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Environmental policies and environmental technologies

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Environmental policies and environmental technologies

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Contents

Foreword

COWI was commissioned by the Danish Environmental Protection Agency to undertake the study "Environmental policy and environmental technology. The study was conducted from December 2010 to October 2011.

The projected was supported by a steering group consisting of:

Jan Tjeerd Boom (EPA) (chairman)
Christian Fischer (Copenhagen Resource Institute)
Karin Dahlgren (The Nature Agency)
Erik Thomsen (former employee in EPA)
Niels Henrik Mortensen (EPA)

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Further, we would like to thank the OECD for providing us with data and for input to fruitful discussions. Representatives of the OEDC in the project were:
Nick Johnstone
Ivan Hascic

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Conclusions and summary

Environmental policies are expected to have significant influence on the nature and extent of ongoing innovation in environmental technology. Mechanisms such as environmental legal requirements, economic instruments and standards create a demand for environmental technology, however, the effect of such mechanisms will vary with the design and the chosen implementation strategy. Further, some instruments will be designed to stimulate environmental technology innovation directly whereas other measures will be designed to work indirectly.

The main objective of a new environmental policy is to preserve and improve the environment; still the policy should consider a number of other interests. There is increasing focus on achieving a cost-effective environmental policy, while at the same time ensuring continuous improvement of the applied technology. Due to the current economic challenges, the export potential and the employment opportunities are important aspects of policy formulation.

The present study should be viewed in this context and with the aim of providing the Danish Environmental Protection Agency with a set of recommendations for environmental policy formulation, which can stimulate environmental technology innovation. The study is based on findings from analysis of patent data.

Purpose
The overall purpose of the study is to analyse the relationship between environmental policies, the particular regulatory instruments applied and their effect on innovation in environmental technologies.

Literature
The literature review provides an overview of the different measures that can be used to explore the link between the environmental policy lead and the level of innovation or technological development. The different measures provide different results even when using the same measure. As a result, it can be concluded that there is no certain and generally accepted way of determining if the link is there and to what extent. So far, the use of patent data in Denmark has been very limited, and therefore the results of this analysis cannot be compared with other, similar analyses.

Further, the study provides an overview of the development in the Danish environmental technologies and Danish strongholds. Together with the description of four environmental policy areas (air, waste, water, soil), the patent data categories are identified.

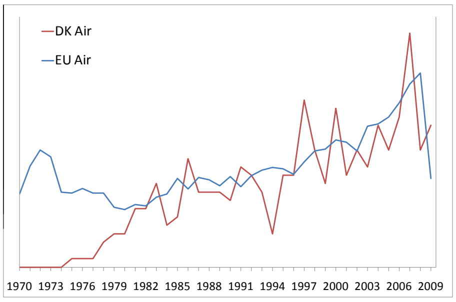
Result of the analysis
The aim of this study is to test the usefulness of patent data in analysing the impact of environmental policy on innovation of environmental technologies. Four main policy areas - air, water, waste and soil remediation - were identified, and patent data for those areas were compiled by the OECD. Data included not only Danish patent applications but also all patent applications within those areas. The scope of data included patent applications but not patent grants, since patent applications are thought to have a higher correlation with policy shocks.

The overall conclusion is that there is no direct link between specific policy initiatives and the development in the number of patent applications. Likewise, the increase in patent activity at the beginning of the 1980s cannot be ascribed to the development of an environmental policy as the general level of Danish patents rose with the same factor. Data were used to illustrate the development in patent activity over time as well as across countries. However, the types of analyses presented in this report should not stand alone, but be part of an overall approach, which includes other sources of information and more in-depth analyses of patent data. Given enough time, the patent database could in principle be used to identify patents directly relevant to specific policy initiatives and even to follow these technologies as they evolve over time.

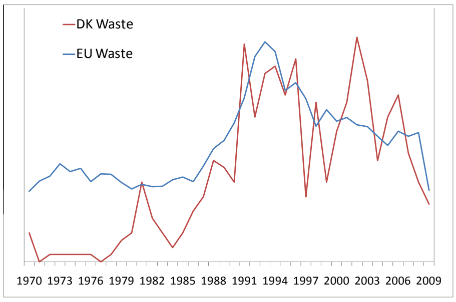
The time series analysis revealed a close relationship between patent activity in three[1] of the four policy areas and the patent activity in the EU. On the other hand, the analysis could not confirm a direct relationship between specific Danish regulations and patent applications.

The figure below illustrates the relationship between Danish and EU patent applications for the four selected policy areas, waste, water, soil and air. The red lines are the Danish applications whereas the blue lines represent the total number of EU applications.

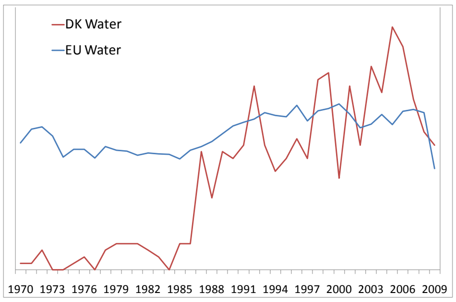
Air



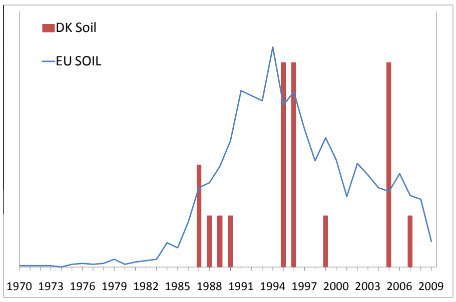
Waste



Water



Soil

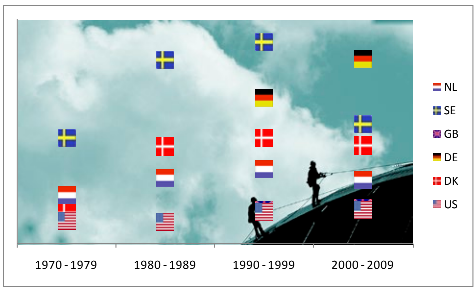


The cross-country analysis of competitiveness seems to indicate that Denmark is not as competitive in terms of patenting abroad as some of our neighbouring countries. Waste is the only area where Denmark is above the average in terms of patents abroad per billion GDP. Comparing these results with the total, national R&D spending, we find a weak indication that Denmark does not derive maximum advantage of this investment.

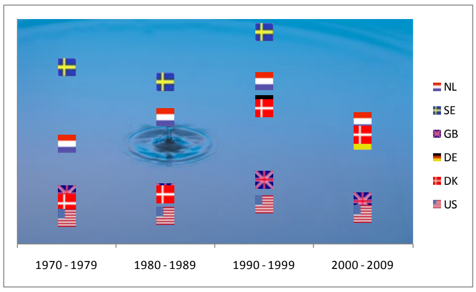
[1] Patent applications in soil remediation were simply too few to allow any kind of statistical testing.

Patent applications outside applicant's home country

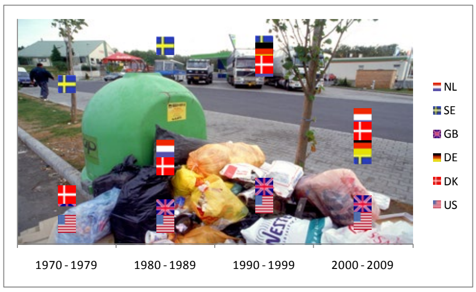
Air



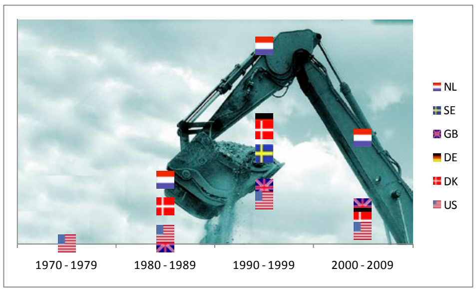
Water



Waste



Soil



A closer look at the different types of analysis on Danish patent data reveals that, competitively, solid waste seems to be the most successful policy area in terms of innovation.

From the experience of using patent data as indicators of innovation, it can be inferred that it is not possible to determine if there is a relationship between policy shock and innovative developments. Further, it is questionable whether the number of patent applications is a good measure of innovation. At least, this analysis has not been able to prove this relationship. This is also supported by the rather diverse conclusions of the literature study, which did not provide certainty of the success of a specific measure. Further, the findings of studies using the same measures or for that matter other measures show large variations.

Sammenfatning

Miljøpolitikker forventes at kunne have afgørende betydning for karakteren og omfanget af miljøteknologisk innovation. Forskellige mekanismer, herunder lovbestemte miljøkrav, økonomiske instrumenter og standarder skaber efterspørgsel efter miljøteknologi, men effekten af tiltagene afhænger af udformningen og den valgte implementeringsstrategi. Derudover sondres mellem instrumenter med direkte effekt på miljøteknologisk innovation og instrumenter med indirekte effekt.

Selv om hovedformålet med en ny miljøpolitik er at bevare og forbedre miljøet, skal den også tage hensyn til en række andre interesser. Der lægges større og større vægt på, at nye politikker både er omkostningseffektive og sikrer en løbende forbedring af den anvendte teknologi. Med baggrund i de nuværende økonomiske udfordringer er eksportpotentiale og beskæftigelsesmuligheder vigtige aspekter i politikudformningen.

Dette er baggrunden for nærværende studie, som har til formål at give Miljøstyrelsen en række anbefalinger til, hvordan miljøpolitikker kan udformes, så de stimulerer miljøteknologisk innovation. Studiet er baseret på resultaterne af en analyse af patentdata.

Formål
Det overordnede formål med studiet er at analysere forholdet mellem miljøpolitikker, de anvendte reguleringsinstrumenter og deres effekt på miljøteknologisk innovation.

Litteratur
Litteraturgennemgangen giver et overblik over de forskellige instrumenter, som kan anvendes til at undersøge sammenhængen mellem den fremherskende miljøpolitik på et reguleret område og innovationsstadet eller den teknologiske udvikling. Anvendelsen af de forskellige instrumenter giver forskellige resultater, selv når det samme instrument anvendes. Det kan derfor konkluderes, at der ikke findes én bestemt og alment anerkendt metode til at fastslå, om der er en sammenhæng, og i bekræftende fald, i hvilken grad. Indtil videre har brugen af patentdata i Danmark være begrænset, og resultaterne af indeværende analyse kan derfor ikke sammenlignes med andre, lignende analyser.

Studiet giver desuden et overblik over udviklingen i dansk miljøteknologi og de danske styrkepositioner. Som en del af beskrivelsen af de fire miljøpolitiske områder (luft, affald, vand og jord), identificeres patentdatakategorierne.

Resultatet af analysen
Formålet med indeværende studie var at teste anvendeligheden af patentdata til at analysere effekten af miljøpolitikker på miljøteknologisk innovation. De fire vigtigste politikområder blev identificeret – luft, vand, affald og jordrensning, og patentdata for disse områder blev derefter indsamlet af OECD. Data er ikke begrænset til danske patentansøgninger, men omfatter alle patentansøgninger inden for de nævnte områder. Data omfatter kun patentansøgninger og således ikke udstedte patenter, da der antages at være en større sammenhæng mellem patentansøgninger og chokeffekten af en ny politik.

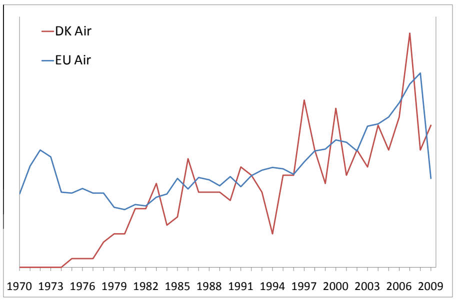
Den overordnede konklusion er, at der ikke kan påvises nogen direkte forbindelse mellem en specifik politik og antallet af patentansøgninger. Ligeledes kan stigningen i patentaktiviteten i

starten af 1980'erne ikke tilskrives udviklingen af en specifik miljøpolitik, da det generelle niveau for danske patenter steg tilsvarende i samme periode. Der er anvendt data til at beskrive udviklingen i patentaktiviteten såvel over tid som på tværs af lande. Imidlertid kan den type analyser, som præsenteres i indeværende rapport, ikke stå alene, men må ses som en del af en større sammenhæng, som omfatter andre informationskilder og yderligere tilbundsgående analyser af patentdata. Med tiden skulle patentdatabasen i princippet kunne bruges til at identificere patenter, som kan relateres direkte til specifikke politikker, og ydermere til at følge de relaterede teknologiers udvikling over tid.

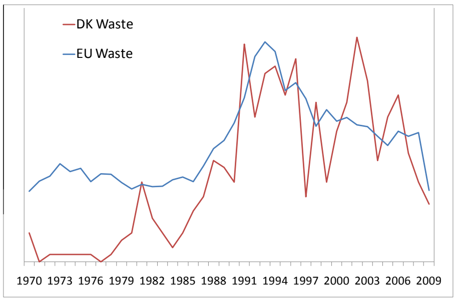
Analysen af tidsserier fandt, at der er en tæt sammenhæng mellem patentaktiviteten inden for tre[2] af de fire politikområder og patentaktiviteten i Europa som helhed. Dog kunne analysen ikke bekræfte, at der er en direkte sammenhæng mellem specifik dansk regulering og antallet af patentansøgninger.

Figuren nedenfor beskriver sammenhængen mellem patentansøgninger fra Danmark og EU for de fire udvalgte politikområder: affald, vand, jord og luft. De røde linjer angiver danske ansøgninger, mens de blå linjer angiver det samlede antal ansøgninger i EU.

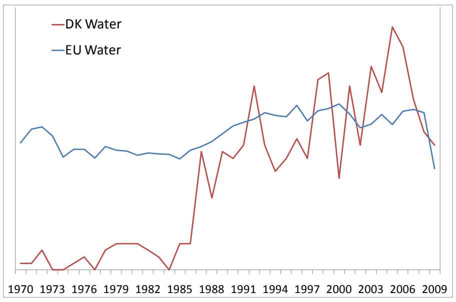
Luft



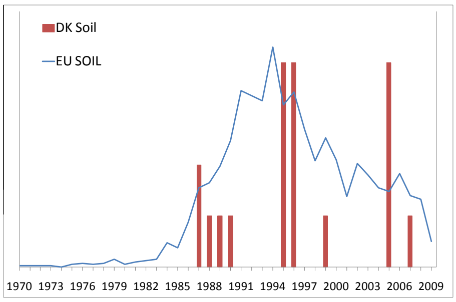
Affald



Vand



Jord

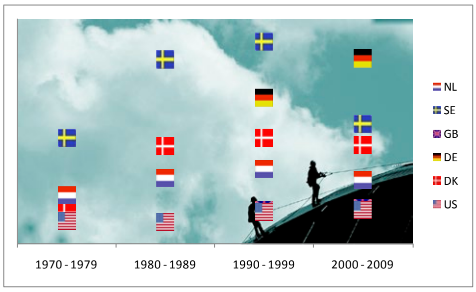


Den tværgående landeanalyse af konkurrenceevnen antyder, at Danmark ikke er helt så konkurrencedygtig, hvad angår patenter i udlandet, som nogle af vores nabolande. Affaldssektoren er det eneste område, hvor Danmarks patentansøgninger i udlandet ligger over gennemsnittet pr. milliard BNP. En sammenligning af disse resultater med de samlede forsknings- og udviklingsomkostninger giver en svag indikation af, at Danmark ikke får maksimalt udbytte af denne investering.

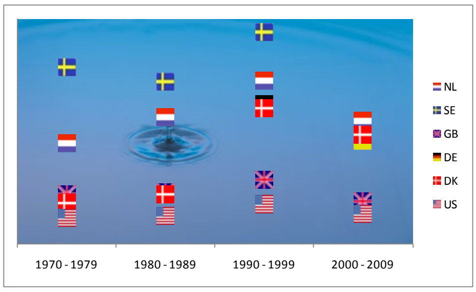
[2] Der var for få patentansøgninger inden for jordrensning til, at der kunne udføres statistiske tests.

Patentansøgninger uden for ansøgers hjemland

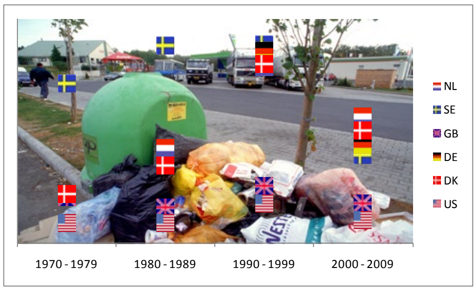
Luft



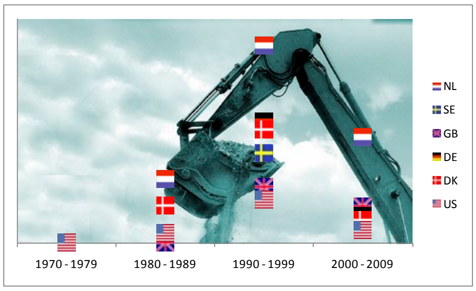
Vand



Affald



Jord



En nærmere gennemgang af de forskellige analyser af danske patentdata viser, at ud fra et konkurrencemæssigt synspunkt har fast affald været det mest succesfulde politikområde inden for miljøteknologisk innovation.

Erfaringerne med at anvende patentdata som indikatorer for innovation fastslår, at der ikke kan påvises nogen sammenhæng mellem chokeffekten af en ny politik og innovationsudviklingen. Endvidere er det usikkert, om antallet af patentansøgninger er en passende indikator for innovation. Dette studie har ikke været i stand til at påvise denne sammenhæng. Dette bekræftes også af de divergerende konklusioner fra litteraturgennemgangen, som ikke har kunnet skabe vished for, at et specifikt instrument har haft den ønskede virkning. Derudover er der store variationer i resultaterne af studier, der har undersøgt de samme instrumenter eller for den sags skyld andre instrumenter.

1. Introduction

1.1 Background

Environmental policies are expected to have significant influence on the nature and extent of ongoing innovation in environmental technology. Mechanisms such as environmental legal requirements, economic instruments and standards create a demand for environmental technology, however, the effect of such mechanisms will vary with the design and the chosen implementation strategy. Further, some instruments will be designed to stimulate innovation of environmental technologies directly whereas others will be designed as indirect measures.

The main objective of a new environmental policy is to preserve and improve the environment; still the policy should consider a number of other interests. There is increasing focus on achieving a cost-effective environmental policy, while at the same time ensuring continuous improvement of the applied technology. Due to the current economic challenges, the export potential and the employment opportunities are important aspects of policy formulation.

This study should be viewed in this context and with the aim of providing the Danish Environmental Protection Agency with a set of recommendations for environmental policy formulation, which can stimulate innovation in environmental technologies. The study is based on findings from analysis of patent data.

1.2 Purpose

The overall purpose of the study is to analyse the relationship between environmental policies, the particular regulatory instruments applied and their effect on innovation in environmental technologies.

In particular, four themes were identified for further study, namely:

- How do environmental policies in general support innovation in (new) environmental technologies?
- How has the actual environmental policy influenced the development of selected environmental technologies?
- How is the competitiveness of Danish environmental technologies in selected areas?
- What are the most important recommendations that can be drawn from the analysis of environmental policy formulation if it is to support the innovation in environmental technologies?

1.3 Scope of the study

To investigate the effect of a new environmental policy on technological development, the study will look at four policy areas, namely waste, water, air and contaminated soil. These are the fundamental areas in the context of environmental policy and its history over the past decades.

As mentioned above, the analysis will be based on patent data, which we will use to look into the selected policy areas to identify patent applications. In this manner, we aim to identify the relationship between environmental policies and technological innovation.

This particular method has been chosen because patents are an interesting and readily available source of information on technological innovation. Furthermore, the classification system of

Intellectual Property Rights (henceforth IPRs) allows for isolation of environmentally related innovations. By selecting particular areas, the policy and the instruments used can be analysed.

Another potential indicator is R&D spending, however, as opposed to information on R&D spending or the number of researchers employed, patents are indicators of innovative output. Whereas input data such as R&D spending reflect the effort put into innovation, output data such as patents reflect the 'productivity' of the input. Another advantage of patent data is a more detailed level of data, which enables us to isolate environmental technologies for cross-country comparison. In contrast, the share of environmental R&D is not easily isolated from overall R&D expenditure.

Another example of a potential indicator of innovation output is scientific publications; however, this type of indicator indicates the extent of knowledge sharing among scientists (e.g. citations etc.), rather than technological knowledge leading to commercial activity.[3] Chapter 2 of this report includes a literature review of previous studies that have investigated the link between environmental policies and environmental technologies. The scope of the literature review has been broadened in response to the wishes of the Danish Environmental Protection Agency and now covers as well literature using patents and other "hard" economics measures as well as literature measuring innovation by more qualitative means.

The OECD[4] has previously used patents as indicators of innovation in an international context. In the OECD analysis, focus was on comparing country characteristics (e.g. the level of ambition of a particular policy) via econometric analysis. The study did not aim at testing the usage of patent data towards environmental policy development; rather it aimed at providing a cross-country comparison of the effect of a certain category of policies. Therefore, an underlying purpose of this study is to test whether patents can be used to establish a statistically significant relationship between Danish environmental policies and innovation in environmental technologies in Denmark.

Competitiveness will be addressed by comparing the number of patents applied for by Danish companies abroad with the same number in four selected neighbouring countries and the US. Further, for the same countries, the number of patents applied nationally and to the EPO divided by BNP has been compared. This could be interpreted as a general measure of innovation in the countries.

The available amount of patent data was much more substantial than initially expected. This allows us to make large, accumulated analyses and identify general trends in environmental technology innovation rather than limit the analysis to selected technologies. To reflect this positive development, we have adjusted the methodology slightly. Consequently, we will no longer analyse technology stakeholders and single patents; but instead concentrate on providing a more general analysis and recommendations in each of the four policy areas. The recommendations will focus environmental policy formulation to stimulate environmental technology innovation in the future.

1.4 Using patents as indicators of innovation

This study uses patent data from the patent database PATSTAT. In addition to the reasoning above, patent data are also interesting in the context of environmental innovation for a number of reasons[5]:

1. Most major inventions are patented
2. Patents are an output indicator
3. Data on patents can be categorised into very specific technologies
4. Data are readily available
5. Patents are based on objective standards
6. Data are consistent.

3 OECD (2008), Environmental Policy, technological Innovation and Patents, chapter 1
4 OECD (2008), Environmental Policy, technological Innovation and Patents
5 OECD (2008), Environmental Policy, technological Innovation and Patents, p.32.

The patent database records patent applications as well as patent grants. In this study, environmental innovation will be measured based on patent applications rather than patent grants. While patent applications are typically filed at the earliest possible stage, the timing of patent grants is much more uncertain as the patent grant process may take years. Consequently, patent applications are much more likely to be highly correlated with the timing of environmental policies. In addition, the costs associated with preparing and filing a patent application are substantial. This increases the likelihood that patent applications are only filed on technologies with an expected high commercial value; or in other words, there is reason to believe that patent applications are a fair representation of the technologies that will end up being patented and becoming a commercial success.

2. Literature review

2.1 Background

Analysis and discussion of the link between the environmental policy lead and the effect on the innovation in the society go a long time back.

The following sections give an overview of the implications in literature of measuring the link between environmental policies and environmental technologies and the results of these measurements.

2.2 Indicators used to measure eco-innovation

This section will present a number of indicators that have been used or can be used to investigate eco-innovation development.

Eco-innovation can be identified by looking at the following four measures (Arundel and Kemp, 2009, p. 15):

- **Input measures**: research and development (R&D) expenditure, R&D personnel, and innovation expenditure (including investment in intangibles, such as design expenditure and software and marketing costs)
- **Intermediate output measures**: the number of patents; numbers and types of scientific publications, etc.
- **Direct output measures**: the number of innovations, descriptions of individual innovations, data on sales of new products, etc.
- **Indirect impact measures** derived from aggregate data: changes in resource efficiency and productivity using decomposition analysis.

Each of these measures has certain characteristics and advantages. In the following, these characteristics will be briefly described, focusing on data requirements.

Input measures

R&D statistics are widely used in innovation research despite their limitations given their tendency to capture formal R&D, typically in formal R&D laboratories, and to underestimate R&D conducted by smaller firms, which is often done on a more informal basis (Kleinknecht et al, 2002). In addition, R&D statistics cannot capture non-technological innovation, such as marketing, organisational and institutional innovations and the efforts of service sectors.

