The impact of environmental policy on energy-efficient innovations in buildings: The case of the Netherlands

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Abstract

This paper looks at the links between environmental policy and technological innovation related to improving energy-efficiency in buildings for the case of the Netherlands. We conduct the analysis using patents data in nine technological areas, ranging from insulation and high-efficiency boilers to lighting and climate control systems over the 1978-2006 period. We first examine the evolution of energy-efficient technologies in buildings in the Netherlands compared to other countries. We then look at the impact of the large number of environmental policy measures implemented in the Netherlands since the end of the 1970s. Our preliminary results suggest that environmental policy, and in particular its intensification in the mid-1990s, has had a positive impact on the incentives for firms to innovate. Since we only conduct the analysis for one country, we face several empirical restrictions in this study. In particular, since some of the major policy measures (i.e. an energy tax and an energy performance regulation for buildings) were introduced simultaneously, we cannot estimate the differential impact of these measures. As a result, we discuss the feasibility of extending our analysis to several countries.

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1 Introduction

The objective of this paper is to look at the links between environmental policy and technological innovations. New developments in energy-efficient technologies can greatly contribute to the reduction of greenhouse gas emissions. As a result, policymakers have been interested in the role that the government can play by using environmental policy instruments, such as standards, taxes or tradable permits, to promote technological innovation. Both theory and empirical evidence suggest that innovation can be influenced by policy incentives (Jaffe et al., 2002). Economic theory generally states that so-called market-based policy instruments can provide stronger incentives than command and control regulations to develop and adopt environmentally friendly technologies (Requate, 2005; Jaffe et al., 2002; Loeschl, 2003). Yet, little is known empirically about which types of policy measures are the most effective in stimulating innovation, even though the number of empirical studies has recently been increasing (Vollebergh, 2007).

The objective of this paper is to study the impact of environmental policy on energy-efficient innovations in buildings. According to the International Energy Agency (IEA, 2006), buildings are responsible for 40% of the world's total primary energy consumption and accounts for 24% of world CO_2 emissions. Energy consumption from buildings is mainly due to heating, hot water production, lighting and cooling and ventilation. Therefore, technological innovations contributing to improving the energy efficiency of buildings (e.g. improved insulation or high-efficiency boilers) could help to achieve large reductions in energy consumption. In addition, innovations in renewable energy technologies (e.g. solar boilers) could also reduce CO_2 emissions from residential and commercial buildings.

This paper provides an analysis of the impact of environmental policy on energy-efficient innovations in buildings for the case of the Netherlands. The objectives of this study are threefold. Firstly, we aim to provide a description of innovative activities in the Netherlands using patent application counts as a measure of innovation. We compare the performance of the Netherlands with other countries in terms of number of patent applications in nine different technological areas related to energy efficiency in buildings over the last thirty years. Secondly, we estimate the impact of Dutch environmental policy on the number of patent applications in energy-efficient technologies in buildings. To this end, we give a detailed overview of relevant environmental policy measures and discuss the limits of our analysis in identifying the differential impacts of those policies. Finally, by looking at the Dutch situation, we aim to provide a feasibility study for a broader multi-country analysis. In the course of our analysis, we highlight the main data requirements that such a broad analysis would imply.

Our preliminary results show that the Netherlands stand in the middle-range of innovating countries regarding energy-efficient technologies in buildings. The Netherlands score high in certain specific technologies, in particular lighting and high-efficiency boilers. Turning to the role played by environmental policy, we find that the intensification of environmental policy in the mid-1990s, notably by the simultaneous introduction of an energy performance regulation for buildings, a tax on energy and other fiscal instruments, has positively contributed to increasing innovation. We also discuss the main challenges we encountered in trying to identify the differential impact of policy measures. At this stage, our analysis requires more detailed information on the differential intensity of each policy measure in a one-country setting. In future work, we aim to extend the present analysis to several countries provided detailed information on national environmental policy is available.

