the organizations may not be actively utilized in the industrial settings or become commercialized. Whether the technologies investigated in this

study materialized in green transition in the regions is therefore up for discussion. Lastly, our analysis is less attentive towards more incremental and smaller-scale technological development as technologies of this sort are less patentable due to the costly patenting process.

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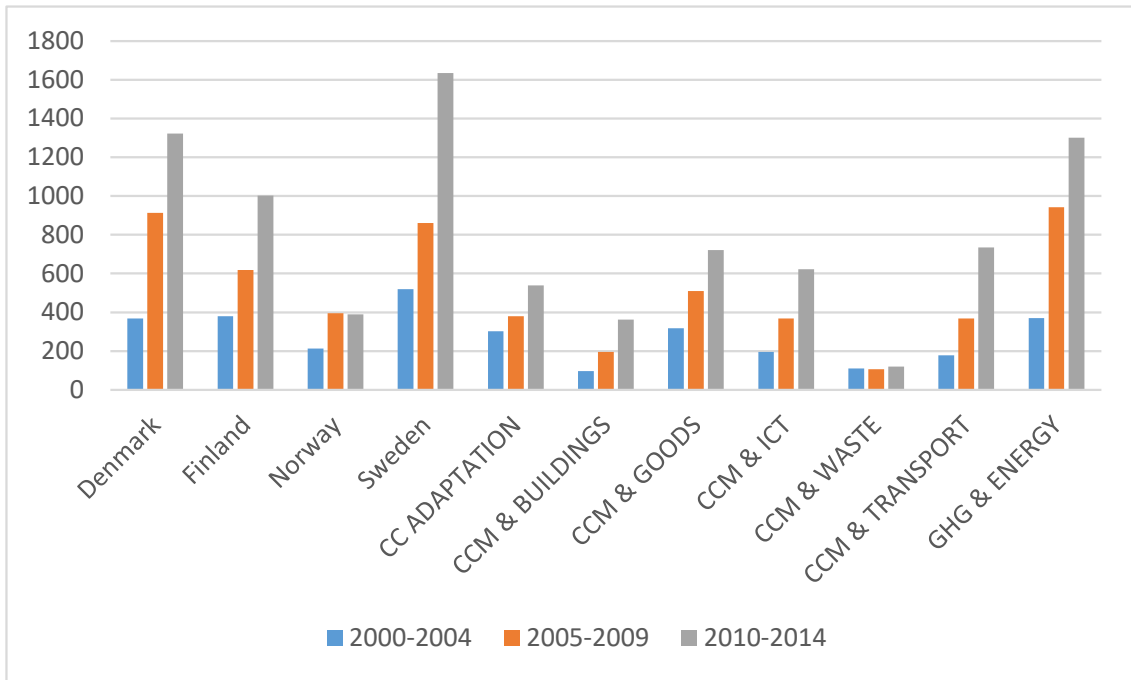


Figure 1: Development of green technological patenting activity across countries and technology areas for three 5 years periods. Source: own calculations based on PATSTAT 2018b(?)

Table 1: Spatial concentration of green patents across the Nordic NUTS3 regions, 2000-2014

	Number of NUTS 3 regions with green patents	Number of green patents	Share of green patents	Mean	Median	St.dev
All green patents	68	9097	100%	133.8	29.5	300.6
All green patents	25	8220	90%	328.8	147	430.6
All green patents	8	6361	70%	795.1	615	505.7
Green patents groups:						
CC ADAPTATION	11	847	71%	77.0	57	47.4
CCM & BUILDINGS	9	465	71%	51.7	40	30.6
CCM & GOODS	7	1126	72%	160.9	111	107.6
CCM & ICT	2	1106	89%	553.0	553	86.0
CCM & TRANSPORT	5	1010	73%	202.0	146	147.0
CCM & WASTE	11	221	71%	20.1	13	23.8
GHG & ENERGY	8	1871	71%	233.9	165.5	211.4