Data on environmental R&D are extremely limited in scope. The only consistent data across OECD countries concern government budget appropriations or outlays allocated to R&D (GBAORD) in 'control and care for the environment'. These refer to budget provisions instead of actual expenditure. The data include both current and capital expenditure and cover not only government-financed R&D in government establishments, but also government-financed R&D in business enterprises, private non-profit sectors and academia as well as R&D undertaken abroad.[6]

Actual innovations are more likely to arise from at least partly privately funded R&D. The latter is therefore a better indicator of environmental innovation. In a private sector context, environmental

6 See http://www.estatisticas.gpeari.mctes.pt/archive/doc/Government_budget_appropriations_or_outlays_on_R_D_0.pdf

R&D can be defined in two ways: (i) the part of R&D that is environmentally motivated and (ii) the part that is environmentally relevant in reducing the environmental burden either in the company or elsewhere (at the point of use). The OECD project "Environmental Policy and Firm-Level Management" investigated which part of R&D budget was used for environmental purposes and the total value of this, finding significant differences in the share of environmental R&D (ranging from 13% for Canadian eco-innovating companies to 35% for Norwegian eco-innovating companies) (Johnstone, 2007). For the purpose of analysing the effect of particular environmental policies on R&D, the term environment is too broad.

To become more meaningful to research and possibly also to companies (to whom the term environment may be too broad); the term environment has to be broken down into meaningful categories, such as waste reduction, resource use reduction, pollution prevention and control etc. Besides asking questions about the value of different types of environmental R&D, it is advisable also to inquire whether R&D activity in particular categories has increased over a certain period. Increases in environmental R&D are indicators of stimuli.

Intermediate output measures[7]

These consist of patents and scientific publications and citations. Patents are the most commonly used data to construct intermediate indicators (Dodgson and Hinze, 2000, p. 103) of *inventions*. A patent is an exclusive right to exploit (make, use, sell, or import) an invention over a limited period (20 years from filing) in the country where the application is made. Patents are granted for inventions which are novel, inventive, and have an industrial application (OECD 2004, p.8), but patents do not need to be commercially applied. Consequently, they are not direct measures of innovation. Furthermore, the standard of novelty and utility for award of patents seem somewhat low. The European Patent Office (EPO) awards patents for about 70% of all applications while the US PTO awards patents for about 80% of all applications. The standard of novelty appears lower in the US than in Europe. In the US, the invention must be 'non-obvious'; in Europe, an inventive step is required.

As an indicator of innovation, patents have several advantages over R&D expenditure: (*i*) they explicitly give an indication of inventive output, (*ii*) they can be disaggregated by technology group, and (*iii*) they combine detail and coverage of technologies (Lanjouw et al., 1998). Moreover, they are based on an objective and slowly changing standard because they are granted based on novelty and utility (Griliches 1990).

Patent counts can be used as an indicator of the level of innovative activity in the environmental domain. In the same way as for innovation in general, patents covering *eco-inventions* can be used to measure research and inventive activities and to study the direction of research in a given technological field. The decision to classify a certain activity as an eco-innovation depends on the environmental effects. To be picked up as an eco-patent, the environmental gain must be described or data on the environmental benefits of a patent class must be available. If not, environmental inventions with non-intentional side effects will not be identified in patent analysis.

An important development is the EPO/OECD PATSTAT database, which is a new database containing 60 million patent applications from over 80 national and regional patent offices, going back as far as the 1880s in some cases (Johnstone and Hascic, 2008a, p. 8). In this database, not only inventions in end-of-pipe technologies but also inventions in 'more integrated technological innovations' (such as fuel cells for motor vehicles) may be identified (Johnstone and Hascic, 2008a, p. 8).

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7 From Arundel and Kemp (2009)

With the new database, measurement possibilities increase. Still, a number of additional limitations of patents need to be taken into account. First, patents measure inventive activity, not real innovation. Second, not all eco-innovations can be usefully analysed through patent analysis. Eco-patents mainly measure identifiable inventions that underlie green *product* innovations and *end-of-pipe technologies*, whose environmental impacts are specific aims and motivations of the inventions. For these kinds of eco-inventions and the innovations that result from them, it is acceptable to use patent analysis, provided they are carefully screened (for which one may use the four-step method described below). Citation analysis helps to select relevant patents and eliminate patents that have no commercial application. For other types of innovation, such as organisational innovation and process changes, patent analysis is less useful because many of these innovations are not patented. Third, patent classification systems do not provide specific categories for environmental patents, and there is no widely accepted agreement in the literature as to what constitutes an environmental technology. The practical solution around this problem is to use relevant search terms. Words such as 'environmental' or 'environment' are not helpful because they may be overly broad or may refer to non-ecological aspects.

For patent analysis, the following four-step method – developed by de Vries and Withagen (2005) - is useful[8]:

- Step 1: Choice of relevant parameters (could be the pollutant under consideration, for example, SO_2, or an environmental technology, such as wind power).
- Step 2. Patent search using keywords – based on relevant environmental technology aspects – in order to generate a set of *potentially* relevant patents
- Step 3. Screening of the abstracts of the patents generated in order to determine whether it was, indeed, a relevant patent. Irrelevant patents are excluded.
- Step 4. Retrieval of patent families. These are the patent applications the inventor filed in countries other than the home country. This helps to exclude patents of minor importance.

Direct output measures

A direct output measure of eco-innovation can be obtained from announcements in trade journals[9] and product information databases. An example is the green car database established by Yahoo.

The problem is the limited number of product databases featuring environmental information. For specific products, a database of eco-innovation output could be created by sampling the 'new product announcement' sections of technical and trade journals or by examining product information provided by producers. The strengths of the product announcement sampling method are that: [10]

- they measure *actual* innovations introduced in the market place
- the indicator is timely: announcement times are close to the date of commercialization.
- the data are relatively cheap to collect and do not require direct contact with the innovative firms. However, data collection is very time consuming but can be undertaken by e.g. students.
- it is possible, from the description, to infer information about the innovation, for instance whether it is a radical innovation, and performance characteristics.

Some limitations are[11]:

- Adequate journal selection is a necessary precondition for ensuring comprehensive coverage.
- In-house process innovations are rarely reflected in technical and trade journals. Direct innovation surveys probably provide superior indicators for environmental process innovations.

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8 The 4 step method was developed by de Vries and Withagen (2005).

9 A trade journal or trade magazine is a periodical, magazine or publication printed with the intention of targeting marketing to a specific industry or type of trade/business. Trade refers to business, not to exports and imports.

10 Coombs et al. (1996) and Kleinknecht (1993).

11 Coombs et al. (1996) and Kleinknecht (1993).

- Although literature-based innovations can be objectively counted, they can only be subjectively valued in importance.

Information from trade journals can be available digitally. Digital information about products can also be available from the internet – allowing researchers to track the evolution of performance characteristics for selected products. Digital new announcement and consumer information databases are a neglected source of innovation output indicators, which should be used more often. Such research is aided by product disclosure requirements in the EU, where manufacturers are required to inform consumers on various environmentally relevant aspects, such as the kind of materials used, and energy efficiency. This information is printed on special product labels, which can be analysed.

Indirect impact measures

Eco-innovation can be indirectly measured based on eco-efficiency performance data or data on changes in absolute impact. Eco-efficiency is a broad concept that is usually measured at the product or service level. Eco-efficiency means

- *less environmental impact per unit of product or service value* (WBCSD, 2000).

$$\frac{\text{Product or service value}}{\text{Environmental influence}}$$

An improvement of the ratio of value added and lessen the environmental influence is indicative of eco-innovation. Such ratios can be determined for company processes, company products, sectors and for nations.

From the above discussion, it is clear that no indicator is perfect; they all have their own specific strengths and weaknesses. According to Arundel and Kemp (2009, p. 34), no single method or indicator is likely to be sufficient. In general, one should therefore apply different methods to analyse eco-innovation – to see the 'whole elephant' instead of just part of it."

Table 1 gives an overview of the usefulness of various indicators for measuring eco-innovation.

TABLE 1
THE USEFULNESS OF VARIOUS INDICATORS FOR MEASURING ECO-INNOVATION

Mode of measurement	Data sources	Strengths	Weaknesses
Generic data sources			
Input measures	R&D expenditures, R&D personnel, other innovation expenditures (e.g. design expenditures, software and marketing costs)	Relatively easy to capture related data	Tend to capture only formal R&D activities and technological innovations.
Intermediate output measures	Number of patents, numbers and type of scientific publications	Explicitly provide an indication of inventive output. Can be disaggregated by technology groups. Combine coverage and details of various technologies.	Measure inventions rather and innovations. Biased towards end-of-pipe technologies. Difficult to capture organizational and process innovations. No commonly agreed and applied category for environmental innovations. The commercial values of patents vary substantially.
Direct output measures	Number of innovations, descriptions of individual innovations, sales of new products from innovations	Measure actual innovations. Timeliness of data. Relatively easy to compile data. Can provide information about types of innovations, i.e. incremental or radical.	Need to identify adequate information sources. Process and organizational innovations are difficult to be counted. The relative value of innovations is hard to identify.
Indirect impact measures	Changes in resource efficiency and productivity	Can provide the link between product value and environmental impact. Can be compiled at multiple levels: product, company, sector, region and nation. Can depict various dimensions of environmental impact.	Difficult to cover environmental impact over the entire value chain. No simple causal relationship between eco-innovation and eco-efficiency.

Source: OECD (2009, p. 24)

Survey analysis
Instead of using existing data, information about eco-innovation can be collected from surveys. There are two basic sources of survey indicators. The first source consists of official, large-scale innovation surveys. These sample thousands of firms and they are performed on a regular basis. The second source consists of smaller 'one-off' surveys by academics or government agencies. These usually focus on a limited region or set of sectors.

One example discussed here is the 1993 survey by Green *et al* (1994). The survey was sent to a sample of 800 firms that had expressed an interest in the UK Department of Trade and Industry's (DTI) Environmental Technology Innovation Scheme (ETIS). Under the scheme, companies could receive a subsidy for industrial R&D that might improve environmental standards. Responses were received from 169 firms, a response rate of 21.1% (Kemp and Arundel, 1998).

The survey questions are summarised in Table 2. The first question concerns the motivation for developing environmental innovations[12] while the second relates to several broad categories of potential applications of environmental redesign. The third question concerns resources (staff and money) for environmental issues. The fourth question is limited to a specific product and process innovation that is selected by the firm. The focus of the sub-questions is on the inputs and information sources required to develop these innovations (Kemp and Arundel, 1998).

TABLE 2
SUMMARY OF QUESTIONS IN THE ENVIRONMENTAL INNOVATION SURVEY BY GREEN ET AL (1994)

Main Question	Response categories
What factors prompted your company to develop environmentally-friendly new products/processes (or redesign existing products/processes)	Regulations Market factors Inputs (cost savings, new technologies) External pressures (environmental campaigns) Internal pressures (company policy)
To what extent during the last five years has your company made the following 'environmentally-friendly'	Products Production processes Distribution & transport Supplier policy Personal motivation General operations
Estimate the change in resources (staff and money) to considering and tackling the environmental aspects of your products and processes	Five categories: decrease, about the same, up to 10% increase, 10-25% increase, over 25% increase
Specify a product and a process innovation undertaken in response to green pressures.	Is this a modification to an existing technology or a major change in technology? Resources required to develop these two innovations: expenditures, skills, collaboration, technical, and investment

Source: Green et al., (1994)

[12] Existing UK/EC regulations turn out to be the most significant factor, both for product and process innovations. This result is confirmed by two other UK studies by Williams et al. (1993) and Garrod and Chadwick (1995), whereas a study by Steger (1993) for Germany finds that social responsibility is the most significant factor, closely followed by environmental regulation.

The questions illustrate the kind of information that can be obtained. It is important to note that surveys collect stated information. The information often involves a subjective element. On this, Arundel and Kemp (2009, p. 25) write, “Some survey questions can involve a highly subjective element but nonetheless be important to ask. For example, the ‘strictness’ of environmental regulation is very difficult to determine from objective data as there are many different parameters. Emission requirements can also differ by production process and enforcement may be uneven. Instead of using objective emission data, one can use subjective information from respondents about the strictness of regulations, using an ordinal importance scale. Ideally, when proxies are poor, one should use multiple indicators to obtain robust results.”

Survey analysis has been successful in monitoring and understanding innovation activities. However, the analysis of eco-innovation cannot be restricted to the specific innovation activities of the firm, as this requires knowledge of drivers and barriers and economic and ecological impacts of eco-innovation. Another challenge of survey analysis is the difficulty in linking survey data with official statistics or other survey data. The survey itself should be used to obtain information on the relevant control variables, such as the influence of different policy instruments.[13]

2.3 The link between environmental policy and innovation[14]

In this section, we examine literature on the link between environmental policy and innovation. Existing studies belong to one of the following five types of literature:

- theoretical models of incentives for eco-innovation
- econometric studies on the effects of environmental policy instruments on technical change
- case studies of the effects of environmental policy instruments on innovation
- surveys of firms where company respondents are asked about drivers for (eco)-innovation
- studies using a mix of methods.

We examine the results of the innovation effects of environmental policy instruments in the five types of literature.

2.3.1 Theoretical models of innovation in pollution prevention and control

Innovation in pollution control and prevention is investigated in theoretical models of the incentives for such innovation. Cost savings under the different regulatory regimes are indicative of the probability that innovation in pollution control will occur. Innovation in pollution control is modelled as a downward shift in the marginal cost curve of emission reduction. In most studies, the agency in charge of environmental policy is assumed to possess perfect knowledge about the marginal conditions and to use this information to realise the socially optimal amount of emission reduction.

13 Kemp and Pearson, Final report MEI project about measuring eco-innovation, 2007, p.12
14 Based on Kemp and Pontoglio (2010).

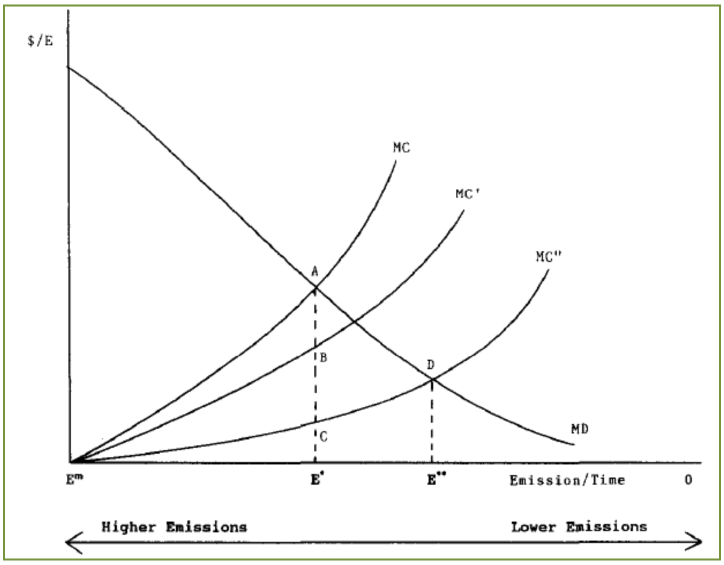

FIGURE 1

INNOVATION AS A SHIFT IN MARGINAL COST CURVES

The seminal study in this field is Milliman and Prince (1989), who assess and rank firm incentives to promote technological change in pollution control for polluting innovators, non-innovators and outside suppliers under two appropriability regimes (with and without patent protection), before and after optimal agency control, for five regulatory regimes (emission standard, emission subsidy, emission tax, free tradable permit, auctioned tradable permit). They find that incentives under emission taxes and auctioned permits are equal to or higher than incentives under direct controls, free permits and emission subsidies in all cases, except for control adjustment with a non-industry innovator. Moreover, only emission taxes and auctioned permits clearly reward positive gains to an industry innovator from the entire process of technological change by providing economic incentives for continuous innovation. Thus, the analysis finds that emission taxes and auctioned permits are better facilitators of technological change than regulation and free permits.

The superiority of incentive-based instruments is questioned by later studies. For instance, the study by Fischer et al. (2003) found that unequivocal ranking was not possible between pollution taxes, auctioned permits and free (grandfathered) permits. The relative welfare ranking of instruments depends on the costs of innovation, the extent to which innovations can be imitated, the slope and level of the marginal environmental benefit function, and the number of pollution firms. When innovators can effectively appropriate a large fraction of the rents from innovation, an emissions tax may induce a significantly greater amount of innovation than free and auctioned permits, due in part to the larger abatement cost effect under the tax. The welfare gain from induced innovation is likely to be greatest under emissions permits when the marginal environmental benefit curve is steeply sloped relative to the marginal abatement cost curve (see Weitzman, 1974).

Requate and Unold (2003) and Requate (2005) provided a comprehensive review of the theoretical inquiries on the incentives for adoption and development (including R&D) of innovations provided by environmental policy. Requate (2005) examined in total 28 different models and concluded "it seems to be difficult to draw clear conclusions on which policy instruments dominate other policy instruments. I think, however, one can draw the main conclusion that instruments which provide incentives through the price mechanism, by and large, perform better than command and control policies" (Requate 2005, p. 193). Requate also observed that some relevant aspects such as the innovation output market and the conflicts between short and long-term incentives provided by environmental policy instruments are missing in traditional models and that these should be brought into the analysis.

The results of such theoretical models are valid under highly stylized, constraining conditions. No attention is given to the capability of companies to innovate, uncertainty about costs and benefits, the choice set for innovation and the strategic games between regulators and polluter over the details of policy. Little attention is given to real-life policy features, such as the regulatory preference for quick and certain results and the industries' resistance to pollution taxes, which usually results in low taxes when used. Such restrictions do not allow one to predict what will happen if a particular instrument is used in a concrete context.

2.3.1.1 Summary

In summary, the theoretical models of innovation in pollution prevention and control do not provide us with a single answer as to which policy instruments are more effective. Some models indicate that emission taxes and auctioned permits are better facilitators of technological change than regulation and free permits. This is supported by the observation that instruments on price mechanism perform better than command and control policies. Still, several factors including the cost of innovation, the extent to which innovations can be imitated, the slope and level of the marginal environmental benefit function and the number of polluting firms affect the effectiveness of any policy instrument.

2.3.2 Results from econometric studies using hard data

The econometric studies of the effects of environmental policy on innovation look at real outcomes. They are an important source of information, but they have a number of limitations too as will become apparent from the following sections. Rather than presenting results from individual studies, we present the findings of two surveys. The first survey of econometric studies is that of Jaffe et al. (2002). It is not exclusively limited to econometric studies, but they feature prominently in it. The main conclusion of this study is that "market-based instruments for environmental protection are likely to have significantly greater, positive impacts over time than command-and-control approaches on the invention, innovation, and diffusion of desirable, environmentally-friendly technologies" (Jaffe et al. 2002). The survey is somewhat dated and largely based on studies in the US. The second survey is the OECD report "Impacts of environmental policy instruments on technological change" (Vollebergh, 2007). The main conclusion of the OECD review is that environmental regulation has a serious impact on technological change in general. Changes in invention, innovation and diffusion of technologies are clearly observable, "although the direct causal link with environmental policies is not clear" (Vollebergh 2007, p. 5).

With regard to the believed superiority of market-based mechanisms (see Milliman and Prince, 1989; Jaffe et al., 2002), it is stated that it is difficult to compare the impacts of different instruments, because the studies analysed vary greatly in methods and the instruments are different in design features that determine their incentive and because of local circumstances (p. 23). The distinction between command and control and market-based instruments is considered too general and requiring further investigation; it is proposed that future research of the dynamic impact of environmental instruments should focus more on the issues of policy instruments' design (p. 28).

Few studies econometric studies based on hard data have compared the influence of different policies on innovation in a certain technology. Exceptions are Greene (1990), Popp (2003) and Newell et al. (1999). Greene (1990) develops a statistical test to discriminate between price and regulatory effects on the fuel economy of American cars and light trucks in the 1978-1989 period, finding that the standards were at least twice as important as market trends in prices (hypothetical taxes).[15] Popp (2003) compared patents before and after passage of the 1990 Clean Air Act, which established a market for SO_2 permit trading in the US. Popp finds that the level of number of successful patent applications for Flue Gas Desulphurisation Units fell after the introduction of sulphur trading but that there was an increase in patents in higher control efficiencies. Newell et al.

[15] According to Pakes et al (1993) the increase in miles per gallon was due to changes in the mix of vehicles in the market, a factor not accounted for in the analysis of Greene (1990).

(1999) studied the influence of energy prices and non-price regulatory constraints (in the form of minimum energy efficiency requirements and policy labelling) on the energy efficiency of air conditioners and gas boilers findings. Energy price increases and energy efficiency standards were both found to have a positive influence on energy efficiency improvement although their influence was not in all cases significant and the same across products. A substantial amount of improvement could not be explained and was referred to as “autonomous”. These mixed findings do not unequivocally support the conclusion of Vollebergh (2007) and (Jaffe et al., 2002) of the success of market-based instruments, which appears to be based on economic assumptions and evidence of price incentives having an impact on technical change. However, it is often difficult to isolate the impact of one instrument, as a mix of instruments is often used.

It is also interesting to look at the innovation effects in low-carbon technologies of the European Union’s Emission Trading Scheme (EU ETS). The issue of innovation effects of the EU ETS is of great significance for the reason that it is the world’s biggest tradable permit scheme and the main instrument of climate policy in the EU. After three years of pilot application overall Europe (2003-2005), and a series of adjustments and improvement in its design, the ETS is now fully operational in 27 Member States and a significant amount of data on the emissions of the installations covered and CO_2 market prices is available.

The paper from Calel and Dechezleprêtre (2011) is based on the preliminary analysis of patents protecting low-carbon technologies. The authors combine difference-in-differences and matching methods to compare the patenting activities of 233 firms that operate installations covered by the EU ETS in Belgium, France, Germany, and the UK with those of 12,427 similar but unregulated firms. The comparison between regulated and unregulated firms controls for country-specific and sector-specific differences in market and regulatory environment. Patent data are drawn from the European Patent Office PATSTAT database, which includes nearly 385,000 patents. The EPO classification identifies low-carbon energy technologies (renewable energy, cleaner coal, nuclear energy, etc.) and other energy efficiency technologies that represented a share of just over 3% of all the patents filed in 1980, on the back of the third oil shock, subsequently falling to around 2%. The results of this analysis of the patenting activity suggest that companies anticipated the launch of the ETS by increasing their innovative activity, mainly in low-carbon technologies, before the starting of ETS. The EU ETS has had a positive effect on innovation in general, and on low-carbon innovation in particular, especially in France and Germany. After 1997, the share of low-carbon patents took off among ETS firms, rising faster than general patents. In particular, the empirical findings suggest that there were more additional patents per year between 2003 and 2005 than in any other year before or after this period. Patenting of low-carbon technologies thus appear to have peaked between 2003 (the year of introduction of the EU ETS Directive) and 2005. The decline observed after 2005 was interpreted as the result of diminishing marginal returns, or as a reaction to the fact that the ETS became less stringent than expected.

Econometric analysis is uniquely suited for analysing large sets of data, but any econometric analysis is only as good as its data (and model structure). For analysing the topic at hand – the innovation effects of particular policies – there are three particular problems for econometric analysis. The first problem has to do with the difficulty of measuring environmental policy. It is very hard to incorporate design aspects of environmental policy instruments in the econometric analysis (strictness, enforcement, differentiation of standards or taxes with regard to type of polluter, and instrument combination where the effects depend on synergies). For environmental regulation, the most common proxy employed in econometric analysis is PAC (pollution abatement cost) that measures the expenditures for achieving compliance (used *inter alia* by Lanjouw and Mody 1996, Shadbegian and Gray 2005, Höglund Isaksson 2005). As pointed out by Rennings (2000), regulatory compliance expenditures fall short of providing a truly exogenous measure, since PAC reflects the nature of an industry’s response to environmental regulation. Other studies (Becker and Henderson 2000, Greenstone 2002) use “attainment status of US counties” as a proxy for regulatory stringency because new and existing plants are subject to much stricter controls in non-attainment areas relative to attainment areas. Brunnermeier and Cohen (2003) used the number of inspections as a measure for the intensity of regulation. De Vries and Withagen (2005) used dummy variables for years in which an important environmental act took effect, which allow them to assess the influence of each of various acts. Newell et al. (1999) also used dummies for policy discontinuities, a reasonable but nonetheless crude measure.