The paper is organised as follows. Section 2 gives an overview of the existing theoretical and empirical literature on the impact of environmental policy on technological innovation. Section 3 describes the main environmental policy measures related to energy efficiency in the building sector. Section 4 describes our procedure to collect the data on the relevant patent applications and describes the major trends in patenting activities. Section 5 describes the econometric methodology and gives some preliminary results on the impact of environmental policies on innovation. Finally, Section 6 concludes and discusses future work.

2 Previous literature

There is an extensive literature on the theoretical impact of environmental policy on technological change (for a review see Jaffe et al., 2002; Requate, 2005; Loeschl, 2003; Johnstone, 2005). The general result from the theoretical literature is that market-based instruments (taxes, tradable permits, subsidies) provide more incentives for firms to innovate than command-and-control instruments (performance and technological standards). This is due to the fact that with a command-and-control instrument firms have no financial incentives to exceed the given target. With market-based instruments, however, firms get a financial reward for performing beyond the target. In addition, standards are prescriptive and thus tend to reduce the space for technological possibilities.

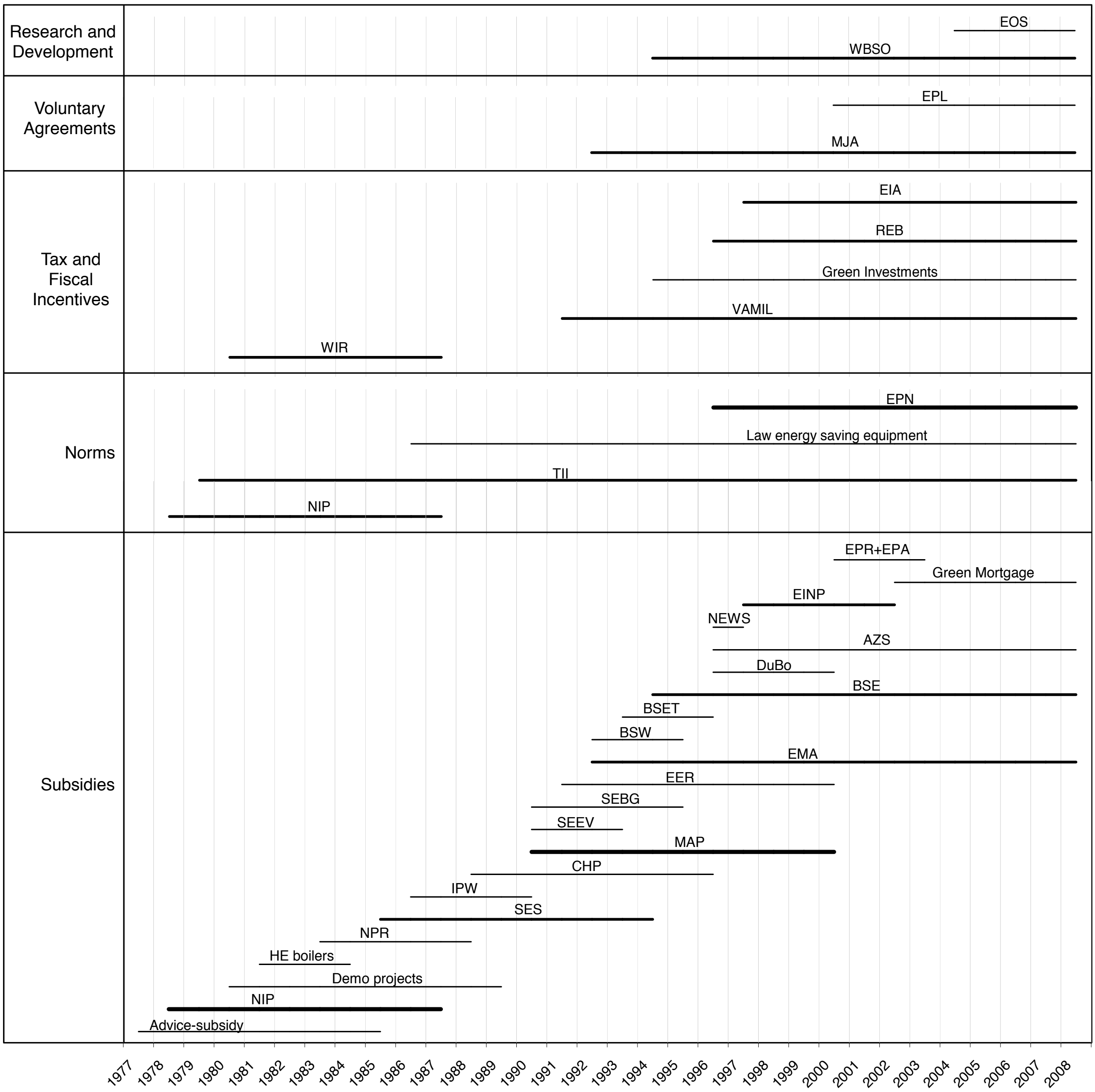
Empirical evidence on the (differential) impact of environmental policy instruments is still relatively limited (Vollebergh, 2007; Jaffe et al., 2002). According to Vollebergh (2007), the small number of empirical studies is explained by three reasons: 1) the use of market-based instruments is still limited in practice, 2) policy instruments are often used simultaneously to achieve the same environmental goal (this leads to identification issues in econometric modelling and thus high data requirements) and 3) policy experimentations with these types of instruments – which would facilitate policy evaluations - are non-existent. We focus here on studies looking at the impact of environmental policy on innovation measured by patents data. Jaffe and Palmer (1997) look at the relationship between environmental stringency and innovation, measured by patents and by industry-wide R&D expenditures, for several US manufacturing industries in the period 1977-1989. They find that an increase in the