Table 2: Green patent activity in the selected regions

NUTS3	Region	Regional type*)	Total green patent 2000-2014	Percent within country	Population in 2014	# patent /population (%)	Percentage of green patents in the region**)	Diversity (Shannon Entropy)	Share of global patents	Top two technology areas
DK042	East Jutland	INC	1139	40	851,769	0.134	39.48	1.032	35	<ul style="list-style-type: none"> • GHG & ENERGY (67%) • CCM & GOODS (20%)
DK012	Copenhagen suburbs	PU	550	20.61	530,612	0.104	10.76	1.473	31	<ul style="list-style-type: none"> • GHG & ENERGY (39%) • CCM & GOODS (30%)
FI1B1	Helsinki-Uusimaa	PU	1484.5	70.17	1,585,473	0.094	6.16	1.699	25	<ul style="list-style-type: none"> • CCM & ICT (31%) • CCM & GOODS (27%)
FI195	Ostrobothnia	PRR	184.5	7.74	180,384	0.102	55.83	0.810	17	<ul style="list-style-type: none"> • CCM & TRANSPORT (76%) • GHG & ENERGY (15%)
NO011	Oslo	PU	225.25	23.35	634,293	0.036	7.81	1.700	33	<ul style="list-style-type: none"> • GHG & ENERGY (30%) • CC ADAPTATION (28%)
NO043	Rogaland	INC	170.75	16.91	459,444	0.037	14.24	1.669	5	<ul style="list-style-type: none"> • GHG & ENERGY (30%) • CC ADAPTATION (30%)
SE110	Stockholm county	PU	1603	48.87	2,163,042	0.074	5.75	1.584	30	<ul style="list-style-type: none"> • CCM & ICT (39%) • CCM & TRANSPORT (25%)
SE232	Västra Götaland County	PU	683	21.41	1,615,084	0.042	12.62	1.384	23	<ul style="list-style-type: none"> • CCM & TRANSPORT (53%) • GHG & ENERGY (18%)

*) PU= Predominantly urban, INC= Intermediate region close to a city, INR= Intermediate region remote, PRC= Predominantly rural region close to a city, PRR= Predominantly rural region remote.

***) Calculated based on the Patents by regions data from OECD (https://stats.oecd.org/Index.aspx?DataSetCode=PATS_REGION#). Number of environment-related patent applications to the EPO by applicant's country of residence between 2000-2012 / Total number of patent applications to the EPO by applicant's country of residence between 2000-2012

Table 3: Largest and second largest patentee and new entrants, incumbent, and university share

NUTS 3	Region	Incumbent share (%)	New entrants share (%)	University/ research institute share (%)	Largest patentee	Largest patentee share (%)	Second largest patentee	Second largest patentee share (%)
DK042	East Jutland	84	14	2	VESTAS WIND SYSTEMS A/S	78	ENVISION ENERGY (DK) APS	6
DK012	Copenhagen suburbs	53	23	24	NOVOZYMES A/S	24	THE TECHNICAL UNIVERSITY OF DENMARK	22
FI1B1	Helsinki-Uusimaa	86	9	5	NOKIA OYJ	28	METSO OUTOTEC OYJ	10
FI195	Ostrobothnia	96	4	0	WÄRTSILÄ FINLAND OY	86	OY KWH PIPE AB	4
NO011	Oslo	50	48	2	NORSK HYDRO ASA	14	PGS GEOPHYSICAL AS	8
NO043	Rogaland	64	32	4	EQUINOR ASA	44	ENERGREEN COMPANY	4
SE110	Stockholm County	90	10	0	TELEFONAKTIEBOLAG ET LM ERICSSON	42	SCANIA CV AKTIEBOLAG	30
SE232	Västra Götaland County	88	12	0	VOLVO LASTVAGNAR AKTIEBOLAG	29	AKTIEBOLAGET SKF	17

Table 4: Regional path development types, main agents, relatedness and global connectivity

Type of regional path development	Agents	Relatedness	Global Connectivity of main agents
Extension			
East Jutland	Vestas, MHI Vestas, Envision	High for wind	High
Renewal			
Västra Götalands (Radical)	Volvo Group, GKN, Aerospace, Volvo Car	High for transportation	Low
Ostrobothina (Incremental)	Wärtsila	High	Medium
Helsinki	Nokia, Nokia Solutions and Networks	Medium	High
Stockholm	LM Ericsson	Medium	High
Diversification			
Rogaland	Equinor, Hywind, Refa, Energreen Company, Wave Energy	Medium for CCS Low for GHG & Energy	Low
Västra Götalands	SKF AB	Medium	High
Copenhagen Suburbs	Novozymes, Novozymes Bioag	High	High
Oslo	Norsk Hydro ASA, PGS Geophysical AS, Sargas AS	Low	High
Creation			
Copenhagen Suburbs	DTU, Amminex, Windar Photonics, Aquaporin, Biogasol, Estibio, Topsøe Fuel Cell, Wave Star Logima	Low for adaptation Medium for GHG & Energy	Medium