The second methodological weakness concerns the measurement of innovation. Studies relying on R&D in a certain sector will fail to capture research and innovation realized outside the sector affected by regulation. Patents can be used for measuring inventions in pollution control technologies and alternative energy technologies but they are a poor indicator for inventive activity in the area of process integrated environmentally superior technologies (Oltra et al. 2010).

The third limitation is that the econometric studies based on observed data cannot capture all relevant factors in the analysis, as many of them are not observable. This goes for business expectations (about market demand for innovation and government support for it), the matrix of institutions that operates on companies and innovation capability of companies acting as a constraint and shaping factor. With special efforts, some of these aspects can be brought into the analysis increasing the relevance of the study.[16]

2.3.2.1 Summary

In summary, the econometric studies demonstrate that environmental policies do have an effect on invention, innovation and diffusion of environmental technologies. Still, no clear results were presented on particular policies, although Jaffe (2002) believed market-based-instruments to be more effective compared with command and control measures. Generally, econometric studies are limited because of their general nature. No details on critical issues such as the technological context in which the policies influence, the design of the policy instruments or other such aspects are integrated in these studies.

2.3.3 Results from technology case studies examining innovation impacts of identifiable environmental policies

The case study literature looks at the innovation effects of real policies and the multitude of factors at work, using interviews as an important source of information for establishing motivations and relevant factors behind eco-innovation. The first important study on environmental policy and innovation bringing together empirical evidence about ten regulatory cases in the US is Ashford et al. (1985). The authors offer a history of environmental regulation affecting innovation, built on ten regulatory cases in the US after 1970 under the Clean Air and Water Act, the Toxic Substances Control Act (TSCA), the Occupational Safety and Health Act (OSHA) and the Consumer Product Safety Act (CPSA). For each case, they examine the degree of stringency (middle or very strict) and the type (product, process) and degree (diffusion, incremental, radical) of the predominant innovative industrial response. The analysis of the regulatory cases showed how standard mechanisms encouraged a variety of innovations, both incremental and radical in nature. In a number of cases, product regulations called forth product innovations, whereas component or pollutant regulations tend to elicit process innovation. A high degree of stringency was found to be a fundamental condition for inducing more innovative compliance responses.

Christiansen (2001) investigated the innovation effects of the Norwegian carbon tax system in the oil industry. The methodology employed is mainly qualitative in nature. Semi-structured interviews with industrial managers and technology experts were conducted and official documents and scholarly literature were reviewed. The author identified the technological solutions and institutional innovations adopted by oil companies operating in the Norwegian Continental Shelf to

[16] Dechezleprêtre et al. (2010) offers an example of what can be done, by incorporating absorptive capacity into a study about the transfer of climate change mitigation technologies.

reduce their carbon intensity. Diffusion of available technologies and incremental process changes were the main innovation pattern observed. Two projects developed in different fields constituted radical innovations. However, the author pointed out that in both cases (a carbon capture and sequestration technology and a system to generate electricity from shore) innovations were carried out in the design phase of new facilities (not as retrofits), and the existence of a carbon tax was but one of the many shaping factors. It offered an advantage but did not start the innovation process.

Mickwitz et al. (2008) examined the role of policy instruments in the innovation and diffusion of environmentally friendlier technologies in two sectors in Finland: pulp and paper and the marine engine industry. The main source of information for the analysis was interviews with innovators and companies using the innovation. They tested eight claims concerning the effects of regulations, environmental taxation and R&D funding. The claims for regulation and environmental taxation are presented in Source: Mickwitz et al. (2008)

Figure 2, together with the empirical evidence for the cases studied. They found evidence supporting conventional wisdom that regulation drives diffusion rather than innovation but also contrary evidence. Contradicting evidence was found for all five received wisdoms.

Claim		Supporting experiences	Contradicting experiences
R1	Environmental regulations (permits, standards, etc.) are often based on existing technology and provide no incentive to innovate but may stimulate diffusion.	▪Activated sludge treatment, diffusion ▪Chlorine-free bleaching of pulp ▪Filters for air emissions	▪Activated sludge treatment, technology development ▪The Alaskan smoke standard ▪The anticipation of the IMO NO_x regulation
R2	Non-binding permit conditions or standards do not provide any incentive to innovate.		▪Wastewater permits, especially for BOD and phosphorus ▪The anticipation of the IMO NO_x regulation
R3	Permit conditions or standards only confirm the development that has taken place otherwise and provide no additional incentive even for technology diffusion.	▪Reduced discharges of chlorine compounds from pulp bleaching ▪Change from sulphite to sulphate pulp production	▪Activated sludge treatment ▪The Alaskan smoke standard ▪The anticipation of the IMO NO_x regulation
R4	Environmental regulations (permits, standards, etc.) can easily hamper innovations, by directly specifying the technology to use or indirectly making try-outs impossible.		▪The flexibility of the Finnish water permits to support try-outs
E1	Environmental taxes are superior to other policy instruments with respect to innovations.	The Swedish fairway and port fee differentiation	▪The Finnish energy taxation, in the case of pulp and paper production

Source: Mickwitz et al. (2008)

FIGURE 2

EMPIRICAL EVIDENCE ABOUT CLAIMS REGARDING THE EFFECTS OF REGULATION AND ECONOMIC INSTRUMENTS ON TECHNICAL CHANGE

One important situational aspect is the distribution of the benefits and costs of a policy instrument as these affect the choice and design of the instrument.

Green product choices are studied by Türpitz (2004). Based on interviews and analysis of company-specific documents (environmental reports, eco-balances etc.), the study investigated technological, political, market-related and company-specific determinants for environmentally-friendly product innovations in six companies[17]. Similar to Ashford et al. (1985), Türpitz finds that regulation is the main driver of product-related eco-innovations: compliance with existing regulation requirements and anticipation of future rules were the most influential incentives among companies underpinning product innovations. As for the role of market stimuli, the analysis finds that their influence varies per sector (each of which representing a different techno-economic context) and that green innovators often faced commercial obstacles. Consumer willingness to pay for the environmental friendliness of a product appears to be low and strongly dependent upon ecological awareness. Further influencing factors are company-specific factors (size and culture). Eco-labels and lifecycle analysis (LCA) did not come out as main drivers of product-related eco-innovations in the author's analysis.

The innovation effects of the European Emission Trading System (ETS) for carbon in stimulating innovation have been studied for power companies by Rogge et al (2010), and for the paper and pulp industry (in Italy) by Pontoglio (2010). In the power sector in Germany and Europe, the ETS was found to have strongly increased RD&D[18] in carbon capture technologies and corporate procedural change (Rogge et al., 2010). Its impact on RD&D for wind and other renewables and on gas efficiency RD&D was negligible. The results correspond with those of Pontoglio (2010) for the paper and pulp sector in Italy. In the first phase of application of EU ETS (2005-2007), companies largely adopted a 'wait and see' strategy. Paper mills in shortage of allowances preferred to postpone abatement decisions to later years, borrowing allowances from subsequent periods. Their compliance decision was influenced by the very low CO_2 price on the market that was not able to reward or provide incentives for investment in low-carbon solutions. Overall, the impact of ETS on innovation was low. The main reason for this is the low price, due to the free provision of large amounts of carbon rights to energy-intensive companies. The auctioning of (lower amounts) of carbon rights in phase 2 of the ETS can be expected to achieve more.

Policy interaction effects are studied by Kivimaa (2008). The generalised lessons, which she draws from case study research in the Nordic Pulp and Paper industry, are that the effects of environmental policies on innovation depend on:

- the aims and characteristics of an individual policy measure
- synergies and conflicts with other policies both within environmental policy and with other policy fields
- the timing of the policy effect in relation to innovation process (in anticipation, during, after)
- the route through which policy signals reach innovation (direct/indirect)
- the recipient, i.e., the organisations that form the policy target group
- the responses of organisations not targeted by policy
- information transfer mechanisms within organisation affected by the policy and in inter-organisational networks
- the nature of the innovation process (process, product)
- the wider context in which the policy effect occurs (markets, system dynamics)
- synergies and conflicts between policy and market changes on a global scale.

2.3.3.1 Summary

Overall, the case studies show that the environmental policy interacts with other factors. The design of a policy is found to be critical to the response. Several cases displayed a clear effect of regulation as a strong driver of innovation (e.g. Türpitz 2004, Ashford et al 1985, Yarime 2003/07). There is more evidence of regulation promoting radical innovation (Ashford et al., 1985) and Taylor et al. (2005) than evidence of market-based instruments promoting innovation new to the world, but this depends on how instruments have been used: taxes and carbon prices have been too low to elicit innovations. The case study literature also brings out the importance of foreseeable, flexible and continuously improving environmental policies as well as the importance of innovation capabilities

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[17] Siemens Medical Solutions, Toshiba Europe GmbH, Schott Glas AG, Continental, Ergo-Fit, Ensinger Mineral-Heilquellen.
18 RD&D stands for Research, Development and Demonstration.

(which may reside outside the problem sector the exploitation of which may require a special innovation support effort) (Norberg-Bohm, 1999b; Kivimaa, 2008).

2.3.4 Results from surveys of firms on the effects of environmental policy instruments on eco-innovation

A fourth methodological resource is surveys. They can refer to a micro-level of analysis (a single industrial sector) or be national or multi-national.

Cleff and Rennings (1999) studied the effects of different environmental policy instruments in Germany based on survey data from the Mannheim Innovation Panel.[19] The study revealed that many policies affected the decision to eco-innovate: 1) state regulations and prohibition; 2) liability for environmental risk; 3) sewage, waste and hazardous waste charges; 4) energy charges, taxes; 5) sectoral voluntary commitments; 6) eco-audits; 7) environmental impact assessment; 8) subsidy/state assistance programmes; 9) green dot (for packaging recycling); 10) eco-labels. Of the different environmental policies, state regulations and prohibition were found to be a more important policy stimulus than charges and taxes. Environmental product innovation was found to depend on strategic market behaviour of firms (a finding confirmed by case study analysis of Kivimaa, 2008).

The survey of Becker and Engelmann (2005) examined factors promoting and hindering the adoption of innovations able to reduce water pollution from chemical industry in West Germany. The authors selected an array of stated drivers and barriers for water benign innovations, based on expert interviews and a literature review. The identified factors were combined in a conceptual framework illustrating the factors influencing a firm's innovative decision, which was later empirically tested by means of a survey. The questionnaire investigated the motivations guiding the innovation decisions, and it was followed up by interviews. On a total amount of 31 respondents (from a randomly selected sample of 80 companies), 12 companies reported the implementation of End Of Pipe and 16 the adoption of production integrated technologies between 1996 and 1998. Process-integrated changes were the most common response; a change in input materials (for example abandoning the use of solvents) rarely occurred. As for the relative importance of the determinants of innovations, environmental regulations proved to be by far the most important factor for both categories of environmental technologies, followed by reputation gains and reduction of material costs (only for process-integrated innovation). The study also found that the most important reason for refraining from innovation is that emissions limits are already being met. This shows again the two-way influence of regulation.

Frondel et al. (2007) studied the influence of various policy instruments on the choice of end-of-pipe and integrated process changes in Germany. Policy stringency is the most significant determinant. The choice of instrument is found to be less important. Regulation is important especially for end-of-pipe solutions but less important for cleaner production for which cost reduction is an important factor. The study found no significant impacts of market-based instruments. These results are in line with the case study findings (especially the findings of Ashford et al. 1985, Ekins and Venn, 2006).

The biggest and most comprehensive survey study of companies' innovation responses to environmental policy is the OECD study "Environmental Policy and Firm-Level Management" involving the collection and analysis of data from over 4000 manufacturing facilities in seven OECD countries (Japan, France, Germany, Hungary, Norway, Canada and the United States (Johnstone, 2007). The survey investigated the role of environmental policy initiatives on environmental management, performance and innovation. Several econometric analyses were undertaken based

19 Companies were considered an 'environmental innovator' if they had introduced an innovation between 2003 and 2005 in one of the following areas for environmental protection: product change, process change, recycling, end-of-pipe pollution control. According to this criterion, 72% of the innovators were environmental innovators.

on the application of different techniques to a database of manufacturing facilities in seven OECD countries. As for the influences wielded by different instruments, it was found that policy instrument choice does not directly affect environmental performance. The influence is through innovation and environmental R&D. It was also found that flexible instruments are more likely to trigger clean technologies instead of EOP solutions. Policy stringency came out as the main determinant for environmental R&D, and environmental accounting was revealed as an intermediating variable, with policy instruments only having an indirect influence through the role of environmental accounting. The measure used for policy stringency is 'perceived environmental stringency' being the respondent's view of the relative stringency of the environmental policy regime to which their facility is subject.

Horbach (2008) analysed German panel data about innovation for the subset of environmental firms. He compared the stimuli for environmental innovation with those for normal innovation, finding that cost savings and compliance with regulation are more significant determinants of environmental innovations. Participation in innovation cooperation and state subsidies also come out as more important for environmental innovation than for normal innovation.

Horbach also analysed the results of the 2008 European Community Innovation Survey from EUROSTAT[20], which contained 15 questions about eco-innovation, including five questions about the influence of particular policies. Results for Germany are given in Table 3
* Whose activities had a non-negligible environmental impact
Source: Horbach et al., (2010) based on data from the CIS2009

Environmental regulations, taxes, customer demands and voluntary codes and industry agreements were revealed as important drivers, in contrast to financial support by government. Unfortunately, the influence of regulations and pollution taxes has not been separated. It is also unclear whether the eco-innovation adopted was developed in-house, in cooperation with others, or purchased.

TABLE 3
ECO-INNOVATION MOTIVATORS IN GERMAN COMPANIES*

Environmental innovations that were introduced in response to	Yes	No
Existing regulations or taxes on pollution	31.5	68.5
Anticipated environmental regulations or taxes	27.0	73.0
Government grants and subsidies	9.9	90.1
Demand from customers	27.4	72.6

* Whose activities had a non-negligible environmental impact
Source: Horbach et al., (2010) based on data from the CIS2009

2.3.4.1 Summary

In summary, the results of the studies using survey as the methodology also indicate that environmental policy to great extent affects the level of innovation within environmental technology (e.g. Cleff and Rennings 1999, Becker and Engelman 2005, OECD). Further, an interesting

20 http://epp.eurostat.ec.europa.eu/portal/page/portal/microdata/cis

observation from the OECD study was that the choice of policy instrument does not directly affect environmental performance; rather influence from the policy is seen on innovation and R&D. Several studies found the stringency of the policy to be more important than the particular policy instrument (Frondel et al 2007, OECD).

2.3.5 Results from mixed method analysis

Innovation impacts of policy can also be examined by applying different methods simultaneously (mixed-method), allowing the researcher to assess the robustness of the results and weigh the evidence of different data sources. One of the best studies into the environmental technology effects of policy is the study by Taylor et al. (2005), into the policy determinants of innovation in SO2 control technology. The study used different measures for innovation (patents, R&D expenditure, technologies, experience curves) to analyse the role of various policies on the innovation in SO_2 control technology. The study is extremely rich in empirical detail. The main goal of the study was to establish the influence of three types of policy on innovation: (1) SO_2 control regulations, (2) public research support, and (3) the emission trading system for sulphur emissions introduced as part of the Clean Air Act Amendments (CAA) in 1990. The effects of the different policy approaches were analysed in three different ways (i) through econometric analysis using information about patent activity and government regulatory activity, (ii) through interviews with technology vendors and specialists, and (iii) through a content analysis of the yearly proceedings of the SO_2 symposium at which FGD vendors met with government and university researchers, utility pollution control operators. The study found that patent activity predated the actual regulations (anticipation effect) and stayed at a high level thanks to SO_2 control regulations introduced in the 1970-1990 period. A second finding is that the regulations curtailed invention in pre-combustion technologies that cleaned coals. Patenting in these technologies fell after the introduction of the 1979 New Source Performance Standards regulations. The emission trading system introduced in 1990 as part of the Clean Air Amendments did not restore patenting levels for pre-combustion technology. The introduction of the emission trading system was found to have little effect on invention. The 1990 CAA did cause a shift in the compliance options, away from dry FGD and sorbent injection systems, which were less economical than the use of low sulphur coal with limited wet FGD application. The emission trading system for sulphur affected the choice of compliance choices.

Martin et al. (2011) undertook a more comprehensive study of ETS based on multiple methods. The authors conducted approximately 800 interviews with managers in six European countries, to explore the reasons behind innovation performance and its dimension (process/product innovation), managers' expectations to future carbon price and the role of expectations in investment decisions, together with the link between innovation and stringency and other prominent policy design issues (e.g. auctioning). Descriptive analysis of interview results demonstrates that almost 70% of firms are engaged in some form of clean process innovation and 40% in product innovation, with country differences. Regression analysis showed that there is no strong evidence that ETS firms in general differ in their innovativeness from non-ETS firms. Anticipated reductions in allowances proved to play a crucial role, greater than price, in influencing innovation decisions: firms that expect a more stringent EU ETS cap in Phase III are more likely to engage in product innovation. However, there is no clear evidence that the same is true for process innovation.

It is interesting to compare the results of this analysis with Calel and Dechezleprêtre (2011). This second study is more positive about ETS spurring innovation and finds a stronger evidence of the difference between ETS and non-ETS companies. However, the innovation activity in ETS companies shows a decline after 2005, when the interviews of Martin et al. were conducted.

2.4 Policy design

The discussion of what instrument is best for promoting eco-innovation has been found to be based on a wrong premise: that policies can be ranked with respect to their impact on innovation. There is a growing consensus that what matters is not what type of instrument is used, but *how* it is used. Weak taxes will inevitably offer a weak incentive to innovate, whereas strong regulation, especially product bans, will offer a strong incentive to innovate.

From the literature, the following aspects of policy design emerge as relevant:

1. Stringency
2. Predictability
3. Differentiation with regard to industrial sector or the size of the plant
4. Timing: the moment at which they become effective, the use of phase-in periods
5. Time path of the standards and the credibility of policy commitments to future standards
6. Possibilities for monitoring compliance and discovering non-compliance
7. Enforcement (inspection and penalties for non-compliance)
8. Combination with other instruments of policy.

Foreseeable, flexible and continuously improving environmental policies are generally viewed as helpful for innovation. This fits with what Porter (1991) said about *innovation-friendly* policies, as policies that

- focus on outcomes, not technologies
- enact strict rather than lax regulation
- employ phase-in periods
- use market incentives
- make the regulatory process more stable and predictable
- develop regulations in sync with other countries or slightly ahead of them
- require industry participation in setting standards from the beginning
- develop strong technical capabilities among regulators.

These propositions correspond with the latest Scandinavian recommendations for proper design of environmental policies as stated at the NMRIPP (Nordisk Ministerråds Integrerat Produkt Policy Grupp) Conference "Environmental Technology and Innovation – Drivers and Policy Measures" held in Copenhagen in September 2008. The recommendations are based on Scandinavian case studies and are meant to support environmental innovation as well as the diffusion of environmental technologies. One important recommendation is that public policies and strategies should be *long term* and *consistent*, ensuring lower risks for producers, consumers and investors, and thus ensuring that environmental innovation benefits from consistent and long-term public policy environments based on long-term environmental goals.[21] Also, the need to align and harmonize environmental and innovation policies is emphasized. *Environmental criteria should be included systematically, consistently and in a coordinated manner into policies*, *collaboration* across ministries should be promoted to facilitate dialogue and working towards the same goal. Multi-disciplinary approaches should be promoted to solve environmental problems through more radical innovations combining knowledge and experiences from a diversity of fields. In addition, *cross-border collaboration* should be promoted to strengthen the innovation potential of sectors, where research activities and collaboration often occur only in a national context.

Coordination across time, layers of government and the public and private sector is viewed essential to successful eco-innovation policies. Coherence in policies must be maintained over time, priorities and needs revised and adapted, and policy makers must understand when and how to introduce an instrument, and when and how to phase out another one. The different governmental layers should develop different capacities to address their environmental concerns.

21 Summary notes from NMRIPP Conference "Environmental Technology and Innovation – Drivers and Policy Measures" held in Copenhagen in September 2008,.

There is a need for cooperation across these layers to ensure an understanding of the respective roles within the government as well as a common strategy towards environmental goals. Furthermore, cooperation between public and private sector and research and industry is important[22]:

- Demonstration of new technologies is ensured by governmental interference in cases where markets fail in linking research and industry
- Knowledge transfer is ensured by partnerships across research and industry
- Public-private partnerships contribute to effective governance supporting environmental technological development.

Important work on the issue of policy design is going on under the OECD programme on eco-innovation. The OECD has funded qualitative studies and is involved in quantitative work on policy features. Instead of looking at instruments, the OECD proposes to look at *dimensions* of policy. According to Johnstone et al, (2010, p. 279) “the stark juxtaposition between market-based instruments and direct forms of regulation is somewhat misleading. It is more helpful to think in terms of vectors of characteristics of different instruments, and the effect that each of these characteristics has on innovation.”

The following vectors are identified as relevant (Johnstone et al., 2010, p. 279):

- *Stringency* – i.e. how ambitious is the environmental policy target, relative to the 'baseline' emissions trajectory?
- *Predictability* – i.e. what effect does the policy measure have on investor uncertainty; is the signal consistent, foreseeable, and credible?
- *Flexibility* – i.e. does it let the innovator identify the best way to meet the objective (whatever that objective may be)?
- *Incidence* – i.e. does the policy target the externality directly, or is the point of incidence a 'proxy' for the pollutant?
- *Depth* – i.e. are there (continuing) incentives to innovate throughout the range of potential objectives (down to zero emissions)?

There is no precise mapping from instrument type to each of these vectors (Johnstone et al., 2010, p. 279). An environment-related tax may have very different attributes. For example, a tax on CO_2 is flexible, targeted, deep, and often predictable. In contrast, a differentiated tax for environmentally friendly products is not very flexible, targeted or deep (Johnstone et al., 2010, p. 279). Depending upon how the tax rate is determined, a product tax may actually have more similarity with technology-based standards than with an emissions tax (Johnstone et al., 2010, p. 279).

Johnstone and colleagues examined the relevance of instrument characteristics for the rate and direction of invention. The characteristic score of the policy is regressed on the share of patents achieved by the different countries, to see if there is a correlation. This gives an indication of the strength of the link between the policy design and the development in environmental technologies.

The preliminary conclusions of this line of research are that:

1. Stringent environmental policies are helpful for innovation as they motivate the developer to be ambitious. So the more stringent the policy, the better it will be in enhancing the development of advanced environmental technologies. In other words, the higher the price on pollution, the bigger the incentive to be innovative.
2. Stability is also positively associated with innovation. If the developers are uncertain of the legislative development, the market is much more risky, and the investment is likely to placed in more safe markets.

22 OECD Studies on Environmental Innovation. Better policies to Support Eco-innovation, 2011

3. Flexible policies will promote innovation more than prescriptive policies. Flexibility gives a wider approach and a framework within which various types of solutions can be explored.
4. Market-based instruments, such as taxes and quotas, have a more positive influence on the development of eco-innovation than regulative legislation. The reason for this is that such instruments provide firms with flexibility in terms of fulfilling environmental objectives and thereby freedom to select the optimal solution while minimising costs: “For a given level of policy stringency, countries with more flexible environmental policies are more likely to generate innovations which are diffused widely and are more likely to benefit from innovations generated elsewhere” (Johnstone and Hascic, 2009, p.1).

2.5 Competitiveness

In the literature, we find different definitions of competitiveness.[23] The OECD (1996, p. 24) defines it as "... the ability of companies, industries, regions, nations, and supranational regions to generate, while being and remaining exposed to international competition, relatively high factor income and factor employment levels on a sustainable basis". The EU Commission (2003, p. 21) uses as a definition of competitiveness "... the ability of an economy to provide its population with high and rising standards of living and a high level of employment for all those willing to work, on a sustainable basis."