environmental stringency has a positive effect on R&D expenditures, but find no significant effect of environmental regulation on the number of patents. De Vries and Withagen (2005) look at the relationship between stringency of environmental policy regarding SO_2 emissions and innovation measured by the number of patent applications for 14 countries over the 1970-2000 period. They assume that environmental stringency is explained by GDP, industrial structure and the level of SO_2 emissions. They find support for a positive relationship between innovation and environmental stringency. Popp (2006) looks at patent data in US, Japan and Germany for SO_2 and NOx abatement technologies over the 1970-200 period. He looks at the number of patents issued (innovation) and at patents citations (diffusion). He finds that innovation is largely affected by domestic regulation - but not by foreign regulation - and by innovation abroad. More recently, Johnstone et al. (2008) look at patents in renewable energy in a panel of 25 countries over the 1978-2003 period. They find that quantity-based policy instruments (obligations, tradable quotas) are most effective in stimulating innovations in wind power, while price-based policy are most effective for innovations in solar and biomass energy.

3 Environmental policy measures

This section gives a general overview of generic and specific policies that had an impact on energy-efficient innovations in buildings in the Netherlands in the last 30 years. The overview of Dutch environmental policies is given in Figure 1. This a comprehensive list, which includes all (small and large) policy measures introduced in the period between 1977 and 2008.[1]

[1]The abbreviations used in Figure 1 are explained in Table 9 in Appendix.

Figure 1: An overview of the environmental policies focused on energy-efficient innovations in buildings in 1977-2008



The most striking feature of Figure 1 is not only the sheer amount of policies in the Netherlands aimed at energy efficiency in buildings, but also the fact that environmental policy intensified in the 1990s and moved away from mostly subsidies to a broader mix of measures. Mid-90s saw the introduction of some of the most significant policy measures, such as the energy tax (REB), the energy performance regulation for buildings (EPN), several fiscal incentives measures (EIA, EINP, VAMIL) and voluntary agreements (MJA). Other subsidy programs were implemented such as MAP which ran