Competitiveness of companies has to do with the ability to compete and earn money. Competitiveness of eco-innovations may be measured based on exports data, sales data, and world market shares of those eco-innovations that are sold as goods or services. A second approach looks not at economic performance but at those factors that affect the ability to compete and to reap benefits from eco-innovative activity. The ability to compete depends on company internal capabilities for altering their processes and products, strengths in marketing and market power, and wider aspects such as the sectoral system of innovation (the value chain), conditions of rivalry, and macro-economy factors (price stability, competition). The indicators about the ability to innovate will tell something about future performance of innovating firms.

2.5.1 The Porter hypothesis

There is a long literature on the effects of environmental policy on competitiveness. The traditional view held that environmental policy reduces competitiveness because it leads to higher costs for the companies and because it crowds out other R&D. This view was challenged by Michael Porter in 1991 when he wrote that "Appropriately planned environmental regulations will stimulate technological innovation, leading to reductions in expenses and improvements in quality. As a result, domestic businesses may attain a superior competitive position in the international marketplace and industrial productivity may improve as well." Porter’s view is based on a dynamic innovation-based conception of companies in which pollution is viewed as resource inefficiency. Regulation signals companies about likely resource inefficiencies and potential technological improvements and spurs them to do something about it. Through innovation, environmental performance and business performance may be enhanced. To do so, regulation must be strict and flexible, based on technological possibilities.

[23] From Fischer and Schornberg (2006, p.3).

Figure 3 summarizes the main causal links involved in Porter's Hypothesis.

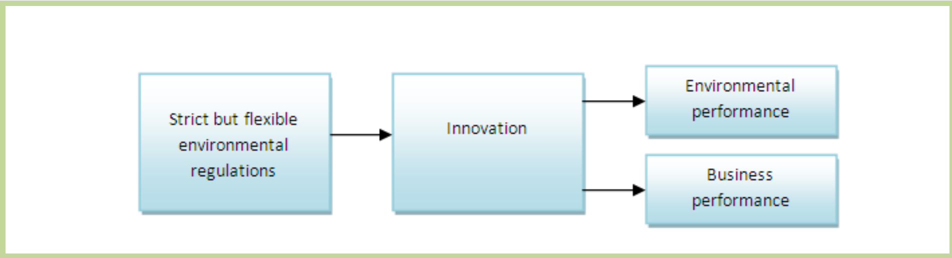


FIGURE 3

INNOVATION AS A SHIFT IN MARGINAL COST CURVES

Briefly stated, the Porter Hypothesis says that properly designed, strict environmental regulation can enhance competitiveness through "innovation offsets" that will not only improve environmental performance, but also offset the additional cost of regulation.

The article of Porter (Porter, 1991) sparked a hot debate about the real effects of regulation and environmental measures.

To this day, the Porter hypothesis remains a source of contention. Positive case examples are provided in Porter and van der Linde (1995) but econometric studies into the effects of environmental regulation on total factor productivity generally find a negative impact on costs and productivity. A limitation of the econometric studies is that they do not account for time-lags, time needed for innovation development and diffusion. When allowing for time lags, Lanoie et al. (2008) find that the effects on productivity become less negative and even positive for certain sectors. The positive effect only applies to less polluting sectors. More polluting industries witness long-run declines in productivity following an increase in the stringency of environmental regulation. This is expected to be due to the heavy investments to satisfy regulation in these areas, or to the high ratio of unproductive to productive investments (such as in end-of-pipe equipment) (Lanoie et al., 2008, based on data from Quebec companies).

Three versions of the Porter Hypothesis are studied by Lanoie et al., (2007), based on data from 4200 companies in seven countries. The authors find strong support for the 'weak' version of the Porter Hypothesis, some support for the 'narrow' version, and some support for the 'strong' version. The 'weak' version says that more stringent environmental regulations enhance innovation and thereby lower costs of compliance; the 'narrow' version of the hypothesis asserts that flexible environmental policy instruments such as pollution charges or tradable permits give firms greater incentives to innovate than prescriptive regulations, such as technology-based standards. Finally, the 'strong' version posits that properly designed regulation may induce innovation that more than compensates for the cost of compliance (Lanoie et al, 2007).

The empirical results have been investigated in the meta-study of Ambec et al. (2010). The consolidated conclusions are that the 'weak' version of the hypothesis that stricter regulation leads to more innovation is fairly well established; the evidence on the 'strong' version (that stricter regulation enhances business performance) is rather mixed. The results of a number of studies on the issue are found to be flawed in not considering the time lag, thus overestimating the costs of regulation.

The study also finds that impacts depend on the way a policy is used. It is found that the evidence speaks "in favour of policies that provide incentives for innovation, are stable and predictable, make use of suitable transition periods, focus on end results rather than means, and economic policy instruments" (Ambec, 2011, p. 12).

Another conclusion is that most previous studies have not adequately taken into account the dynamic dimension of the Porter Hypothesis by not taking into account time lags between regulation and innovation offsets. They also note that the Porter hypothesis was premised on flexible, market-based regulation – not rigid command-and-control regulation. A third aspect neglected in the studies investigating the Porter hypothesis is the interaction of environmental regulations with other government policies.

Popp (2006) examines the effect on the environmental regulation both in a national and in an international context. The conclusion is that national regulation has an effect on the national level of innovation, which then strengthens competitiveness as in the strong version of the Porter Hypothesis. Hascic et al (2009) analysed patent data for the automotive industry in EU, US and Japan. The automotive industry is very globalised and they also found a significant influence on domestic innovation by 'foreign' regulation. The analysis actually found that foreign regulation had a greater impact on innovation than national regulation. One explanation for this is the role that national manufacturers play in the development of domestic regulation. Since the influence of national manufacturers is greater then the one of the international manufacturers the development in the legislation will come as a shock and can therefore not be captures in the dummies designed for this analysis. Further, it is concluded that the regulation generating the highest degree of innovation is regulative standards. Finally, the article points out that initiating excessive innovation through standards and taxes may actually reduce social welfare while it can be the economically optimal solution to companies as it can inspire manufacturers e.g. to exploit synergies. Popp (2006) compared the level of innovation and the spill-over effect in the US, Japan and Germany through implementation of SO_2 and NO_X standards. It was concluded that the strength of standards lead to more domestic patenting, but no more foreign patenting. Further the analysis found that even if a regulation was adopted later in a country the technologies were brought and developed domestically.

2.5.2 Measurement of competitiveness

Competitiveness of eco-innovations can be measured by their market performance, i.e. by use of export and sales data as well as the world market shares of the eco-innovations sold as goods and services.[24]

A well-known trade-based indicator of competitiveness is Revealed Comparative Advantage, proposed by Balassa (1965). The RCA-value of a country for a product group i at a given point of time t may be calculated as follows (see e.g. Horbach (1999)):

$$RCA_{it} = \ln\{\frac{EX_{it} / IM_{it}}{\sum_{i=1}^{n} EX_{it} / \sum_{i=1}^{n} IM_{it}}\}$$

EX: Exports; IM: Imports

A positive RCA – value signifies that the country shows a higher export-import relation in the product group i compared to the export-import relation of the whole economy. Therefore, the RCA may be interpreted as an indicator for the specialization of a country pointing to relative competitive advantages (or disadvantages) in the analysed product group.

Patent data can be used to measure the technological capabilities of the companies in eco-technology by searching for environmental relevant patents. This may give information about the strength of European manufacturers in emerging environmental technology areas such as nanotechnology, fuel cells or climate related policy technologies.

24 Kemp and Pearson, Final report MEI project about measuring eco-innovation, 2007, p.75

Relative patent advantage (RPA): for every country i and every technology field j the RPA is calculated according (see e.g. Legler (2007) to

$$RPA_{ij} = 100 * \tanh \ln[\frac{P_{ij} / \sum_j P_{ij}}{\sum_{i=1}^{n} P_{ij} / \sum_{ij} P_{ij}}]$$

P_{ij} denotes the number of patents of a country i in the technology field j. The RPA can take values between – 100 (extremely weak specialization) and + 100 (extremely strong specialization). The interpretation of the RPA is as follows: A positive (negative) sign of RPA signifies that technology field j has a higher (lower) relative importance in country i compared to the whole world.

In TablE 4, RPA are given for environmental technologies of different countries

TABLE 4

RPA VALUES FOR ENVIRONMENTAL TECHNOLOGIES OF DIFFERENT COUNTRIES FROM 1985 TO 2004

Tab. A.3.1: Patentspezialisierung bei Umwelttechnologien ausgewählter Volkswirtschaften 1985-2004

	USA	GER	JPN	GBR	FRA	SUI	CAN	ITA	NED	SWE	FIN	KOR	DEN	AUT	EU15
Abfall															
85-87	-18	32	-57	-72	37	-73	56	43	-40	24	-5		52	54	19
93-95	-37	29	-38	-6	47	43	33	5	-43	-10	-33	-88	79	56	25
02-04	-34	36	42	-9	52	39	70	-72	-100	-11	-100	-100	22	-6	-31
Recycling															
85-87	-40	47	-74	-13	-19	42	75	-25	35	31	-7		-13	78	29
93-95	-32	38	-50	-14	-27	27	61	3	39	23	55	-93	59	82	25
02-04	-59	6	-8	-1	-34	-15	22	57	33	27	-30	-74	63	86	19
Lärm															
85-87	-36	40	-77	-14	-9	76	-100	-37	23	39	-100		-100	91	28
93-95	-48	49	-29	-26	18	-4	-69	10	43	57	41	-64	82	20	34
02-04	-36	43	-27	-45	31	43	-10	8	-25	39	-86	-57	-56	62	25
Luft															
85-87	-54	63	-17	-71	-58	-29	38	-87	-44	22	82		30	43	28
93-95	-49	44	43	-26	-46	-6	-69	-33	-74	46	-30	-75	13	17	10
02-04	-71	44	54	-32	16	-57	-85	-17	-79	48	-22	-100	2	26	18
Wasser															
85-87	-22	31	-70	0	-25	32	34	-35	33	20	88		56	77	23
93-95	-26	27	-51	16	5	-7	71	-33	-1	45	33	42	32	33	18
02-04	-6	0	-25	-14	25	-23	24	-33	-36	30	38	-42	74	53	9
Umweltmesstechnik															
85-87	29	12	-64	20	13	-84	-8	-50	-77	-58	-100		-100	-72	0
93-95	17	-21	-63	48	43	-51	-36	-43	-24	38	47	-60	84	-57	11
02-04	32	-32	-73	-32	21	-45	14	-42	25	6	30	-39	34	-100	-5
Rationelle Energienutzung und Klimaschutz															
85-87	6	1	-77	0	34	41	-62	98	-63	38	10		4	-91	16
93-95	-10	-37	-37	-26	-39	74	-43	92	-7	-17	49	91	4	-55	7
02-04	-22	1	-23	12	-28	58	-16	74	-87	-26	-99	93	-100	-38	0
Regenerative Energien															
85-87	18	5	6	-20	-51	1	-100	-60	-45	28	-11		48	-79	-14
93-95	-39	0	44	-18	-57	5	-70	-74	-3	-9	2	41	73	63	-11
02-04	-53	17	13	10	-31	-12	0	-3	20	6	-17	-78	93	43	19
Umweltanmeldungen															
85-87	-22	40	-52	-26	-12	12	30	43	-9	23	63		27	57	21
93-95	-30	26	-14	-4	-4	20	26	16	-5	29	26	10	59	47	16
02-04	-34	16	7	-6	1	5	-6	27	-28	18	-21	9	56	42	12
Brennstoffzellen															
85-87	72	-83	-1	-100	-88	-100	-2	-100	-100	-100	-100		-100	-100	-91
93-95	9	6	15	28	-100	53	91	-44	-29	-100	-100	27	59	-100	-28
02-04	-15	-26	69	-57	-61	-16	73	-54	-84	-100	-97	-4	22	-100	-50

S

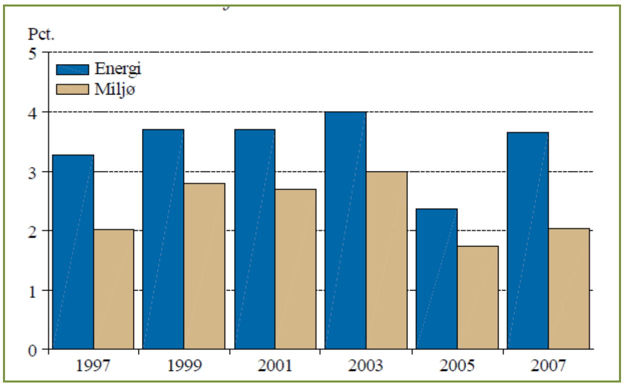
ource: Legler et al. (2007), p. 150.

The ranking of countries for each of the environmental technology areas changes a lot. Denmark has positive scores for waste, recycling, air pollution, water and renewable energy. The ranking of countries varies not only per field but also varies over times. A deeper analysis is needed to determine whether the changes in RPA reflect changes in technological capabilities. Patent data are best discussed with sector and technology experts, as is done in this study.

2.5.3 Patent data used in a Danish context

DØR (2011)[25] (Danish Economic Councils) has investigated the link between the resources spent on R&D and the number of patents obtained. The analysis focused on the patents awarded for energy-related technologies and environmental technologies.

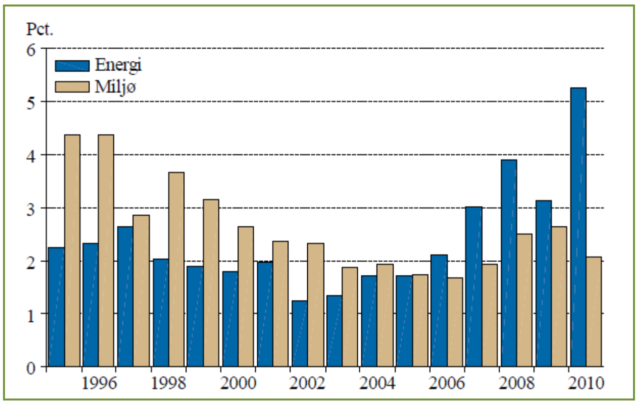
The first two graphs illustrate the percentage of total R&D expenditure spent on energy and environmental technologies by the public and the private sectors. It is clear that the government-funded R&D has seen a shift in recent years from environmental technologies towards energy-related technologies. This reflects a direct link between the policy objectives and public resources spent on R&D.



Source: DØR (2011)

FIGURE 5

PERCENTAGE OF R&D SPENT BY BUSINESSES ON ENERGY AND ENVIRONMENTAL TECHNOLOGIES



Source: DØR (2011)

FIGURE 6

PERCENTAGE OF GOVERNMENT-FUNDED R&D SPENT ON ENERGY AND ENVIRONMENTAL TECHNOLOGIES

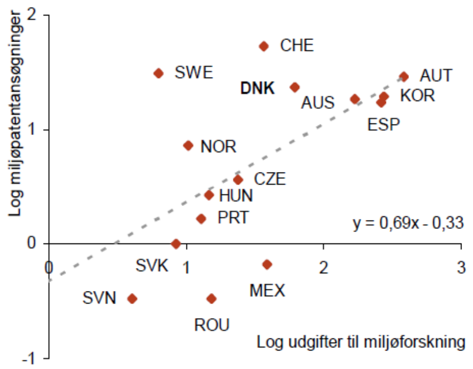
Further, the number of patents applied for from 1996 to 1998 and from 2006 to 2008 is presented. The number of patents for environmental technologies applied for has been almost stable at 2.7% of the total amount of patent applications. In contrast, the share of patents applied for in energy technologies increased from 1.1% to 4.7% of the total number of patent applications. The majority of patents in energy technologies fall within sustainable energy.

Given that the magnitude of patents is significant for environmental and energy technologies, it follows that Denmark has a strong focus on these particular areas compared with other countries.

25 DØR (2011), Økonomi og Miljø 2011, Chapter 2

In recent years, the percentage of Danish patents in energy and environment has been the highest of any EU15 country.

Moreover, an analysis of the number of patents for environmental technologies applied for have been plotted on a graph together with resources spent on R&D in different countries. The graph below shows the result of this exercise. The countries above the line obtain a relatively high number of patents for the money invested in R&D. Denmark is well above the average in both environmental and energy technologies, signifying that Danish R&D expenditure is well spent in terms of the amount of innovation generated.



Source: DØR (2011)

FIGURE 7

PLOT OF THE NUMBER OF ENVIRONMENTAL TECHNOLOGY PATENTS APPLIED FOR WITH THE RESOURCES SPENT ON ENVIRONMENTAL R&D

In a comparison of Danish R&D expenditure on environment and energy and the patents applied for in these areas, DØR finds that patents in energy have a much higher price tag than patents in environment. Compared with the average, Danish R&D expenditure per patent application, energy and environmental technologies are both relatively expensive. Thus, even though Denmark is relatively efficient compared with other countries in terms of number of patents applied for relative to the R&D expenditure, patents in environment and energy are still relatively expensive.

Finally, DØR looks at the number of patent citations. This is used as an indicator of the value of the investments made in R&D. DØR concludes that Danish patents in general and patents in sustainable energy in particular obtain relatively many citations compared with other countries, i.e. they must be more valuable.

It is interesting to note that DØR does not attempt to explain the differences in 'productivity' of R&D spending among the countries analysed. If R&D spending were the only factor determining the number of patent applications from a country, all countries would lie on the line in Figure 7. Other factors that would contribute to differentiating the countries' 'productivity' include national environmental and energy policy besides R&D funding and existing critical mass in scientists and knowhow.

Denmark's relatively high 'productivity' from R&D spending suggests that the political environment and the pool of scientific knowhow are at a place where R&D spending is very productive. If the patent vs. R&D spending type analysis is taken to a more detailed level, it may actually be possible to provide evidence of differences in policy and scientific knowhow in different areas of Danish environmental policy.

3. Strongholds in environmental technology in Denmark

3.1 The environmental business cluster

420 companies with approximately 60,000 employees and 46 knowledge institutions were identified[26], all engaged in the environmental technology area[27]. This means that the environmental business cluster is one of Denmark's largest business clusters.

In this analysis, the environmental business cluster is divided into sub-clusters based on the environmental challenge faced by the company or knowledge institution. Overall, eight sub-clusters were identified: a) energy/climate, b) water, c) materials consumption, d) land use, e) chemicals, f) air pollution and g) soil pollution/contamination.

Of these, three environmental clusters were selected for further analysis, primarily based on the size of the clusters as measured by the number of companies as well as the number of employees in the different clusters. The three selected clusters are energy/climate, water and chemicals.

According to the above analysis, they constitute three sizable clusters encompassing both high-tech companies and large companies with a strong global competitive power, as well as a range of knowledge institutions that conduct world-class R&D.

3.2 Promising technology areas in selected sub-clusters

Based on the further analysis[28], five promising areas were identified:

- Wind energy from mega turbines
- Water purification
- Industrial biotechnology
- Bio fuels
- Fuel cells.

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26 This has been done by applying the so called snowball method.
27 For the purpose of this analysis, a company engaged in the environmental technology area is quite broadly defined as a company fulfilling at least one of the following three criteria:
- The company develops and market solutions, products or technologies that directly improve the environment
- The company develops and markets solutions, products or technologies that improve the environment through improving resource efficiency
- The company develops and markets solutions or consultancy services that improve the environment through optimisation and efficiency gains of processes
28 Companies and knowledge institutions in these three areas have been asked to what extent they are involved in the development of new environmental technologies, and the analysis also details company expectations for future potentials and possible collaboration partners in meeting the potentials.
The emerging environmental technology areas identified by companies and knowledge institutions are assessed on the basis of three criteria:
- Critical mass – do the number of companies constitute a business stronghold?
- Knowledge – how is the quality rated against the world's best?
- Potential – does a large global market exist?
Furthermore, it has been assessed whether the development of new environmental technologies presupposes collaboration between companies, knowledge institutions and government authorities.

According to the analysis, wind energy, water purification and industrial biotechnology are founded on well-established businesses that have developed solutions and technologies to support an industry. Bio fuels and fuel cells are spin-offs from established industries, but the technologies remain somewhat under-developed compared to wind, water and industrial biotechnology.

3.3 Specifically on water purification

With regard to water purification - in this analysis encompassing technologies for purification and extraction/winning of drinking water (e.g. purification of surface water and desalination of ocean water) as well as technologies for sewage treatment/sewage purification - it is assessed that

"*...in the next few years, new solutions for water purification will surface, combining and further developing technologies from various disciplines. This applies to both new combinations of existing purification technologies and to combinations of environment-effective technologies in the industrial biotechnology field.*

Denmark possesses strongholds in both areas; thus the creation of a Danish water cluster will make it possible to develop new, competitive water purification solutions, so that Denmark can maintain and develop the current stronghold."

Among potential specific areas for development of strongholds in water purification, the analysis mentions:

- development of membrane technology for wastewater treatment
- advanced techniques for removal of anthropogenic substances, for instance by adding chemicals or through UV technologies
- electro-chemical treatment to remove of anthropogenic substances (with a longer time horizon)
- enzyme technology for water purification, partly in the water purification process itself, partly as support product in the cleaning of membranes and bio filter surfaces
- treatment of sludge, for instance by extracting more gas and thus reducing the amounts of solid waste.

Some of these findings are also supported through the results of another analysis by Vækstfonden[29] (2007)[30] finding that the primary strength of Danish companies operating in the water sector is their knowledge and ability to find the right solutions, whereas technological competences are primarily about constructing well-functioning plants based on existing technologies[31].

It is claimed that for many years, only few new companies established themselves in the water sector. However, in recent years, a number of new companies have emerged. The companies offer a number of different technologies, such as membranes, industrial biotechnology and environment-friendly filters. The new companies have the potential to create innovative solutions and increase the innovative level in Denmark.

Finally, concerning the water sector it is concluded that, globally, water is a growth market. Growing populations, increased welfare and pollution will intensify pressure on water resources in

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[29] A state investment fund, which aims to create new growth companies by providing venture capital and competence.

[30] Vækstfonden (2007), "Miljøsektoren i Danmark - Perspektiver for iværksætteri og venture kapital" , Vækstfonden, 2007.

[31] The exception is mentioned to be the component suppliers Grundfos and Danfoss, which are considered among the technological world leaders in their respective fields.

the next few years. Against this background, there is a good market potential in a number of areas, such as water extraction, purification of fresh water and wastewater, water saving technologies etc. Regulative measures are expected to contribute to the establishment of new markets, especially in the field of wastewater treatment.

Thus, in the analysis by Vækstfonden (2007) Denmark is found to have a firm foothold in sewage treatment sector[32]. Further, it is found that most new companies operate in the water sector, partly due to increasing demands for water purification technology, as water is becoming an ever-scarcer resource.

In a later study undertaken by COWI on behalf of the Danish EPA, COWI (2009)[33], building on the above-mentioned FORA (2006) analysis, the environmental business cluster related to chemicals is analysed with the purpose of identifying technological strongholds in this cluster - and with a special focus on the substitution of problematic substances/chemicals. In this analysis, a number of biotechnological strongholds are identified that could be viewed as - to some degree - overlapping with (or even as well belonging to) the water and waste sectors. The most significant examples mentioned are an enzyme that supersedes the use of phosphates in washing powder - a product with significant relevance in countries and regions where wastewater treatment does not effectively detain phosphates. Further, a strong and significant potential is seen within the utilization of enzymes in the waste treatment sector, for e.g. treatment of wastewater, of industrial waste etc. as well as treatment of slurry.

An earlier study on the environmental benefits and challenges from nanotechnology, biotechnology and information and communication technology, initiated by the Danish EPA, DEPA (2006)[34] also found that Danish companies have developed strong positions in so-called industrial biotechnology or white biotechnology[35], with applications that could be viewed as to some degree overlapping with (or even as well belonging to) the water and waste sectors. Among such applications emphasised are

- The use of enzymes in detergents has reduced necessary washing temperatures and water resources used with promises of further reductions.
- The use of enzymes in the textile industry has (compared to the alternative processes) significantly reduced the use of rinsing water as well as reduced the amount of chemicals that are released into the environment, hereunder to the water environment.
- The use of enzymes in the leather industry is stated to have reduced alternative problematic chemical use, and increased recirculation of rinsing water.
- The use of enzymes in the bleaching process in the pulp and paper industry is stated to have significantly reduced the chlorine use, contributing also to reducing the release of chlorine.
- In the animal feed industry, the development of phytase has led to a better exploitation of phosphorus in animal feed and thus to the reduction of emissions of phosphorus to the ground water (especially from pigs and poultry).

Also, Vækstfonden (2007) finds a stronghold to be present not least with regard to enzymes used in the industrial biotechnology - e.g. enzymes that are added to animal food to enhance the take up of phosphates by the animals and thus reduce leaching of nutrients.

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32 The Danish company Krüger became one of the leading developers of wastewater treatment plants building 90% of all treatment plants in Denmark and taking care of the around 1500 Danish plants that needed extensions in order to fulfill the new requirements. Krüger also became an important player in the development of wastewater plants outside Denmark, especially in Eastern Europe. This was stated in one of the individual interviews with the members of the steering group connected to the project.

33 COWI (2009), " Analyse af danske styrkepositioner inden for teknologier, der kan føre til substitution af kemikalier", COWI for Miljøstyrelsen, 2009

34 Danish EPA (2006), "Green Technology Foresight about environmentally friendly products and materials - The challenges from nanotechnology, biotechnology and ICT", Danish Environmental Protection Agency, 2006

35 White biotechnology, also termed industrial biotechnology, is biotechnology applied to industrial processes, with the aim to synthesize products that are easily degradable, require less resources (such as water and energy) and create less waste during their production. An aim that is achieved through the use of e.g. living cells or not least enzymes in the industrial production processes.

3.4 Strongholds in technologies for reducing air pollution

In a follow-up to the aforementioned study, the FORA on behalf of the DEPA, FORA (2007)[36], mapped Danish companies and knowledge institutions working with technologies and solutions for reducing air pollution to identify strongholds and assess the nature and extent of the cluster[37].

The study identifies a sub-cluster of the environmental technology cluster[38] engaged in products and technologies for reducing air pollution. According to the study, the cluster consists of 37 companies with 11,700 employees and has a total turnover annually of approximately DKK 6.5 billion. Export of products and technologies totals DKK 3.5 billion[39] and a large share of the companies reports that they compete and cooperate internationally, leading to the study conclusion that the cluster is generally oriented towards international markets. The companies also report that their level of knowledge is on a par with the best in the world. They spend a comparatively high proportion of their budgets on R&D.

According to the study, 80% of the companies indicate that they work with new environmental technology or environmental solutions.

The study found that the cluster could be subdivided into six areas according to the environmental challenge faced by the company. These areas are reductions of a) emissions of NO_X, b) emissions of particulates, and c) emissions of hydrocarbon and sulphur, d) emissions of ammonia e) emissions of environmental toxins, and finally f) other aspects of air pollution[40].

A particularly interesting stronghold is claimed to be in the field of reduction of air pollution from cars, where Denmark has outstanding competencies.

The analysis thus identifies a group of companies of particular interest working with methods for purification of exhaust gases, especially filters for removing particulates from exhaust gases and catalytic converters and other methods of reducing emissions of NO_X.

Outside the environmental technology cluster, there are a number of companies, which could potentially join the cluster by developing environmental-friendly products and solutions (as alternatives to existing products and solutions). Of particular interest is the production of wood-burning stoves, ship engines and coal-based power plants.

In these areas, it is concluded that Denmark *potentially* has an advantage in manufacturing environmentally friendly products.

Some of these findings are supported by the results of another study by Vækstfonden (2007) to the effect that Denmark has built a position of strength in the field of air pollution prevention.

There are a number of companies that manufacture filters and exhaust systems for emission control, both for stationary and mobile sources. These companies export a large share of the production by supplying components and parts of solutions to global players, both for retrofitting and as OEMs (original equipment manufacturer), meaning that they manufacture equipment that other companies use in the production process.

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[36] FORA (2007), " Kan man tjene penge på ren luft? - danske styrkepositioner inden for teknologier, der reducerer luftforurening", FORA for Miljøstyrelsen, 2007

[37] A second purpose of the analysis was to consider whether new policy measures are needed to ensure optimal development of such Strongholds and the air pollution abatement cluster in general.

[38] Again, this has been done by applying the so-called snowball-method.

[39] It is estimated that roughly around 60% of turnover in these companies can be related to activities concerned with reduction of air pollution.

[40] Measured by the number of employees the three first areas are the largest, while the last areas are somewhat smaller.

The global market potential is claimed to be high as the market is primarily driven by regulation in the form of various national requirements and standards as well as Euronorms for new cars.

Thus, also according to the study by Vækstfonden (2007), strongholds are found in the field of reduction of air pollution, not least for filters for removing particulates from exhaust gases.

3.5 Strongholds in technologies in the waste sector

As touched upon previously, the Danish Vækstfonden reached almost the same conclusions in a study of the environmental business sector in Denmark, Vækstfonden (2007) - a study undertaken with the aim to assess the perspectives for attracting venture capital investments in the so-called cleantech sector. Thus, it was found that Danish companies have established a number of strongholds in the environmental business sector.

One of the specific strongholds identified in this study is in the waste sector, more specifically recycling and treatment of hazardous wastes.

The Danish system of waste treatment is claimed to be one of the most environmentally friendly systems in the world with a recycling rate of waste of approximately 65% and another 27% used for energy through incineration.

According to the study, the sector is characterized by relatively few high-technology companies, a strong incineration industry as well as a number of consulting companies.

The sector is, however, also characterised by a number of technological leaders. Attention is drawn, among other companies, to an enterprise that is claimed to be a technological leader in incineration of hazardous wastes (Kommunekemi), and to a company being an innovative and principal supplier of equipment in the sector (Babcock & Wilcox Völund).

Finally, the sector is characterised by a number of small and relatively new companies that are operating in certain well-defined niche areas. One example is a company with a unique concept for composting that extracts gas from organic waste (Solum Gruppen). Another example of a niche company is Genan specialising in recycling of tires.

The largest knowhow base in the sector is found in consulting companies that are claimed to be among the world leaders. Attention is in particular drawn to three large consulting engineering companies (COWI, Grontmij - Carl Bro and Rambøll) due to their competences and services offered in project design/engineering of waste disposal facilities, as well as technologies for incineration facilities and soil cleaning.

The results of a concluding SWOT analysis of strengths, weaknesses, opportunities and threats regarding the Danish waste sector are summarised in the table below:

TABLE 4
SWOT ANALYSIS OF THE DANISH WASTE SECTOR

Strenghts	Weaknesses
- highly efficient and environmentally sound waste system - leading in the field of recycling - tradition for political support - treatment of 'hazardous waste' and other niches - solid consultancy sector	- modest home market - few new companies - limited technological innovation - limited knowledge sharing - no patentable solutions - high access barriers - lack of innovative culture
Opportunities	**Threats**
- booming global market - new waste types, e.g. windmill wings and LCD screens - niches in the field of recycling - export of knowhow on system solutions - district heating to markets abroad - biomass	- present consolidation process hinders innovative pilot projects - public owner structure hinders export - decreasing margin of profit

As indicated in the table, strengths and opportunities are

- the Danish system for waste treatment, which is very environmentally friendly, with strong competences in recycling as well as energy generation from incineration of waste.
- Consulting engineering companies, which possess knowhow and competences and offer services within integrated end-to-end solutions and process optimisation
- technologically strong competences in certain niche areas of the waste sector, including in the treatment of hazardous waste and new kinds of waste.

3.6 Mapping of the environmental business sector in Denmark

In a relatively new study undertaken for the DEPA, the FORA (in cooperation with Statistics Denmark) mapped the environmental business cluster in Denmark, one of the objectives being to identify strongholds in environmental technology, FORA (2009)[41].

The study identified 720 companies in Denmark that develop and market environmentally friendly technologies. In total, these companies employ 120,000 staff (measured in full time units) and generate a turnover of more than DKK 300 billion (approximately EUR 40 billion).

The study concludes that Danish environmental technologies seem to be very competitive on the global market, as approximately 40% of technologies and solutions from companies in the Danish environmental business cluster are exported. For industrial companies in the environmental business cluster, the export share of turnover is as high as 60.2%, which is reported to be a somewhat larger share than for other industrial companies with an export share of 47.9% (2006 figures). Further, the export share of the turnover has been increasing since 2001.Turnover from exports has increased by 50% while total turnover has increased by 35% in the period from 2001 to 2006. In general, industrial companies in the environmental business cluster has experienced growth rates significantly above those of other industrial companies during this period.

The environmental business cluster is characterised by many large companies in the industry and business services sectors (especially consultancy companies such as consulting engineers). The companies primarily sell their products, services and solutions to the energy utility sector, the industry sector, the building sector and public institutions.

[41] FORA (2009), "Kortlægning af miljøteknologiske virksomheder i Danmark", FORA, 2009

Products, services and solutions marketed by these companies are characterised by products and services with high knowledge content. For example, 150 companies sell research and development in environmentally friendly technology.

The companies in the cluster focus on a number of different environmental challenges[42]:

- The majority of companies focus on environmental challenges from climate change, water pollution, air pollution and consumption of (raw) materials.
- Companies with the highest turnover from exports focus on substitution of problematic chemicals in various products or on air pollution.
- Companies experiencing the sharpest growth in foreign turnover are those that focus on water pollution, waste or climate change.

Further, as illustrated in Figure 8 below, companies concentrating on the environmental challenges in the water sector had the highest export increase in the period from 2001 to 2006, followed by companies focusing on environmental challenges caused by waste and climate change. In the same period, increases in exports were lowest with companies targeting environmental challenges caused by chemicals and soil pollution.

As also illustrated by the figure, apart from sharp increases in exports, companies targeting environmental challenges from waste also had a sharp growth in productivity. Companies focusing on other environmental challenges only experienced a moderate growth in productivity.

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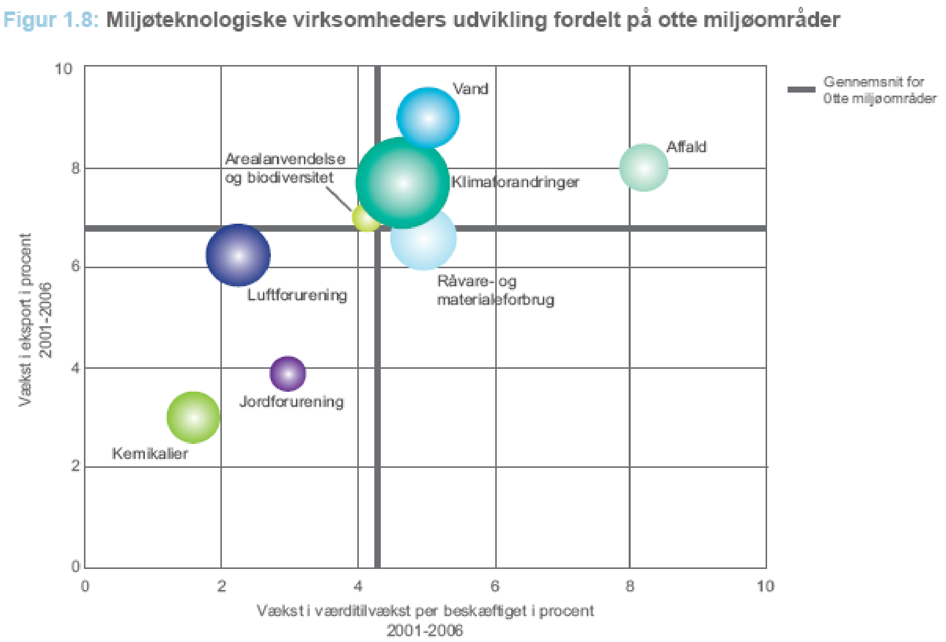
[42] Similar to previous analyses the environmental business cluster is divided into eight sub-clusters based on the environmental challenge faced by the company: a) Energy/Climate, b) Water, c) Materials consumption, d) Land use, e) Chemicals, f) Air pollution and g) Soil pollution/contamination.



Kilde: Snowball-undersøgelse, 2008, FORA
Anm.: Størrelsen på cirklerne illustrerer størrelsen på det respektive miljøområde målt på beskæftigelse. En række af de identificerede virksomheder afsætter flere typer miljøeffektive teknologier. Når det er tilfældet, er virksomheden og dens ansatte talt med inden for flere typer af løsninger. Det betyder, at summen af antal fuldtidsansatte inden for de otte miljøudfordringer overstiger det samlede antal virksomheder, der beskæftiger sig med miljøeffektiv teknologi.

Source: Snowball survey, 2008. FOR A.
Note: The size of the circles illustrates the magnitude of the individual environmental area in terms of employment. A number of the companies identified sell more than one type of environmental technology. In these cases, the company and its staff were interviewed for several types of solutions. This means that the number of full-time employees employed in the eight environmental areas exceed the total number of companies engaged in environmental technologies. Vand = water, affald = waste, klimaforandringer = climate change, Arealanvendelse og biodiversitet = land use and biodiversity, luftforurening = air pollution, råvare- og materialeforbrug = consumption of raw materials and other materials, jordforurening = soil pollution, kemikalier = chemicals

FIGURE 8
DEVELOPMENT IN ENVIRONMENTAL TECHNOLOGY COMPANIES DISTRIBUTED ON EIGHT ENVIRONMENTAL AREAS

The overall conclusion is that, in the environmental business cluster, companies targeting environmental challenges from waste, water, climate change and consumption of (raw) materials have strong positions in the market. Also, companies focusing on environmental challenges from air pollution and chemicals are worthwhile considering due to large foreign turnovers. Overall conclusions seem well in line with previous analysis of environmental strongholds referred above.

4. Policy development

Along the lines of the section on strongholds in environmental technologies in Denmark, this chapter will provide input to the approach to data collection and data analysis. The chapter is based on individual interviews with the members of the project steering group and conclusions from a workshop held at the EPA. Further, a number of COWI experts were interviewed. For each of the areas waste, water and air, major milestones for national policy development have been identified.

It should be noted that national policy development is often driven by international policy development. In the case of Denmark, new policy initiatives often emerge from the implementation of new EU policies. Some Danish milestones are therefore directly linked to EU milestones, but the focus is here on the specific Danish initiatives.

At the workshop, it was emphasised that technological development is driven by many other factors than national policies. One example is the development in the Danish windmill industry, which could be believed to be partly motivated by the Kyoto protocol (1997). However, the actual driver behind the fast development in the 1980's was a mix of policy instruments consisting of, among other things, an obligation to buy wind power at 85% of the retail price and the introduction of a 30% investment subsidy for investments in new wind turbines.[43] In addition, huge Danish research and development activities as well as Danish capabilities naturally promote technological development, which then push the development of new environmental policies and adjustment to Best Available Technologies (BAT).

From 1987 to 2002, there was a number of public research funding schemes under the heading 'Cleaner Technologies'/'Cleaner Products'. These funding schemes had a very broad aim that incorporated all aspects of environmental pollution from the manufacturing industry. In the early years, the focus was primarily on small to midsized manufacturers, while the latter years focused on the life cycle of the products and the substitution of harmful chemicals in products for less harmful or benign chemicals. This funding scheme is therefore likely to provide technologies for many of the fields where patents have been obtained.

4.1 Waste

In the 1960's, Denmark made a political commitment to implement a district heating infrastructure, which was accelerated by the oil crisis in the 1970's. A large part of Denmark became connected to this heating infrastructure. Especially in densely populated regions, district heating became widespread. The heating infrastructure provided a natural foundation for setting up a strategy for waste incineration, which still is more widespread in Denmark than in any other country. The outcome of the Danish waste incineration strategy is that very limited amounts of waste are deposited at Danish landfills today.

Below is an illustration of the most important waste policy milestones in Denmark since the 1970's.

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[43] Kristinsson, K., and Rao, E. (2006) Learning to grow: a comparative analysis of the analysis of the wind turbine industry in Denmark and India, paper for DRUID conference

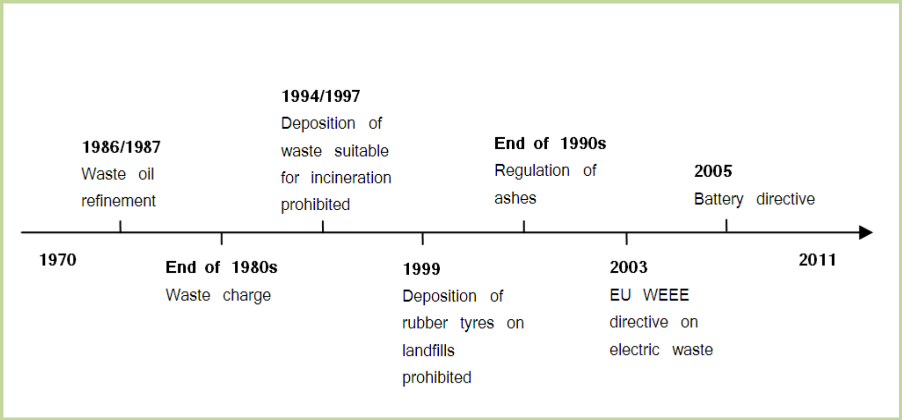

FIGURE 9

GRAPHICAL PRESENTATION OF MILESTONES IN DANISH WASTE POLICY

As can be seen, the first part of the period was dominated by national policies whereas in recent time, policies have been formulated at the EU level. This development follows the general development in the formulation of environmental policies.

The major policy milestones can be divided into three groups. The first is a general economic instrument aiming at limiting the resources consumption of society. The second focuses on waste treatment, which in a Danish context mainly concerns incineration. The third group concerns the management and treatment of certain waste fractions.

Economic instruments

At the end of the 1980's, waste charges were implemented to create incentives for limiting the use of resources in Denmark *(Lov nr 838 af 19/12/1989 om afgift af affald og råstoffer)*. The policy does not set specific requirements for handling of waste or options for achieving discounts by handling waste in specific ways. The introduction of the waste charge policy generated revenues and guaranteed that the recycling potential was maximized. The simple waste charge resulted in revenues in the order of DKK 70-80 million gradually increasing in the following decades to more than DKK 1 billion today. To begin with, revenues were spent on R&D in waste management development, but today less of the revenue is used for R&D funding in the waste sector, and revenues now go directly to the state budget. The figure beneath shows the level of the waste charge over time.

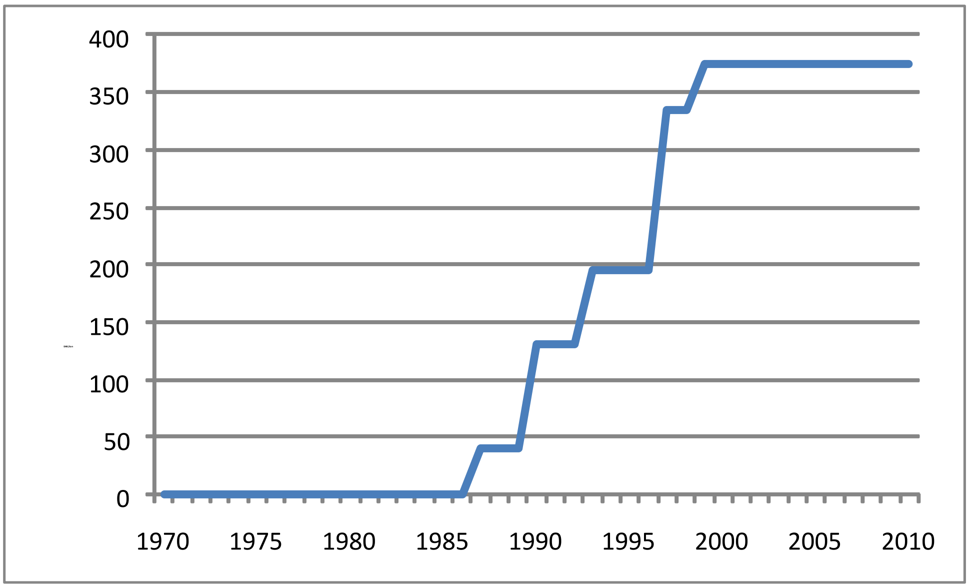

FIGURE 10

WASTE CHARGE IN DKK PER TON

Especially in the case of company waste, there is a strong incentive to reuse or recycle part of the waste instead of depositing it at landfills or sending it to incineration.

R&D investments were spent on research on waste handling and waste management. In the context of patents, it is likely that some investments were supported by the revenue generated from this tax.

Policies controlling treatment methods

As mentioned in the introduction to the section on waste, Denmark has long focused on district heating and to support this policy, the wish to enhance waste incineration grew.

In 1993, Danish legislation prohibiting deposition of waste suitable for incineration was passed followed by implementation in 1997 *(Bekendtgørelse nr. 131 af 21. marts 1993 om bortskaffelse, planlægning og registrering af affald)*. The main objective of the legislative instrument was to utilise the energy contained in waste and to lower the price of district heating. In the same period, it also became a requirement that incineration plants should develop capacity to produce not only heat but also electricity. This requirement led to a new generation of waste incineration plants. In order to support the transition of incineration plants, tax obligations of new plants were reduced.

Legislation to promote incineration involved a new challenge. When waste is incinerated, ash is produced as a by-product. Due to new requirements to the spreading of ash on farmland as well as the general handling of ashes, a consolidated act on ashes was introduced to reduce contamination by phosphorus and cadmium. The new act required phosphorus and cadmium to be separated from ashes *(Bekendtgørelse nr. 39 af 20/01/2000 om anvendelse af aske fra forgasning og* *forbrænding af biomasse og biomasseaffald til jordbrugsformål - Bioaskebekendtgørelsen).* As Denmark's and one of Europe's leading plants for incineration of hazardous waste, *Kommunekemi* developed a mechanism to handle the separation. However, *Kommunekemi* does not receive enough ashes to maintain a profitable business in this area.

Policies directed at specific waste fractions

Finally, policies and legislation have been introduced to regulate the handling or treatment of specific waste fractions.

1986/1987 saw the introduction of an act on waste oil refining in Denmark and EU wide *(Waste oil directive EEC87/101).* The act set requirements for the refining, collection and disposal of waste oil. In Denmark, this motivated companies to develop new inventions. However, the act was later amended, and the requirements no longer exist.

In 1999, a consolidated act came into force prohibiting landfilling of rubber tyres *(Bekendtgørelse nr. 860 af 29/11/1999 om håndtering af affald i form af motordrevne køretøjer og affaldsfraktioner herfra).* Subsidies for disposal of tyres were therefore changed, and subsidies for incineration of tyres were funded by a tax on purchase of tyres. Collection of tyres continued to be subsidized, and this subsidy combined with a factor five increase in rubber prices created a powerful incentive for recycling rubber tyres. One of the innovators in this area is the Danish company, GENAN VIBORG, which has developed a method to produce percolate from tyres, which can be used for e.g. artificial grass and playground surfaces.

In 2003, the EU WEEE Directive on waste from electronic and electric equipment came into force (Directive 2002/95/EC). Responsibility for collecting WEEE went to manufacturers of electronics, so that households would have the possibility of returning WEEE free of charge. By 2005, all countries but the UK had transposed this directive into national legislation. The UK followed in 2007.

In 2005, the EU Battery Directive (Directive 2006/66/EC) was introduced into Danish legislation. The directive's requirements to the processing of certain battery substances led to the need for a battery sorting system. The company Force Technology developed an automatic battery sorting system.

Other inventions identified during the interviews without being directly linked to policy are the following:

- The utilisation of waste gas. To promote the use of waste gas, a higher price is offered for green electricity.
- "The Danish model": a system to optimise collection. The fundamental principle of the model is that coordination of the waste management is a public task. The Danish Waste Model is a comprehensive system covering waste prevention, collection and treatment for both household waste and industrial waste. The model often includes a public-private partnership, but in general it seeks to optimise the collection of waste from households and companies.
- Biogas plant. It is expensive to collect and/or to separate suitable waste from the mixed waste. Experiences so far have shown that the biogas plant cannot operate on household waste alone, but with a combination of sludge and slurry. This has been a barrier to the success of biogas. *Vestforbrænding Solum Gruppen* has attempted to solve this problem.
- Waterproofed wood. A ban has been introduced in Denmark on incineration of waterproofed wood. So far, there is no cost-effective technology for reusing/recycling or treatment of the wood, and the wood is therefore disposed of at landfills. Kommunekemi has a facility that can handle this type of wood, but as long as it is legal to export the wood at a lower price, the facility is not utilised. The export option will be changed in 2012, and in the future it will no longer be possible to export waste in the same quantities as today.

These themes were used by the OECD in the data collection phase, where the information provided details of which types of patent data to include in the data set.