Table 1: Comparison of CO_2 emission reduction impacts of Dutch environmental policies on energy-efficient innovations in buildings

Policy	CO_2 emission reduction (in Mton.)	Time period
REB	0.9 - 3	1995-2002
MAP	0.7 - 0.9	1995-2000
EIA/EINP/VAMIL	0.1 - 0.7 (removing the overlap with MJA and EPN) or 0.2-1.4 (gross)	1997-2002
EPN	0.3 - 0.5	1995-2002
EPR	0.2	2000-2002
MJA	0.1	1995-2002

Based on the calculations by Joosen et al. (2004).

all the way through the 1990s and the EPR subsidy measure which was introduced in 2000. Table 1 presents the impact of these measures on CO_2 emission reductions in buildings.

Another particularity of environmental policy in the Netherlands is that it has not been very stable. Some subsidies were stopped due to the lack of financing and then continued again after some time. This might affect the incentives for firms to innovate. Indeed, to ensure the successful innovation process, supporting policies have to be continuous and reliable. Failure to create a trust in the policy measure means that fewer companies will embark on innovation activities, fearing the loss of financial support before an innovative product is created. This could mean that despite the rich choice of environmental policies for energy-efficient innovations in buildings, their effect on innovations could be of smaller magnitude than expected.

Although a large part of the measures are generic policies affecting all energy-efficient technologies in buildings (such as the energy tax), other measures are more technology-specific. For instance, in the 1980s small-scale subsidies were introduced aimed exclusively at promoting HE boilers or CHP technologies. Another example is the EIA programme, which promotes technologies stated in the Energy list. Although most of the main technologies for energy-efficiency improvement in buildings have been listed from the beginning on, there are some differences in the intensity and use of the EIA measure per technology group over the years. For the purpose of our empirical analysis, we tried to collect as much data as possible on the intensity of policy measures per type of technology. In Section 5 we explain in more details how we modelled our indicators for environmental policy.

In Figure 1 all the policies are divided into 5 groups. Given the amount of policy measures, this section will only describe the main policies per group.

Tax The Regulatory Energy Tax (REB), also known as ecotax, was introduced in 1996 for households and medium-small enterprises, and in 2004 - for large commercial users. The tax is levied on the consumption of 'grey' energy: gas and electricity produced from fossil fuels.

Standards and norms One of the major policy measures is Energy Performance Norm (EPN), which came into force in December 1995. EPN dictates that the energy performance of new buildings is measured by the Energy Performance Coefficient (EPC). Calculation of the EPC includes energy features of the building itself and the efficiency of it's installations. The EPC calculations are stated in two national standards: one for non-residential and one for residential buildings. The coefficient is bounded to a certain maximum, such that lower coefficient means better energy efficiency.

When first introduced, the maximum value of EPC for residential buildings was 1.4. In 2006 the EPC for residential homes has been tightened down to 0.8. The level of EPC for non-residential dwellings depends on their function. For example, for non-residential office buildings EPC is set to 1.5. But for shops or health clinics EPC is still quite high - more than 3. Joosen et al. (2004) observes that in the residential buildings lower EPC usually corresponds to a lower average use of gas for heating.

Fiscal Incentives From 1997 the Energy Investment Allowance (EIA) provides a tax deduction for investments in energy-saving equipment and renewable energy. Energy-saving technologies or equipment eligible for EIA are stated in the Energy List, which is updated on the yearly basis. EIA is focused on a broad variety of energy-saving technologies, that can also be implemented elsewhere outside energy-efficient innovations in buildings. Joosen et al. (2004) gives an idea of how important EIA is for the sector by estimating that in the period 1997-2002 around 10% of total investments made under EIA were spent in the non-residential building sector.

Another fiscal incentive is a Regulation for an accelerated depreciation of investments in environmentally-friendly technologies (VAMIL), which came into force in 1991. VAMIL provides an option of an accelerated depreciation of investments, which can result in lower interest payments and improved liquidity.