An upcoming problem not yet taken care of is the wings of wind turbines. Made from fibreglass, the wings are not suitable for incineration, but there may be other recycling options using available technologies.

Efforts have also been made to recycle other waste fractions in areas not regulated by specific legislation; consequently technologies have not been successful. An example is PVC, which is not covered by legislative requirements. As a result, technologies failed (RGS90).

4.2 Soil contamination

Denmark has a long tradition for handling contaminated soil. The reason is Denmark's strong dependency on untreated ground water for water supplies, which may be put at risk by contaminated soil. As with most environmental policies in Denmark, legislative work began with the general act on the protection of the environment in 1974 *(lov nr. 372 af 13. juni 1973 om Miljøbeskyttelse)*. Around ten years later, the first specific act on contaminated soil was implemented *(Lov nr. 262 af 8. juni 1983 om kemikalieaffaldsdepoter)*.

Since 1995, two financing programmes have been in place. The first lasted from 1995 to 2000, and the second, opened in 2000, is still in operation. These programmes have provided support to projects, which have investigated new technologies for cleaning up contaminated soil, but projects with an organisational perspective have also received support.

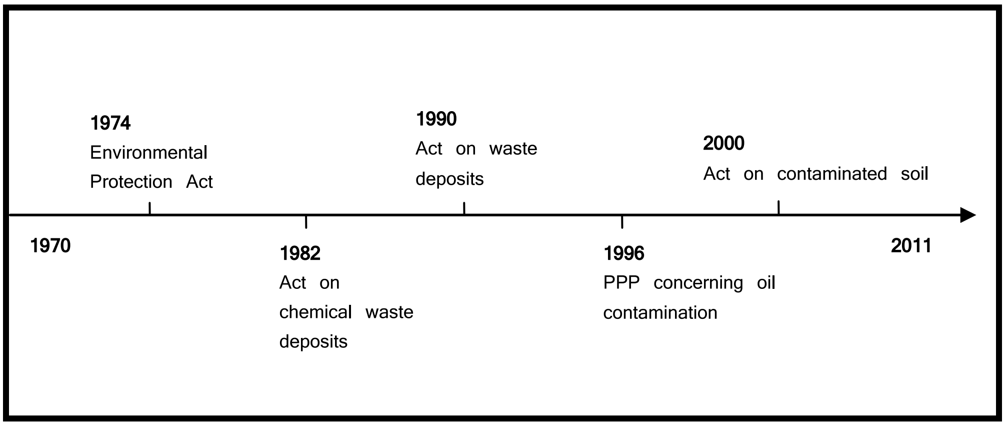

FIGURE 11

GRAPHICAL PRESENTATION OF MILESTONES IN THE DANISH CONTAMINATED SOIL POLICY

Legislative trends in the area are moving in the direction of a more all-inclusive approach. The first specific act on contaminated soil from 1983 had as its primary objective to clean up contaminated sites, the so-called brown fields *(Lov nr. 262 af 8. juni 1983 om kemikalieaffaldsdepoter)*. As work with brown fields progressed, an increasing number of contaminated sites were identified, which made the need for mapping evident. In 1990, the act on waste disposal sites was passed *(lov nr. 420 af 13. juni 1990 om affaldsdepoter)*. The aim was to map sites, rank them according to degree of contamination and to clean them up in order of priority. At the same time, financial support for all relevant action in the area (e.g. cleaning up, investigations, R&D)was increased substantially (with a factor 4 approximately).

The mapping showed that the sites of many former fuelling stations were contaminated, and the business association of the oil companies became interested in avoiding bad publicity. In 1996, a public-private agreement *(Oliebranchens Miljøpulje - OM)* paved the way for a system by which oil

companies cleaned up contaminated soil at former filling stations. The scheme was financed by a tax on petrol.

In 2000, legislation on contaminated soil still in force was adopted *(Lov nr. 370 af 2. juni 1999 om forurenet jord)*. The objective of this piece of legislation is to protect groundwater interests and land use. The mapping became even more important as it turned out that the number of contaminated sites was much higher than initially expected. Regulation setting requirements for soil transport and soil deposition was adopted *(Bekendtgørelse nr. 675 af 27/06/2000 om anmeldelse af flytning af forurenet jord og jord fra forureningskortlagte arealer og offentligt vejareal)*..

4.3 Wastewater[44]

In 1973, the Danish Ministry of the Environment was established, and in 1974 the first environmental act was adopted *(lov nr. 372 af 13. juni 1973 om Miljøbeskyttelse)*. This first act focused on chimney filters, discharge of chemical waste to the ground and cleaning of the most visible water pollution, which was done by so-called mechanical treatment plants that remove large particles and organic matter. These were 'end of pipe' solutions in the sense that production was handled without consideration for environmental issues with cleaning operations initiated at the end of the production process.

From the mid-1980's, cleaner technologies and environmental management received increasing attention. Cleaner technologies meant inclusion of environmental considerations in the production process, which led to the introduction of requirements to the production process and the choice of production input.

Since then, Danish wastewater history has seen two major milestones.

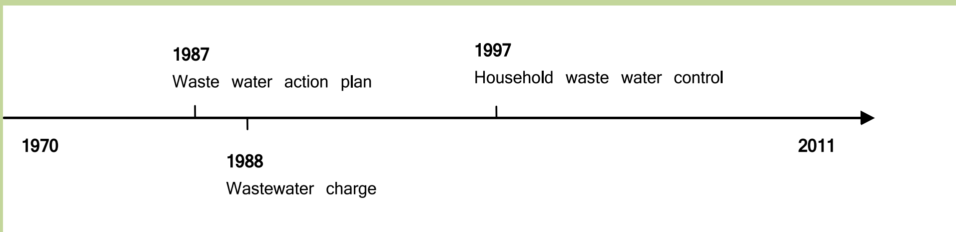

FIGURE 12

GRAPHICAL PRESENTATION OF MILESTONES IN DANISH WASTEWATER POLICY

Specific water policies were not introduced until later. The two water policy milestones involved an overall water action plan and legislation directed at households. Before 1987, there were no threshold requirements to water entering wastewater treatment plants, but in 1987 the first wastewater action plan (Vandmiljøplan I) was implemented resulting in nitrogen and phosphorus treatment requirements to plants above 5000 PE[45]. It became a requirement that best available technologies (BAT) were implemented, and specific threshold values were introduced to the water entering the wastewater plants together with requirements to wastewater discharge in general, e.g. directly into recipients.

In 1988, a wastewater charge was introduced through a consolidated act *(bekendtgørelse af 21/08/1998 om afgift af spildevand)*.

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[44] Some wastewater policies are connected to and affected by agricultural policies. However, the development in agricultural policy is omitted from this context to limit the scope of the study.
[45] Person Equivalent, a unit for measuring the capacity and/or the load of wastewater treatment plants.

In 1991, the urban wastewater treatment directive *(directive 91/271/EEC)* was adopted and implemented in Denmark. However, this did not lead to any major changes to existing Danish legislation as the wastewater action plan already included most of the issues.

One challenge remained which was not targeted by the wastewater action plan. This concerned developments in the countryside. To cater for this area, requirements to the handling of wastewater in the countryside were formulated and implemented. Acting on this, the Danish Ministry of the Environment, in 1997, introduced a policy to regulate developments in the countryside, such as new construction works, wastewater treatment etc. *(Bekendtgørelse nr. 723 af 12/09/1997 om kontrol af beholdere for flydende husdyrgødning, ensilagesaft eller spildevand).* This meant that approximately 100,000 homeowners were required to replace existing wastewater installations due to new requirements and to avoid the risk of contamination of soil, recipients or groundwater. The new policy motivated the development of a mini treatment plant, which was approved by the Danish EPA (Danish Environmental Protection Agency) as an alternative to contaminating wastewater installations. Another alternative to homeowners was to lead sewage water through filters into the ground.

From 1987 to 1992, DKK 30 billion were spent on R&D in the field of wastewater and the related administration of the funding. Further, in 1994 a voluntary agreement was drawn up with the municipalities on the renovation of the existing sewage system. An evaluation of the progress in 2004 found that renovation works at this point had not been sufficient and that the renovation works had to be accelerated from 2003 to 2008 where the agreement expired.

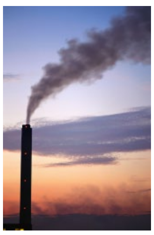
Other inventions identified without any direct links to policy are the following:

- A very promising invention is the whirl separator. It can quickly provide simple cleaning of water in case of e.g. flooding (*Bonnerup* patent). Could be driven by the Water Framework Directive (WFD).
- Technologies that can be used for monitoring. E.g. intelligent (radar-based) management of treatment plants. Some Danish companies (Krüger, *Aalborg University*) have been working in this field. These technologies offer improved accuracy of measurements and faster results.
- Sludge: sludge that cannot be spread on farmed fields is sent to Germany. New initiatives have been taken in this field; one involves the extraction of phosphorus from the sludge, another is to use the sludge as sandblasting material.
- In 2006, requirements to 'COD' were set for plants bigger than 2000PE. This paved the way for changes to the production processes and production input.
- Online measurement of the quality of drinking water. The rapid possibilities of monitoring the water quality improve the security of water supply.
- As water is a scarce resource especially in some parts of the world, recycling and water saving can be essential. E.g. recycling of water from rooftops for washing and toilet flushing.

These themes were used by the OECD for the data collection phase as it was expected that there could be Danish inventors among them. The information provided details on which types of patent data to include in the data set.

4.4 Air

Already in the 1960's, there was a realisation that SO_2 worsened air quality. In the early 1970's, this knowledge paved the way for regulation targeting the SO_2 content of fossil fuels. The general act on protection of the environment from 1974 *(lov nr. 372 af 13. juni 1973 om Miljøbeskyttelse)* made it possible to regulate emissions through implementing thresholds for the quality of the air emission. These thresholds were mainly directed towards industries. Later, the policy has been extended to include a wider range of instruments, and today it encompasses economic instruments, auditing schemes, voluntary labelling and agreements.



A major challenge of the implementing process is monitoring the effect of regulation. Much effort has been devoted to measuring air quality and setting realistic thresholds in a cost-efficient way.

The history of air policy in Denmark has seen a number of major milestones since the beginning of the 1970's.

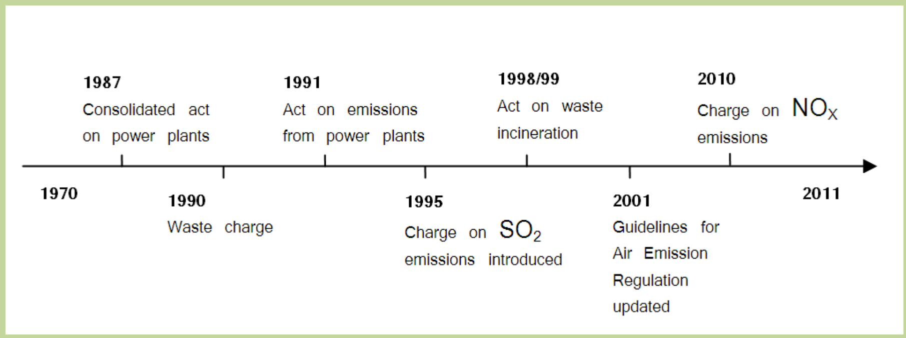


FIGURE 13

GRAPHICAL PRESENTATION OF MILESTONES IN DANISH AIR POLICY

The Danish policy in the area of regulating the air quality is made up of national acts, charges and guidelines.

Acts

Three major acts were passed and implemented over a period of 10 years. They all three addressed major plants and introduced thresholds and more or less targeted the same substances.

In 1987, EU legislation was implemented in a consolidated act on power plants *Bekendtgørelse nr. 119 af 12. marts 1987 om grænseværdi for luftens indhold af nitrogendioxid*. Particular focus was on emission thresholds for NO_X, SO_2 and nuisance dust. Furthermore, it became important to control and to differentiate between the requirements to new versus existing power plants.

In 1989, the Montreal protocol, designed to protect the ozone layer, came into force. The protocol would be expected to have significant impact on national policy development. However, in this case Denmark had already taken action on ozone depleting substances by the implementation of a consolidated act in 1987 *(Bekendtgørelse nr. 119 af 12. marts 1987 om grænseværdi for luftens indhold af nitrogendioxid)*. This and several other initiatives are described in the following. The specific issues related to the technologies developed to protect the ozone layer will not be dealt with in further detail here, as these initiatives do not address specific air pollution problems but rather climate-related challenges.

In 1991, a consolidated act on the limitation of sulphur dioxide and nitrogen oxide emissions from power plants was implemented, introducing quotas on NO_X and SO_2 (*Bekendtgørelse nr. 885 af 18. december 1991 om begrænsning af udledning af svovldioxid og kvælstofoxider fra kraftværker - Kvotebekendtgørelsen*).

In 1998/99, an EU directive was transposed into Danish law by the consolidated act on waste incineration (*Bekendtgørelse nr 900 af 07/12/1999 om brandværnsforanstaltninger ved afbrænding af halm, kvas, haveaffald og bål m.v. (Halmbekendtgørelsen)*. Stricter thresholds were introduced especially for contaminating substances, including dioxin and heavy metals.

Charges

To address sources of air pollution other than those from major plants, economic instruments were introduced. The instruments introduced a charge on emissions of certain substances. (*Lov nr. 838 af 19. december 1989 om afgift af affald og råstoffer*). By way of example, the SO_2 tax is a tax on the sulphur content in fuel, or with the possibility for larger plant to pay related to their emissions of SO_2.

In 1995, an act on SO_2 charges was passed *(Bekendtgørelse nr. 1163 af 21/12/1995 om måling af svovl)*, and from 1996, a charge on SO_2 emissions was gradually introduced, which came into full effect in 2000. In 2010, a charge on NO_X emissions was introduced *(Bekendtgørelse nr. 1412 af 21. december 2009 om måling af udledningen af kvælstofoxider (NO_X) og om godtgørelse af afgiften)*.

Guidelines
In 1990, guidelines for air emission regulation for industries were implemented (excluding power and incineration plants) *(Miljøstyrelsen vejledning nr. 6/1990 om begrænsning af luftforurening fra virksomheder)*. The act introduced emission thresholds based on best available technology (BAT) for all industry substances. In addition, B-values for substances were introduced, indicating the maximum allowed contribution from each source to the environment. The legislation included a mechanism allowing assessment of thresholds for new substances based on the B-values. Particularly toxic substances with severe impacts on the environment were identified. Nuisance dust and flux were not included, and no thresholds were set for these substances.

In 2001, the Guidelines for air emission regulation from 1990 were updated with new and stricter thresholds as well as differentiated thresholds across sectors *(Miljøstyrelsens vejledning nr. 12415 af 1. januar 2001 om begrænsning af luftforurening fra virksomheder)*. Especially for the shipping sector, IMO ship pollution rules are contained in the "International Convention on the Prevention of Pollution from Ships known as MARPOL 73/78. The MARPOL Annex VI sets limits on NO_X and SO_X emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances. Denmark ratified the annex VI in 2008.

Other inventions identified that could not directly be linked to policy include:
- Bag-type dust collector
- VOC carbon filter or combusting
- NO_X specific filters
- SO_2 swabs.

These themes were used by the OECD for the data collection phase, where the information provided details of which types of patent data to include in the data set.

5. Patent data

The patent data for the analysis have been extracted from the OECD patent database with the help of the OECD.

The data used in this analysis are based on patent applications - NOT patent grants. The aim of the study is to analyse the relationship between environmental regulation and innovation in environmental technologies. Since the patent grant process can take several years from the filing of the actual application to the issue date, the link between policy and innovation is potentially much stronger for patent applications than for patent grants, cf. section 1.4.

In its raw form, patent data from OECD are inflated in the sense that patents with more than one inventor will be counted several times. This is because each inventor and each company involved in the patent application is registered as unique data entries. As an example, a technology developed by a joint venture of three firms each employing one inventor would lead to nine entries in the patent data. Each firm is registered, and for each firm all three inventors have to be acknowledged.

In future analyses of these patent data, inflation of data would be worthwhile exploring. On the one hand, it makes sense that each invention is followed by only one data entry in order to convey the true volume of patent applications. On the other hand, we have been searching for a means of identifying 'important' patents. It could perhaps be argued that patents with many inventors and many firms involved are more likely to be more important than patents with fewer participants - simply because several participants reflect a substantial investment.

All charts and tables presented in this section of the report count patents only once, i.e. there is no distinction between important and less important patents.

Data for 2010 are incomplete, and charts depicting time series will thus not show data for 2010.

5.1 Patents in environmental technology

Establishing relevance to the four policy areas has been an iterative process between COWI and the OECD. COWI provided descriptions of all the known policy shocks of relevance. The OECD then provided a list of potentially relevant IPC codes as well as guidance to the expected relevance of these codes. COWI reviewed the IPC codes and adjusted the list. Over the course of a few weeks and several iterations, the list was finalized and the OECD could prepare to extract the data. The finalized list of IPC codes are provided in Appendix 1. The table below describes the data available for each patent.

TABLE 5
DATA AVAILABLE FOR EACH PATENT

Appln_id	**Unique id for each patent application (internal surrogate key; it has no real-world meaning)**
Appln_auth	Application authority - patent office where application was deposited. See also http://www.wipo.int/standards/en/pdf/03-03-01.pdf
Appln_nr	Application number
Appln_kind	Application kind code (this is complex; it suffices to know that the triple auth-nr-kind is unique)
Appln_filing_date	Date of application
prio_appln_id	Id of the priority application
Appt_id	Applicant id (again, this an internal surrogate key)
Appt_ctry	Country of the applicant
Appt_name	Name of the applicant
Prio_date	Indicates the earliest application date worldwide (within a given patent family).
Prio_year	Only the year part of Prio_date
Invt_ctry	Country of the inventor
Doc_type	So-called 'document type' – indicates whether this is a singular, claimed priority, or a duplicate
appln_title	Extensive title of application with ultra brief statement of the subject of the patent

Patent data are available for each policy area (i.e. waste, water, soil, air) as well as for some of the major sub-areas: waste collection, waste recycling, waste fertilizer, waste incineration, air SO_X and NO_X, air particulates (PM) and air heavy metals. The chart below describes the number of Danish patents in each category in the period from 1970 to 2010.

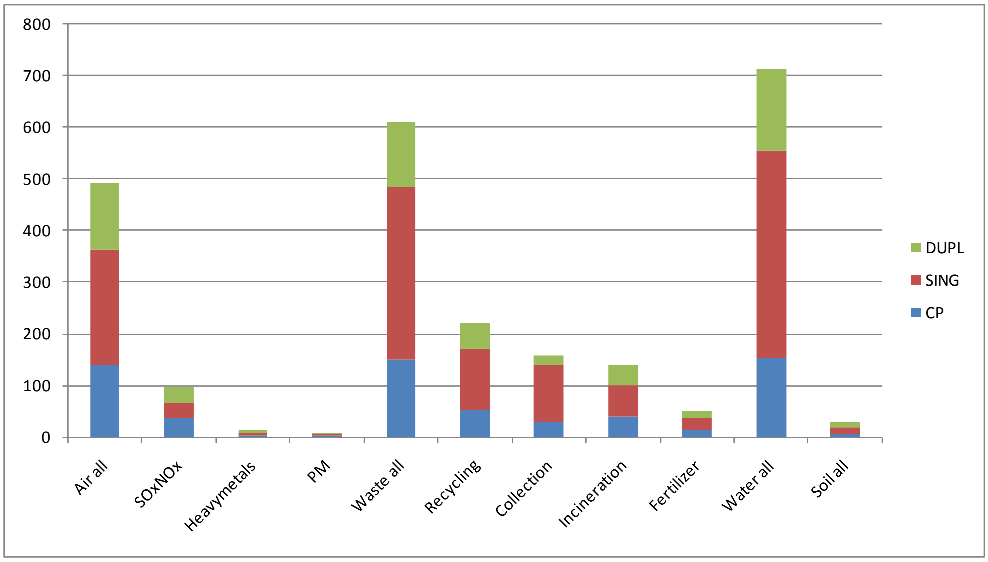


FIGURE 14
DANISH APPLICATIONS TO THE DK AND EU PATENT OFFICES, 1970 - 2010

5.2 Identification of Danish patents

Identifying Danish patent applications is a matter of defining what constitutes a Danish patent. An application filed for the first time with the Danish patent office by a foreign company employing Danish inventors could in some instances be construed as Danish and in others not. The same goes for an application filed with the Danish patent office by a Danish company that has bought the rights from a foreign company. These are just examples of cases where the nationality of a patent is not exactly clear.

Generally, there are two main factors contributing to the identification of Danish patents. First, the roles of the nationality of the patent office, the applicant and the inventor must be determined. Second, the type of application - is this the first time it is patented or not - plays a vital role.

The identification of nationality of a patent is also heavily dependent on the context in which it is to be used. In this case, the focus is on the relationship between Danish environmental policy and innovation in environmental technology. The optimal solution would then be to define Danish patents as all applications to the Danish patent office as well as all applications by Danish applicants to the European Patent Office. Further, to avoid double counting, the applications to the EPO should not be duplicates of existing patents. In practice, however, this solution is not feasible, as it will become clear in the following.

Nationality

The patent data specify for which country the application is made, the nationality of the applicant and the nationality of the inventor(s). Very often, the applicant is the company that employs the actual inventors, such that the inventors are credited for the invention but the company owns the rights to utilize the technology. In cases where the inventors themselves file the application, applicant and inventor will be identical in the database.

To determine the nationality of a patent, it will be necessary to decide what defines a Danish patent in relation to property rights versus the actual act of inventing new technology. If focus was on determining the Danish educational system's ability to educate inventors, then it would be relevant to define nationality by way of inventors. In this case, however, the main issue is how Danish regulation interacts with innovation.

To determine how regulation interacts with innovation, it is not relevant to limit nationality to Danish inventors. Foreign inventors and companies could be just as likely to react to changes in regulation in Denmark as Danish companies. Further, Danish companies could employ foreign inventors. Instead, it is more relevant to define nationality at the applicant level and the patent office level.

Type of patent

The patent data also specify whether the application is for a previously patented technology (Duplicate) or a new technology (Claimed Priority or Single). A Single is typically a patent for a technology that has never been patented before. A Claimed Priority is a Single, which has subsequently been applied for in other countries. Claimed Priority is a patented technology, which has demonstrated to have or is believed to have international market potential. A Claimed Priority can start out as a Single and develop into a Claimed Priority as the technology proves to be marketable. When a Single is patented in a new country, the new patent will become a Duplicate, and the Single (the original patent) becomes a Claimed Priority.

The charts below show the number of patent applications filed with the Danish Patent Office. Patent applications are split up by environmental policy areas and sub-areas as well as by Danish and non-Danish applicants.

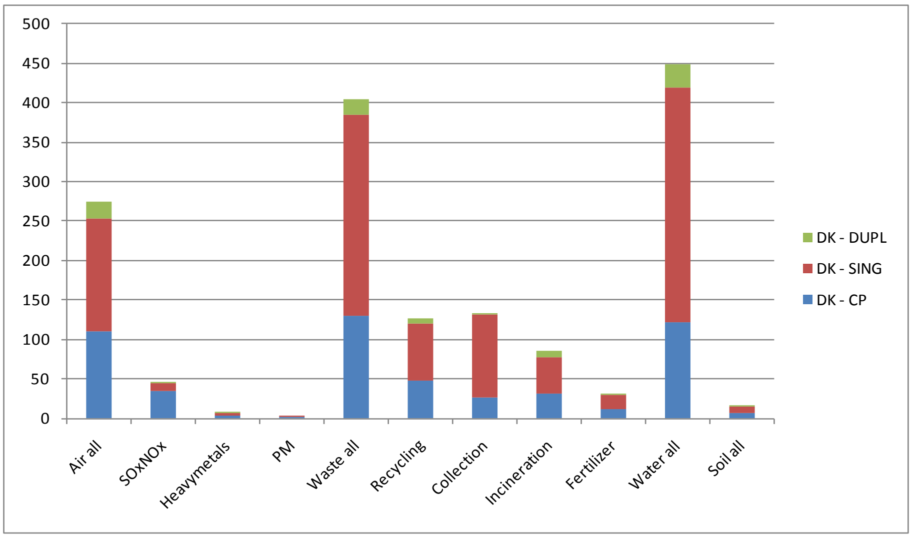


FIGURE 15

APPLICATIONS TO THE DANISH PATENT OFFICE BY DANISH APPLICANTS, 1970 - 2010

The charts reveal a distinct difference in the structure of patent applications by Danish and foreign applicants. Danish applicants primarily apply for Singles and Claimed Priorities while foreign applicants primarily apply for Duplicates. This makes immediate sense on an intuitive level.

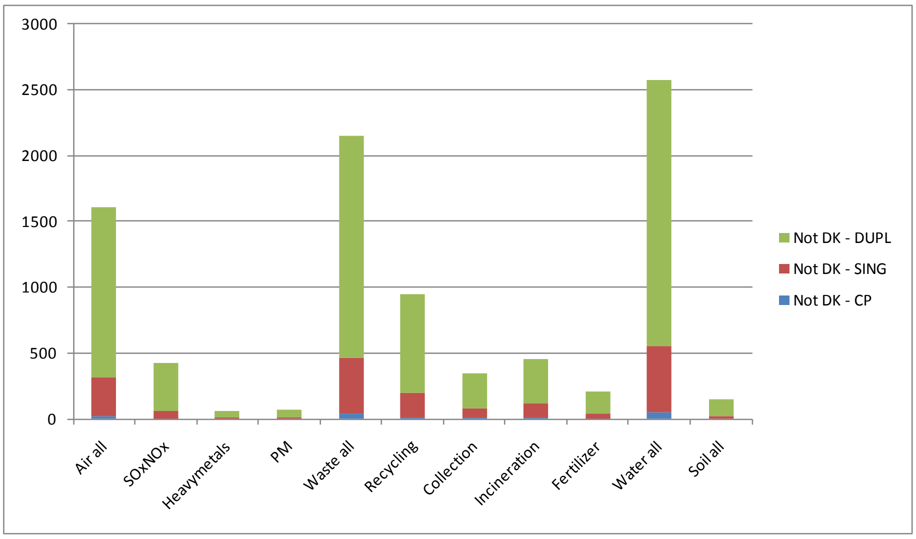


FIGURE 16

APPLICATIONS TO THE DANISH PATENT OFFICE BY FOREIGN APPLICANTS 1970 - 2010

The European Patent Office

In 1978, the European Patent Office (EPO) was established to ease the process of patenting in Europe (not exclusively EC). Applications made to the EPO would be valid for all Member States supporting the EPO, such that patenting in a Member State only requires the EPO patent to be translated into the official language of the Member State; no further applications are needed. Denmark did not become a member of the EPO until 1990. Today, the EPO has 38 European Member States.

The introduction of the EPO and the Danish membership from 1990 have drastically lowered the inflow of international patent applications to the Danish Patent Office. In the years prior to 1990, international applications constituted more than 80% of all applications to the Danish Patent Office. Today, there are virtually no international applications, cf. chart below.

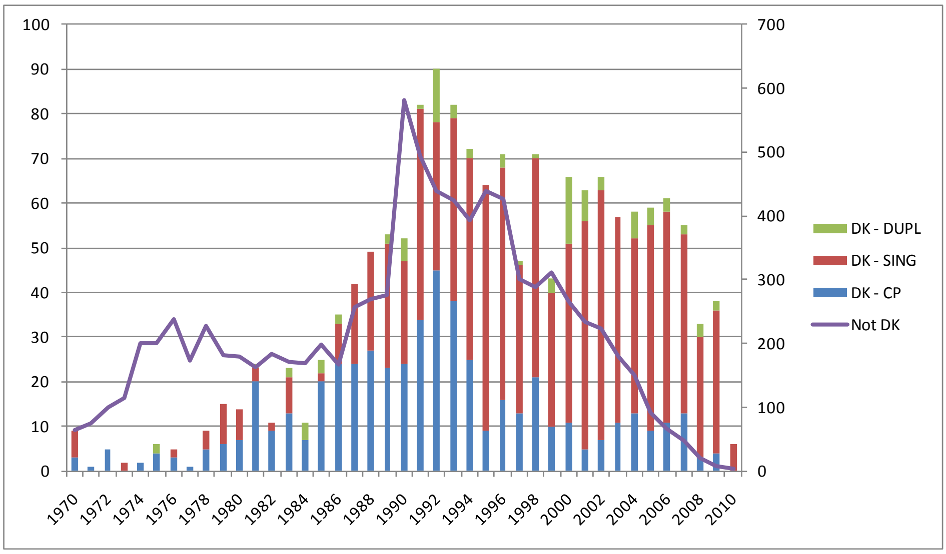


FIGURE 17

PATENT APPLICATIONS WITHIN THE ENVIRONMENTAL AREA TO THE DANISH PATENT OFFICE

In addition to the changes to the way patents are applied for in Europe, there is possible evidence in the data of a change in how applications are registered in the database. Around the same time as Denmark became a member of the EPO in 1990, there appears to have been a significant upward shift in the number of applications from Danish as well as international applicants. Although there is a downward trend in applications from 1990 onwards (at least for the international applications), the shift seems to persist.

Conclusion

Returning to the issue of defining Danish patents in the context of environmental regulation, foreign applications to the Danish Patent Office cannot be included. The decline in foreign applications to the Danish Patent Office is not necessarily an expression of a decline in international interest in Denmark; it is rather a result of the introduction of the EPO. To include international patent applications relevant for Denmark, it would thus be necessary to identify relevant applications to the EPO, however, this is not possible.

The alternative is to include the international applications made to the Danish Patent Office without regard for the declining trend. This would severely impair any kind of inference made on the development in applications over time, as the declining trend in international applications would dominate to the extent of excluding all else.

The only viable solution is to restrict the analysis to patent applications by Danish applicants made to the EPO and the Danish Patent Office. The analysis is further restricted to include only singles and claimed priorities. It would be especially misleading to include duplicate applications to the EPO as these would very likely have a claimed priority in Denmark. As the number of duplicate applications by Danish applicants to the Danish Patent Office is very small, these can be left out as well to avoid double counting or other peculiarities.

6. Method

The aim of this section is to describe how patent data are used as an indicator of eco-innovation. There are two different types of approaches to using patent data, which can be combined to a lesser or higher degree depending on data availability and aim of the analysis. In addition to describing the two approaches, this chapter will also describe how they are applied to this project.

Each of the policy areas identified (i.e. water, waste, soil, air) will be subjected to the same baseline analysis. This comprises a time series analysis and a cross-country comparison, both at the policy area level. Where data permit, the analysis will go into further detail in the form of more elaborate econometric modelling.

6.1 Time series analysis

As regulation sets new standards for emissions and other environmental parameters, new technological solutions may need to be applied to comply with the standards or new solutions are needed that lower the cost of compliance. However, the technological solutions may or may not exist at the point in time where new standards are introduced. Either new regulation starts a wave of innovation, or innovation inspires or provides an opportunity for tighter regulation. An analysis of the timing of regulation compared with the development in patent applications may provide insight into the causalities between regulation and innovation.

In addition to the timing aspect, a time series analysis may also provide clues to which types of regulation are more efficient in initiating innovation.

A time series analysis of patent data and regulation has the potential to provide important insights on several levels. The data for the time series analysis can be aggregated to an environmental policy area (e.g. solid waste, wastewater or air), or it can be disaggregated to a particular environmental pollutant (e.g. SO_X, NO_X, P, N), a type of regulatory regime or a single policy shock. However, there is a minimum threshold for the number of observations (patents) needed for this kind of analysis. The likelihood of this threshold being violated increases as the analysis becomes increasingly disaggregated.

The time series analysis will employ simple linear regression models to identify policy shocks that have a statistically significant correlation with patent applications. Model fit results, parameter values and test results will not be reported, but can be found in Annex 2. Whenever a policy shock has a statistically significant parameter estimate in the models, this will be reported using the exact wording: "statistically significant".

In all models, the total number of patent applications in the EU for the relevant environmental policy area will be included as a baseline. In that way it will be possible to isolate instances where national development in environmental patent applications differs from the European development. It will not be possible to identify whether the differences in development are the result of national environmental regulation or the general development in Danish patent applications. However, it is still the best option for isolating purely national effects from the general European trend.

Another interesting option for a baseline trend in patent applications would be the total number of applications by Danish applicants to the Danish and European Patent Offices. This would provide an opportunity to isolate the effect of all environmental policies regardless of origin.

Ideally, both trends (EU environment and DK total) could be included to truly isolate the impact of Danish environmental regulation. However, due to the high degree of correlation between the two trend series, this is not feasible. Further, the data on total Danish patent applications do not have the same quality as the data on environmental patents due to the method of extraction and available variables in the dataset.

6.2 Cross-country analysis

The goal of the cross-country analysis is to benchmark Danish patenting activity against other relevant countries. The analysis is split into two parts: 1) patent applications filed with the national patent office and 2) applications filed with foreign patent offices. In order to overcome issues of scaling due to differing population sizes and sizes of the national economy, all patent counts in the cross-country analysis are normalized by GDP and population.

In the first part, Danish applications to the Danish patent office are compared with e.g. German applications to the German patent office. This will offer an opportunity to test the notion that Denmark is a frontrunner when it comes to environmental technology and nurturing creative environments where innovation is second nature.

In the second part, Danish applications to foreign patent offices are compared to e.g. German applications to foreign patent offices. This will feed into a discussion of the competitiveness of Danish environmental technology. This is discussed further below.

Competitiveness

Competitiveness has many aspects. For one, competitiveness could refer to the benefit industry or even all exporting businesses experience due to e.g. increased resource efficiency or increased productivity. Another aspect of competitiveness would be the ability of producers of environmental technology to benefit from the advancements in the technology made at home and abroad.

Measuring competitiveness is very complex, and covering all aspects of competitiveness is certainly outside the scope of this project. However, there is one aspect of competitiveness that may be explored using patent data. By counting the number of patent applications made by applicants with a different nationality than the patent office, it is possible to make inference on the relative strength of the environmental innovation in selected countries.

7. Results

7.1 Time series

This section presents the results of the time series analysis. The main observation is that there is a statistically significant relationship between the patent activity in environmental technologies and the patent activity in EU in the same environmental areas. This is based on extensive analysis of the patent dataset. This observation means that the development of environmental technology in Denmark follows the same tendency as in the rest of the EU expressed by the number of patent applications. At the beginning of the 1980's, a pronounced increase in the number of patents is seen for all Danish patents as well as for those concerning environmental technology. This means that there is a general shift in focus on and awareness of patents. Further, the relationship is so strong that it leaves no room for statistically significant effects from national policies. The basis of these results will be presented in the following.

The figure below illustrates the relationship between Danish and EU patent applications for the four selected policy areas, waste, waster, soil and air. The red lines are the Danish applications and the blue total Number of EU applications.

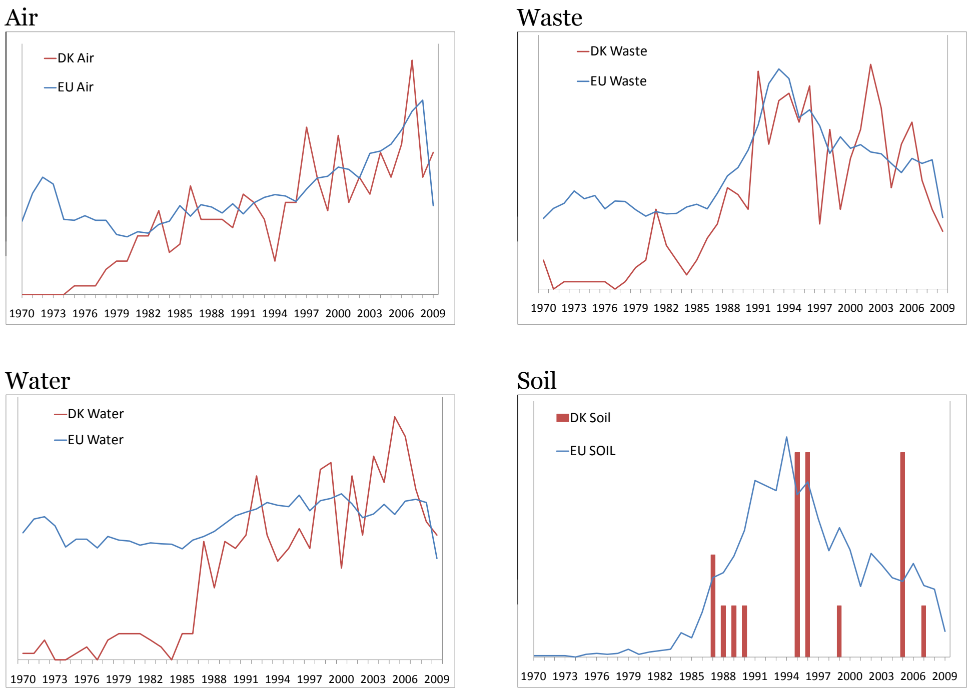


FIGURE 18

RELATIONSHIP BETWEEN DANISH AND EU PATENT APPLICATIONS FOR THE FOUR SELECTED POLICY AREAS

It is evident that for air, waste and water, there is a high correlation between patent applications in Denmark and patent applications in the EU. In regards to soil, the lack of data makes any comparisons meaningless (here the red line has been replaced by columns, otherwise the graph was difficult to read as there are very few applications related to soil).

It is important to bear in mind that the analyses carried out look into the *number* of patents applied for; however, the effectiveness of any given patent is not addressed. It is assumed that all patents have the same marginal contribution to reaching the overall policy goals. Within that framework, many patents are better than few patents. This is most likely oversimplified. As an example, a very large share of patents in waste concerns new and improved waste containers for households which individually only contributed with a limited economic return.

Wastewater

On environmental technologies related to wastewater, the overall result of the analysis of the patent data shows that there is a statistically significant relationship between the Danish patent activity and the total EU patent activity in environmental technologies related to wastewater. In other words, the Danish development in patent activity within wastewater technologies follows the European development. The figure below presents the Danish patent applications in wastewater technologies and the predicted number of Danish patent applications estimated as a function of the development in total EU patent applications in wastewater technologies. The figure also presents 95% confidence limits for the predicted values.

In the figure, the two major water policy milestones in the past 40 years, apart from when Denmark introduced the first environmental act in the 1970's, have been highlighted. These are the Waste Water Action Plan from 1987 and the Household Waste Water Control from 1997.

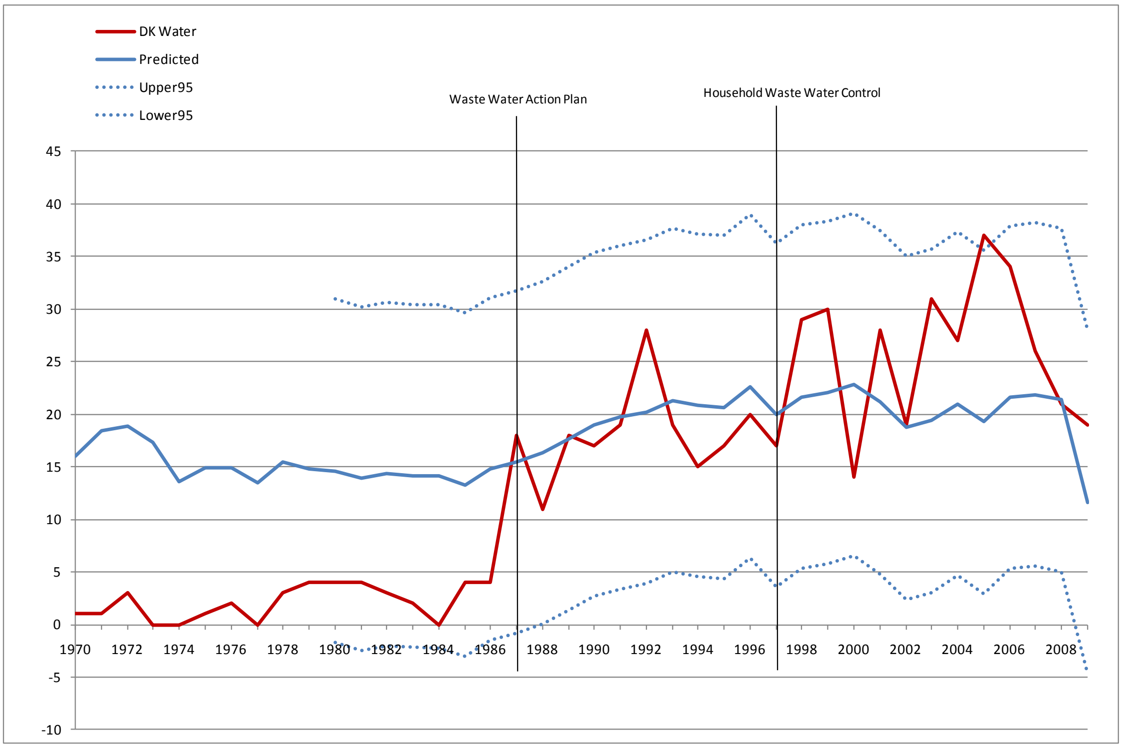


FIGURE 19

NUMBER OF PATENTS WITHIN WATER TECHNOLOGIES IN DENMARK; OBSERVED AND PREDICTED

The overall fit of the model (R^2) is 84%, i.e. 84% of the variation in Danish patent applications can be explained by EU patent applications. The confidence limits illustrate the uncertainty of the predicted values. Taking into account this uncertainty, not much room is left for other explanatory variables such as national policy initiatives. The only effect that could possibly contribute to a better model fit seems to be a slightly higher rate of growth in the Danish patent application than in the EU. Such a trend has not been suggested in the research on regulation in chapter 4 and has therefore not been tested in the model.

Solid waste

In relation to environmental technologies related to waste, the overall result of the analysis of the patent data once more demonstrates a statistically significant relationship between the Danish and European patent applications. In other words, the development in the Danish patent activity in waste technologies follows the European development. The following figure presents the Danish patent applications in solid waste technologies and the predicted number of Danish patent applications estimated as a function of the development in total EU patent applications in solid waste technologies. The figure also presents 95% confidence limits for the predicted values.

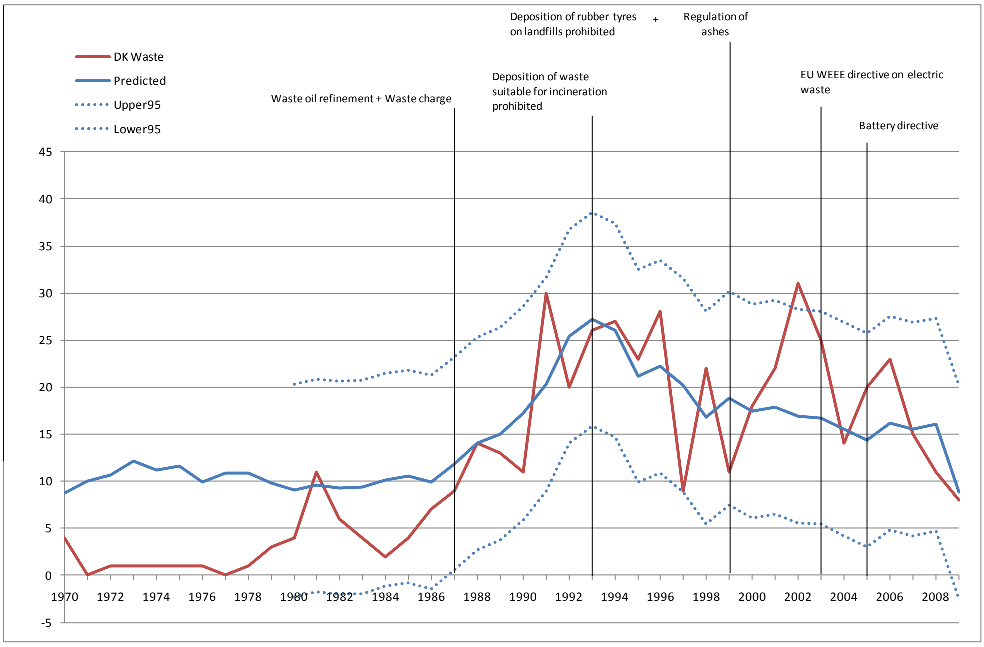


FIGURE 20

NUMBER OF PATENTS IN SOLID WASTE TECHNOLOGIES IN DENMARK; OBSERVED AND PREDICTED

The overall fit of the model (R^2) is 89%, i.e. 89% of the variation in Danish patent applications can be explained by EU patent applications. The confidence limits illustrate the uncertainty of the predicted values. Taking into account this uncertainty, not much room is left for other explanatory variables such as national policy initiatives. The only exception could be the spike in applications around the time of implementation of the WEEE Directive in 2003. It has not been possible to confirm this observation by statistical testing, but the effect is of a magnitude that surpasses what can reasonably be termed random variation.

Air

As with the other policy areas, the overall result of the analysis of the patent data displays a statistically significant relationship between the Danish patent applications and European patent applications on technologies related to air. In other words, the development in Danish patent applications follows the development in total European patent applications in air technologies. The following figure presents the Danish patent applications in air technologies and the predicted number of Danish patent applications estimated as a function of the development in total EU patent applications in air technologies. The figure also presents 95% confidence limits for the predicted values.

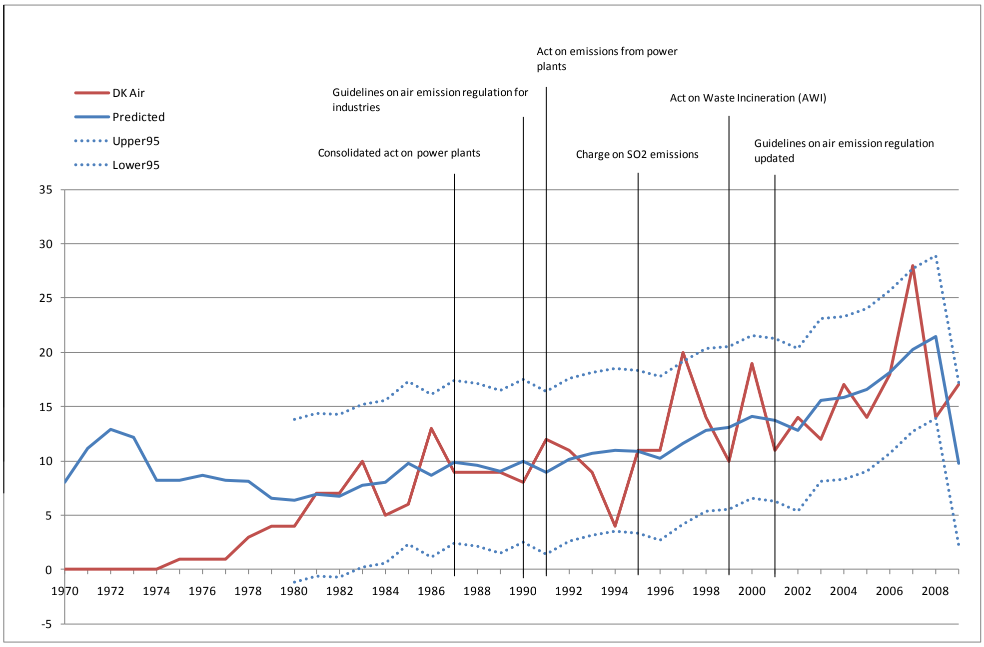


FIGURE 21

NUMBER OF PATENTS WITHIN TECHNOLOGIES RELATED TO AIR IN DENMARK; OBSERVED AND PREDICTED

The overall fit of the model (R^2) is 91%, i.e. 91% of the variation in Danish patent applications can be explained by EU patent applications. The confidence limits illustrate the uncertainty of the predicted values. Taking into account this uncertainty, not much room is left for other explanatory variables, such as national policy initiatives. None of the spikes in patent applications are of a magnitude or duration (all are one-year anomalies) that suggests anything other than random variation.

Contaminated soil

The total number of Danish patent applications to the Danish patent office in the 40 years from 1970 to 2009 is 19 - less than one every second year. This is not nearly enough to justify any kind of econometric modelling.

7.2 Cross-country analysis

The cross-country comparison of patent applications covers Denmark, Sweden, Germany, Great Britain, Netherlands and USA. For each country, the number of patent applications is normalised by GDP to make them comparable. The figures below show the results for each of the four policy areas.