Another general fiscal programme was introduced in the 1980s - the Law on Energy Investment Support (WIR). It was the first fiscal policy aimed at energy saving. WIR allowed Dutch companies an additional tax refund on all energy-saving investments, including investments in renewable energy sources. The International Energy Agency (IEA) estimated the costs of this programme to have been around 150 million per year (IEA, 1981).

Subsidies The National Insulation Programme (NIP) was introduced in 1978 and provided grants and loans for insulating the existing residential buildings. Total costs of the whole programme were estimated to be fl. 1.75 billion and around 3.751.000 existing houses were insulated under NIP (SNIP, 1988).

Next, the Environmental Action Plan (MAP) provided subsidies for various energy-saving equipment and appliances in residential and non-residential buildings. The MAP consisted of several sub-programmes: MAP-I (1991-1993), MAP II (1994-1996) and MAP-III (1997-2000). Eiff et al. (2001) estimates the total achieved CO_2 emission reduction to have reached 18,523 Mton. by the end of the programme in 2000. This corresponds to the 109% of the target for emission reduction set by MAP-II and MAP-III. The biggest contributors to the CO_2 emission reduction were combined heat and power (CHP, also known as co-generation) and heat distribution, and energy-efficiency measures in residential buildings. The same report estimates that MAP cost fl. 2194.5 million. Joosen et al. (2004) estimates that between 1995 and 2000 more than €180 million was spent on MAP subsidies. For residential dwellings, the largest share of the subsidies was spent on insulation and the rest - on high-efficiency boilers and other appliances, according to the same report. For non-residential dwellings the opposite was true.

In 1997 the non-profit version of EIA was introduced in a form of an investment subsidy - Energy Investment Allowance for non-profit organisations (EINP). According to calculations in Joosen et al. (2004) in a five-year period of EINP existence, in 1997-2002, €725 million was spent in the sub-sector of non-residential buildings. This shows that non-residential sub-sector used the EINP regulation more extensively than it did EIA. That is mostly due to the fact that under EINP a bulk of investments was made in the governmental, healthcare and education buildings.

A short but effective subsidy to improve the energy efficiency of the existing residential houses ran from 2002 to 2003 - Energy premium for existing dwellings (EPR). It subsidised the advice given to improve the energy efficiency of a house and partially financed the energy-saving measures. Joosen et al. (2004) estimates that in the period of 2000-2002 about €400 million was distributed under EPR of which 70% was spent on insulation and the rest - on energy-saving equipment.

Voluntary Agreements In 1992 Long-Term Agreements (MJA) were reached between business and government. Various arrangement were made with industries, mostly services and non-profit, to improve their energy efficiency.

Research and Development Apart from the environmental policies, we can also expect generic policies promoting innovations to have an effect on innovating activities for buildings. One of them is the Research and Development Promotion Act (WBSO), which is a fiscal regulation, introduced in 1994. Under WBSO, a fiscal contribution is given towards the wage costs of employees directly involved in R&D. Around 20% of the total amount spent under WBSO in 2000-2005 goes to energy-efficient innovations in buildings, according to SenterNovem (2007).

4 Patents data

In our analysis we use patent application counts as a measure of innovative activity. Dernis et al. (2001, p. 130) defines patent as an "intellectual property right relating to inventions in the technical field". An individual or an organisation can apply for a patent. Certain requirements have to be met for a patent to be granted: it has to contain a novel invention and be capable of industrial application. A patent has a limited validity and has to be renewed in order for an invention to stay protected.

As a measure of innovative output, patent statistics present several advantages. Firstly and most importantly, there is a substantial evidence that patents are a good indicator of invention and innovation as most significant inventions are eventually patented. Griliches (1990) finds that there is a strong relationship between patent numbers and R&D expenditures in the cross-sectional dimension, implying that patents are a good indicator of inventive activity. Comanor and Scherer (1969), Acs and Audretsch (1989) and Hagedoorn and Cloodt (2003) offer further empirical evidence that patents provide a fairly reliable measure of innovative activity. Comanor and Scherer (1969) find a strong correlation between yearly patent counts and measures of new product introduction and R&D for the pharmaceutical industry in the 1950s and 1960s. Based on the empirical evidence Acs and Audretsch (1989) find only minor differences between patent counts and a more direct measure of innovation. Finally, Hagedoorn and Cloodt (2003) again find no major disparity among 4 indicators of innovative performance: patent counts, R&D expenditures, patent citations and new product announcements in four industries: pharmaceuticals, computers, electronics and communication, aerospace and defence in the 1990s. A second advantage of using patents data is that patents are readily available, on national and international levels and over significant time periods (Griliches, 1990). In addition, patents contain a lot of data - on the invention itself, on the applicant and the inventor, date of filing, etc. and cover a broad range of technologies for which they are sometimes the only source of information.

There are, however, several disadvantages of using patent statistics. The biggest concern voiced over patents is that not all innovations get patented, either because they are difficult to patent (e.g. process innovations) or because an inventor decides not to patent the invention for fear of disclosing important information in a patent document. By limiting the analysis to a single sector or industry or by introducing an industry dummy variable, Griliches (1990) suggests the problem will be taken care of. Another concern is that patents are of heterogeneous nature - some patents are extremely valuable and lead to successful commercial applications, while others are of little value or never used. However, that patent data are prone to this quality variability problem, note Comanor and Scherer (1969, p. 393) "is not fundamentally different from those encountered in using a simple count of scientists or engineers, or research and development expenditures, as an index of innovative input". Another drawback is a different propensity to patent across countries and sectors. For instance, electronics industry tend to file several patents for each invention, pursuing the strategy of deterring the entrance for new competitors. In contrast to it, pharmaceuticals industry is characterised by a smaller number of patents with higher value. Propensity to patent might also differ between companies. Large companies might have a larger propensity to patent than smaller companies due to scale effects and high fixed costs of obtaining a patent (OEC, 2008). Finally, classifying a patent into relevant industry or technology area is not always an easy task. As Griliches (1990, p. 1670) puts it "how does one allocate patent data organized by firms or by substantive patent classes into economically relevant industry or product groupings?" One possibility is to use a concordance table that links patent classes to industry classification (SIC). Another possibility to opt for the expert approach, allowing experienced patent examiners to choose the relevant patent classes.

4.1 Patents database and search strategy

Dutch organisations or individuals wishing to apply for a patent might do so at the European Patent Office (EPO) or the Netherlands Patent Office (NPO). The European Patent Office processes patent applications for 19 European countries since 1978 (Dernis et al., 2001). A granted patent automatically protects the invention in all the European countries that an applicant has chosen. To protect the patent in more countries than just Europe, an applicant can file a patent application under the Patent Cooperation Treaty (PCT) with the World Intellectual Property Organization (WIPO). Under PCT a patent can be protected in any of the 139 contracting states (www.wipo.int). The Netherlands Patent Office has been issuing patents in the Netherlands since 1912. The patent application process is simpler and less expensive, compared to the one at the EPO and the patent is protected only in the Netherlands. Data from the Netherlands Patent Office has been digitised starting from 1992. Patents issued before that date are available in paper format only and contain little usable information.

In our study the search for the relevant patents has been performed using the EPODOC (EPO DOCumentation) database, which contains references to patent documents which compose the systematically classified search documentation of the European Patent Office (EPOQUE, 2007). The database contains published applications and granted patents filed with both EPO and WIPO for 81 countries over the period of 1977-2006. The EPODOC record data include the most important information components of a patent, which we use extensively to build the search strategy on:[2]

- Title of a patent.
- Abstract and list of claims describing an invention.
- International Patent Classification (IPC) classes a patent belongs to. IPC class provides a means of technical classification, identifying an area(s) of technology to which the invention belongs.
- The list of applicants and inventors with their addresses and countries of residence.
- Priority Date - date of the filing of a patent application.
- Publication Date - 18 months after the Priority Date.
- Cited patents and scientific papers.