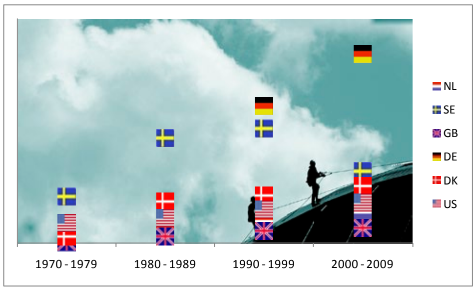
The results are solely presented for patents/billion GDP as opposed to patents/population. In the case of countries such as the ones in this analysis - where GDP/capita is fairly close - the two methods yield almost identical results.

Only the relative position of the countries is relevant, therefore the y-axis (patents/billion GDP) is not shown. For reference, the scale on the y-axis is roughly 0.00001-0.008 patents per billion Euros. The scale on the y-axis is linear and starts at 0, i.e. if Germany appears to have more than twice as many patents per GDP in air from 2000 to 2009 than Sweden, then that is correct.

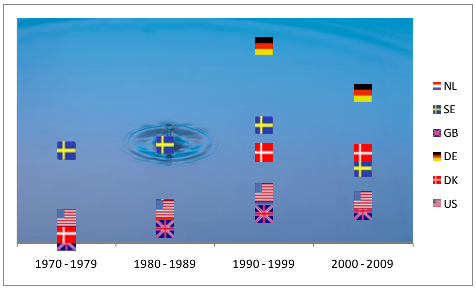
Patenting at home

The charts below show for each nationality of patent applicants the number of applications at the domestic patent office as well as applications to the EPO. This is the same definition of nationality as the one used in the time series above.

Air

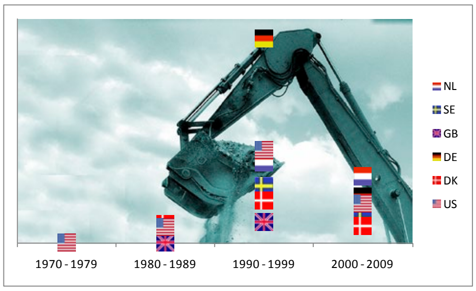


Water



Waste

Soil



Note: All countries (indicated by flags) are in included all graphs. If a country is not visible, it is at the same level as some of the other countries included in the analysis.

FIGURE 22

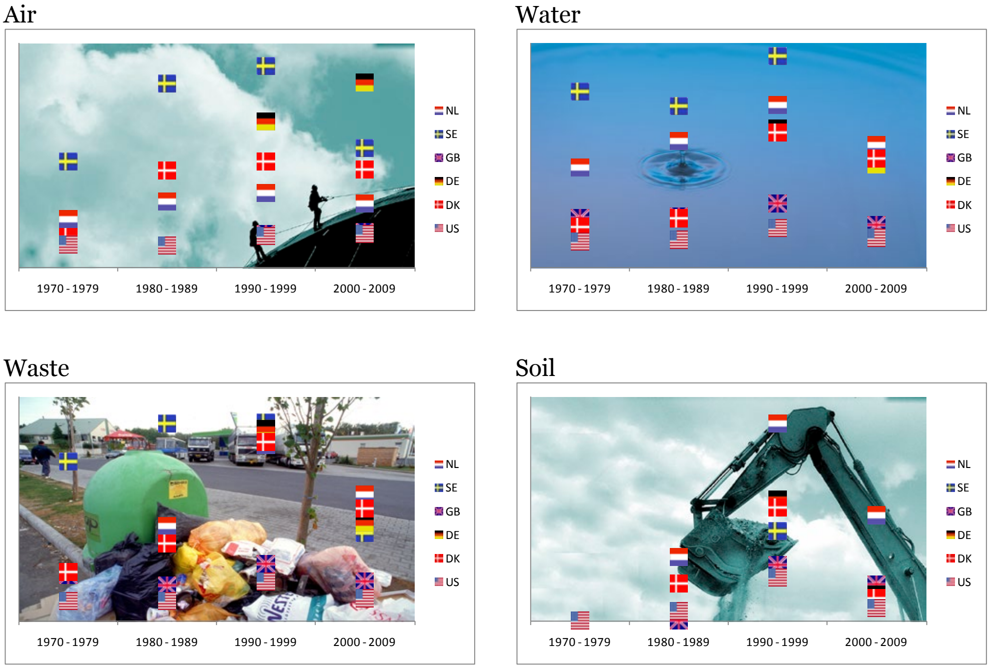
PATENT APPLICATIONS IN APPLICANT HOME COUNTRY AND EPO (PATENTS/BILLION GDP)

In general, Germany and Sweden are doing very well - soil being the exception for Sweden. Denmark comes in third on air, water and waste, but at a lower rate of patents/GDP than Sweden and Germany. On soil, Denmark did relatively well before 1990, but performance has been low in later years.

It is interesting to note that soil seems to be very different from the other three areas. Air, water and waste have seen roughly the same development over time and in relative performance of the countries. For soil, the relative performance of the countries has virtually been turned upside down. The US would seem to have a much stronger position in soil than in any of the other areas; the same goes for the Netherlands.

Export of technology or competitiveness

For each nationality of patent applicants, the charts below show the number of applications at patent offices other than the domestic patent office. The EPO is included in this count, which implies that there will be an overlap with the counts in the domestic comparison above. This cannot be helped. The EPO is central to all patent activity in Europe, as described in chapter 5.



Note: All countries (indicated by flags) are in included all graphs. If a country is not visible, it is at the same level as some of the other countries included in the analysis.

FIGURE 23

PATENT APPLICATIONS OUTSIDE APPLICANT HOME COUNTRY

What is immediately evident is that no country has enjoyed a permanent dominant position in any of the policy areas over the entire 40-year period from 1970 to today (except maybe the Netherlands in soil remediation, but lacking data for 1970-1979). Sweden was at the forefront of air until the late 1990's, where they were overtaken by Germany. In waste, Sweden again enjoyed a competitive advantage at least in the 1970's and 1980's while Germany, the Netherlands and Denmark have caught up in later decades. The same development has taken place in the field of water, while in soil remediation, the Netherlands have been alone in front for the last three decades.

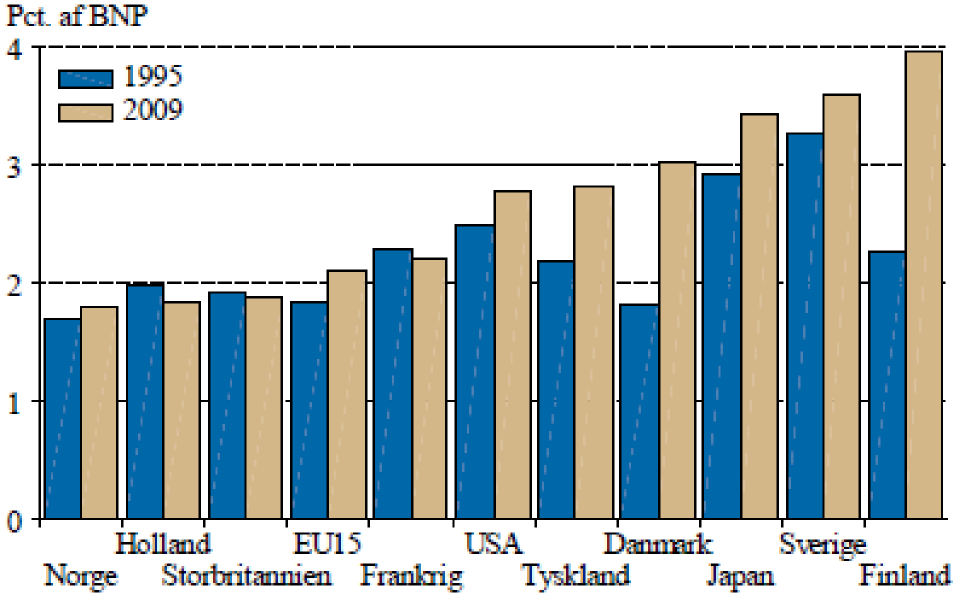
With the exception of waste, it seems that Denmark has performed below average in terms of exporting environmental technology compared with Germany, the Netherlands, Great Britain and Sweden. One explanation, put forth by among others Mikael Skou Andersen[46] is that many Danish inventions are sold off before patenting to industry outside Denmark.

R&D spending

Below is a figure presenting total R&D spending as a percentage of GDP in selected countries. Of the six countries in this analysis, only Sweden spent more on R&D than Denmark in 2009 implying that Denmark should be more competitive in patenting technology than the patent data imply. However, the R&D spending below is the total across all sectors making a direct comparison with the patent data for environmental technologies weak.

It should also be noted that Danish R&D spending has increased by more than 50% from 1995 to 2009. There is reason to believe that the full impact of this has yet to be seen in terms of increased competitiveness and patenting activity. In 1995, Danish spending was the lowest of all the six countries selected for this analysis, which matches the above impression that Denmark performs below average in terms of patenting and exporting environmental technology.

[46] Mikael Skou Andersen. *Grøn vækst og miljøteknologisk udviklingsindsats - hvilken rolle spiller tilskudsprogrammer?*. DMU.



Source: DORS 2011.

FIGURE 24

RESEARCH AND DEVELOPMENT SPENDING IN SELECTED COUNTRIES

In terms of competitiveness in exporting environmental technologies, it is difficult to say where Denmark would be without the current environmental policy. However, it seems as if the Danish environmental policy effort has not been as efficient in boosting export of technologies as in some of our neighbouring countries. The question is whether this stems from insufficient R&D spending, or from lack of relevant Danish investors to take the technology the last step from concept to market.

8. Conclusions

The aim of this study was to test the usefulness of patent data in analysing the impact of environmental policy on innovation of environmental technologies. Four main policy areas - air, water, waste and soil remediation - were identified, and patent data for those areas were compiled by the OECD. Data included not only Danish patent applications but also all patent applications within those areas. The scope of data included patent applications but not patent grants, since patent applications are thought to have a higher correlation with policy shocks.

The overall conclusion is that there is no direct link between specific policy initiatives and the development in the number of patent applications. Moreover, the rise in patent activity at the beginning of the 1980's cannot be ascribed to the development of an environmental policy, as the general level of Danish patents rise by the same factor. Data were used to illustrate the development in patent activity over time as well as across countries. However, the types of analyses presented in this report should not stand alone, but be part of an overall approach, which includes other sources of information and more in-depth analyses of patent data. Given enough time, the patent database could in principle be used to identify patents directly relevant to specific policy initiatives and even to follow these technologies as they evolve over time.

The time series analysis revealed a close relationship between patent activity in three[47] of the four policy areas and the patent activity in the EU. On the other hand, the analysis could not confirm any direct relationship between specific Danish regulations and patent applications.

The cross-country analysis of competitiveness seems to indicate that Denmark is not as competitive in terms of patenting abroad as some of our neighbouring countries. Waste is the only area where Denmark is above the average in terms of patents abroad per billion GDP. When these results are compared to total national R&D spending, we find a weak indication that Denmark does not derive maximum advantage of this investment.

A closer look at the different types of analysis on Danish patent data reveals that, competitively, solid waste seems to be the most successful policy area in terms of innovation.

From the experience of using patent data as indicators of innovation, it can be inferred that it is not possible to determine if there is a relationship between policy shock and innovative developments. Further, it is questionable whether the number of patent applications is a good measure of innovation. At least, this analysis has not been able to prove this relationship. This is also supported by the rather diverse conclusions of the literature study, which did not provide certainty of the success of a specific measure. Further, studies using the same measures show great variation in findings.

8.1 Recommendations for optimal policy design to stimulate innovation

The outcome of this analysis indicates that the design and implementation of environmental policy measures have so far not been successful in raising the number of patent applications. It may be possible to do so but no examples were found in this study.

[47] Patent applications in Soil remediation were simply too few to allow any kind of statistic testing.

In the absence of a relationship between policy interventions and the number of applications, it is impossible to identify instruments that are more successful than other instruments. As a result, we cannot make any recommendations for policy measures that are more successful in stimulating innovation or implementation strategies that bring about the desired outcome.

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Appendix 1 Overview of patent definitions

The following table presents an overview of the IPC classes defining the patents. In the analysis, we have included total classes for A.1-A.5, plus sub-fields for A.3.1, A.3.2, A.3.3, and A.3.4. In addition to this, data has been extracted for particular technological fields, presented below (codes from both IPC and ECLA, the European classification.

A. General Environmental Management	**IPC class**
A.1. AIR POLLUTION ABATEMENT	
Filters or filtering processes specially modified for separating dispersed particles from gases or vapours	B01D46
Separating dispersed particles from gases, air or vapours by liquid as separating agent	B01D47
Separating dispersed particles from gases, air or vapours by other methods	B01D49
Combinations of devices for separating particles from gases or vapours	B01D50
Auxiliary pre-treatment of gases or vapours to be cleaned from dispersed particles	B01D51
Chemical or biological purification of waste gases	B01D53/34-72
Separating dispersed particles from gases or vapour, e.g. air, by electrostatic effect	B03C3
Use of additives to fuels or fires for particular purposes for reducing smoke development	C10L10/02
Use of additives to fuels or fires for particular purposes for facilitating soot removal	C10L10/06
Blast furnaces; Dust arresters	C21B7/22
Manufacture of carbon steel, e.g. plain mild steel, medium carbon steel, or cast-steel; Removal of waste gases or dust	C21C5/38
Exhaust or silencing apparatus having means for purifying or rendering innocuous	F01N3
Exhaust or silencing apparatus combined or associated with devices profiting by exhaust energy	F01N5
Exhaust or silencing apparatus, or parts thereof	F01N7
Electrical control of exhaust gas treating apparatus	F01N9
Combustion apparatus characterised by means for returning flue gases to the combustion chamber or to the combustion zone	F23B80
Combustion apparatus characterised by arrangements for returning combustion products or flue gases to the combustion chamber	F23C9
Incinerators or other apparatus specially adapted for consuming waste gases or noxious gases	F23G7/06
Arrangements of devices for treating smoke or fumes of purifiers, e.g. for removing noxious material	F23J15
Shaft or like vertical or substantially vertical furnaces; Arrangements of dust collectors	F27B1/18

A.2. WATER POLLUTION ABATEMENT	
Arrangements of installations for treating waste-water or sewage	B63J4
Treatment of water, waste water, sewage or sludge	C02F
Fertilisers from waste water, sewage sludge, sea slime, ooze or similar masses	C05F7
Chemistry; Materials for treating liquid pollutants, e.g. oil, gasoline, fat	C09K3/32
Devices for cleaning or keeping clear the surface of open water from oil or like floating materials by separating or removing these materials; Barriers therefore	E02B15/04-06
Cleaning or keeping clear the surface of open water; Devices for removing the material from the surface	E02B15/10
Methods or installations for obtaining or collecting drinking water or tap water; Rain, surface or groundwater	E03B3
Plumbing installations for waste water	E03C1/12
Sewers – Cesspools	E03F
A.3. WASTE MANAGEMENT (includes all classes through to A.3.6.)	
A.3.1. Solid waste collection	
Street cleaning; Removing undesirable matter, e.g. rubbish, from the land, not otherwise provided for	E01H15
Transporting; Gathering or removal of domestic or like refuse	B65F
A.3.2. Material recovery, recycling and re-use	
Animal feeding-stuffs from distillers' or brewers' waste; waste products of dairy plant; meat, fish, or bones; from kitchen waste	A23K1/06-10
Footwear made of rubber waste	A43B1/12
Heels or top-pieces made of rubber waste	A43B21/14
Separating solid materials; General arrangement of separating plant specially adapted for refuse	B03B9/06
Manufacture of articles from scrap or waste metal particles	B22F8
Preparing material; Recycling the material	B29B7/66
Recovery of plastics or other constituents of waste material containing plastics	B29B17
Presses specially adapted for consolidating scrap metal or for compacting used cars	B30B9/32
Systematic disassembly of vehicles for recovery of salvageable components, e.g. for recycling	B62D67
Stripping waste material from cores or formers, e.g. to permit their re-use	B65H73
Applications of disintegrable, dissolvable or edible materials	B65D65/46
Compacting the glass batches, e.g. pelletizing	C03B1/02
Glass batch composition - containing silicates, e.g. cullet	C03C6/02
Glass batch composition - containing pellets or agglomerates	C03C6/08
Hydraulic cements from oil shale, residues or waste other than slag	C04B7/24-30
Calcium sulphate cements starting from phosphogypsum or from waste, e.g. purification products of smoke	C04B11/26
Use of agglomerated or waste materials or refuse as fillers for mortars, concrete or artificial stone; Waste materials or Refuse	C04B18/04-10

Clay-wares; Waste materials or Refuse	C04B33/132
Recovery or working-up of waste materials (plastics)	C08J11
Luminescent, e.g. electroluminescent, chemiluminescent, materials; Recovery of luminescent materials	C09K11/01
Working-up used lubricants to recover useful products	C10M175
Working-up raw materials other than ores, e.g. scrap, to produce non-ferrous metals or compounds thereof	C22B7
Obtaining zinc or zinc oxide; From muffle furnace residues; From metallic residues or scraps	C22B19/28-30
Obtaining tin; From scrap, especially tin scrap	C22B25/06
Textiles; Disintegrating fibre-containing articles to obtain fibres for re-use	D01G11
Paper-making; Fibrous raw materials or their mechanical treatment - using waste paper	D21B1/08-10
Paper-making; Fibrous raw materials or their mechanical treatment; Defibrating by other means - of waste paper	D21B1/32
Paper-making; Other processes for obtaining cellulose; Working-up waste paper	D21C5/02
Paper-making; Pulping; Non-fibrous material added to the pulp; Waste products	D21H17/01
Apparatus or processes for salvaging material from electric cables	H01B 15/00
Recovery of material from discharge tubes or lamps	H01J 9/52
Reclaiming serviceable parts of waste cells or batteries	H01M 6/52
Reclaiming serviceable parts of waste accumulators	H01M 10/54
A.3.3. Fertilizers from waste	
Fertilisers made from animal corpses, or parts thereof	C05F1
Fertilisers from distillery wastes, molasses, vinasses, sugar plant, or similar wastes or residues	C05F5
Fertilisers from waste water, sewage sludge, sea slime, ooze or similar masses	C05F7
Fertilizers from household or town refuse	C05F9
Preparation of fertilizers characterized by the composting step	C05F17
A.3.4. Incineration and energy recovery	
Solid fuels essentially based on materials of non-mineral origin; on sewage, house, or town refuse; on industrial residues or waste materials	C10L5/46-48
Cremation furnaces; Incineration of waste; Incinerator constructions; Details, accessories or control therefore	F23G5
Cremation furnaces; Incinerators or other apparatus specially adapted for consuming specific waste or low grade fuels	F23G7
A.3.5. Landfilling	
[Search strategy currently not available] *Note: Landfilling patents are largely covered by IPC class B09B. However, this class also covers many aspects of recycling and incineration. Therefore, B09B is only used to generate aggregate 'waste management' counts (see above).*	
A.3.6. Waste management not elsewhere classified	
Disposal of solid waste	B09B
Production of liquid hydrocarbon mixtures from rubber or rubber waste	C10G1/10
Medical or veterinary science; Disinfection or sterilising methods specially	A61L11

adapted for refuse	
A.4. SOIL REMEDIATION	
Reclamation of contaminated soil	B09C
A.5. ENVIRONMENTAL MONITORING	
Monitoring or diagnostic devices for exhaust-gas treatment apparatus	F01N11
Alarms responsive to a single specified undesired or abnormal condition and not otherwise provided for, e.g. pollution alarms; toxics	G08B21/12-14
Note: This search strategy is under development, the counts generated are incomplete.	

Patent data has been extracted for 17 particular technological fields, presented on the following list:

A.1:
SOx specific:
B01D53/50: Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases or aerosols ... *for Sulphur oxides*
B01D53/14H8: ... By absorption; gases containing acid components; containing only sulphur dioxide or sulphur trioxide
B01D53/86B4: ... Catalytic processes; removing sulphur oxides

NOx specific:
B01D53/56; Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases or aerosols ... *for Nitrogen oxides*
B01D53/56D; ... By treating the gases with solids
B01D53/86F2; ... Catalytic processes; removing nitrogen oxides
B01D53/86F2C; ... Catalytic processes; removing nitrogen oxides
B01D53/86F2D; ... Catalytic processes; removing nitrogen oxides
B01J29/06D2E; Catalysts comprising molecular sieves Crystalline aluminosilicate zeolites; Isomorphous compounds thereof containing metallic elements added to the zeolite (note: '2E' not explained in definition, neither IPC nor ECLA)

Simultaneous Sox and NOX:
B01D53/60; Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases or aerosols ... *for Simultaneously removing sulphur oxides and nitrogen oxides*
B01D53/86G; ...*Catalytic processes; simultaneously removing sulfur oxides and nitrogen oxides*

Dust/Particulate Matter
F23J15/02D; Arrangement of devices for treating smoke or fumes of purifiers, for removing solid particulate material from the gas flow [N9910]
C21B7/22; Blast furnaces *for Dust arresters*
F27B1/18; Shaft or like vertical or substantially vertical furnaces *for Arrangements of dust collectors*
C10L10/02; Use of additives to fuels or fires for particular purposes *for reducing smoke development*
C10L10/06; Use of additives to fuels or fires for particular purposes *for facilitating soot removal*

Heavy metals
B01D53/64: Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases or aerosols *for Heavy metals or compounds thereof, e.g. mercury*

A.3.2:
Luminescent
C09K11/01: Luminescent, e.g. electroluminescent, chemiluminescent, materials - Recovery of luminescent materials

Appendix 2 Results of times series estimations

Air

Regression Statistics	
Multiple R	0.956225
R Square	0.914366
Adjusted F	0.879883
Standard E	3.823589
Observatic	30

ANOVA

	df	SS	MS	F	gnificance F
Regressioı	1	4527.025	4527.025	309.6495	1.13E-16
Residual	29	423.9752	14.61983		
Total	30	4951			

	Coefficients	andard Err	t Stat	P-value	Lower 95%	Jpper 95%	ower 95.0%	pper 95.0%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable	0.01153	0.000655	17.59686	5.11E-17	0.01019	0.01287	0.01019	0.01287

Water

Regression Statistics	
Multiple F	0.916982
R Square	0.840855
Adjusted I	0.806372
Standard I	8.321656
Observati	30

ANOVA

	df	SS	MS	F	gnificance F
Regressio	1	10610.75	10610.75	153.224	7.14E-13
Residual	29	2008.249	69.24995		
Total	30	12619			

	Coefficients	andard Err	t Stat	P-value	Lower 95%	Upper 95%	ower 95.0%	pper 95.0%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable	0.015292	0.001235	12.37837	4.25E-13	0.012766	0.017819	0.012766	0.017819

Waste

Regression Statistics	
Multiple R	0.945567
R Square	0.894096
Adjusted F	0.860763
Standard E	5.779454
Observatic	31

ANOVA

	df	SS	MS	F	gnificance F
Regressioı	1	8459.937	8459.937	253.2757	7.23E-16
Residual	30	1002.063	33.40209		
Total	31	9462			

	Coefficients	andard Err	t Stat	P-value	Lower 95%	Jpper 95%	ower 95.0%	pper 95.0%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable	0.015701	0.000987	15.91464	3.6E-16	0.013686	0.017715	0.013686	0.017715

Summary
The aim of this study was to test the usefulness of patent data in analysing the impact of environmental policy on innovation of environmental technologies. The overall conclusion is that there is no direct link between specific policy initiatives and the development in the number of patent applications.

Resumé
Indeværende studie har testet anvendeligheden af patentdata til at analysere effekten af miljøpolitikker på miljøteknologisk innovation. Konklusionen er, at det ikke kan påvises at specifikke miljøpolitiske initiativer i form af love, handlingsplanen o.l. direkte påvirker antallet af danske patenter.

Analysen peger dog på at der er en mere generel sammenhæng mellem miljøpolitikken og antallet af miljøpatenter, således at antallet af danske miljøpatenter generelt steg frem mod år tusinde skiftet.

Efter årtusindeskiftet er der foretaget en række ændringer af den europæiske organisering af patentområdet, der gør det vanskeligt at sammenligne med udviklingen før årtusinde skiftet.

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