Regarding the source of the patent data, we make use of the patents registered with the EPO or under the PCT. Applying for patent at the EPO or the PCT involves considerable costs and time. Assuming that an applicant would be willing to go through this costly procedure only with inventions that are deemed important and profitable, we hereby proxy for quality innovations. Due to only partial availability of data on the patent applications registered with the Netherlands Patent Office and because our patent experts consider these patent applications likely to represent inventions of lower value, we do not take these applications into our analysis.

To quantify innovations, we take the number of patent applications per year. Schmookler (1954) argues that patent applications are better suited to appraise the volume of inventive activity, than granted

[2]This list is not exhaustive and mostly focuses on the components that were used in our patent search.

patents. Patent applications are dated closer to the actual invention than granted patents and their amount is less influenced by variations in the work of patent offices or in the standards of patentability applied by them. In our analysis, we look at Dutch patent applications filed every year between 1977 and 2006. A patent has to be applied for by a Dutch company or individual. Patents with Dutch inventors but no Dutch applicants are discarded.

The search for patent applications containing relevant energy-efficient inventions in buildings has been performed based on the following strategy. As a first step, technical experts from Ecofys [3] identified several application fields with the highest potential for energy-efficient innovations in buildings. Each of those fields was further elaborated in detail, with a list of specific technologies that constitute it and keywords describing the technologies.

Secondly, after having established a list of technologies and corresponding keywords, IPC classes were assigned to each technology. To ensure the quality and precision of the data, experts of the Netherlands Patent Office carried out the search of the IPC classes. Assigning IPC classes to relevant technologies was one of the most challenging parts of the work. Indeed, a striking feature of energy-efficient technologies in buildings is that they touch upon a large number of diverse IPC classes. To take just one example, insulation contains patent applications taken from the IPC section of Fixed Construction, Chemistry and Metallurgy, Mechanical Engineering, as well as Performing Operations/Shaping (see Table 10 in Appendix). We benefited a lot from the fact that the Netherlands Patent Office has been recently involved in the project aiming at identifying environmental technologies.

As a third step, with keywords and IPC classes assigned to every technology a search for relevant patent applications has been conducted. The search was based on both IPC classes and keywords, that had to be present either in a patent title, an abstract or a claim. Some IPC classes, however, are defined precisely enough to conduct a search without the keywords, but with the IPC class alone (see Table 11). In searching for the relevant patents, there are two types of errors that can occur: inclusion of irrelevant patent applications or exclusion of relevant ones. Experts of the Netherlands Patent Office kept the queries broad enough to prevent the second type of error, at the same time trying to minimise the occurrence of the first type. The presence of irrelevant patent applications was tested by means of checking the samples of the results of every query. We intend to further test the quality of the obtained data by running different queries.

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[3] Ecofys is a company offering research and consultancy services in the field of sustainable energy.

As a fourth step, patent applications data were sorted and cleaned up. Firstly, patent application doubles were deleted. In general, if patent applications had the same restricted family number, experts of the Netherlands Patent Office opted to keep the ones registered with the EPO, rather than the PCT. The reason for this is that under the PCT, an inventor also features as an applicant in the patent information, which gives a different picture compared to the EPO patent applications. Since we are only interested in the applicants and not inventors, the EPO data were of more use to us. Further, if patent applications were registered with the EPO but still had the same restricted family number, the experts first checked whether the applications contained the same invention. If inventions differed, both applications were left in the dataset. Secondly, the expertise of the Netherlands Patent Office was used to correct for specificities of patenting activity of some Dutch companies, most notably Philips. To give just one example, Philips Intellectual Property in Germany is a main applicant for German patents, however, Philips Netherlands is always present as a second applicant in those patent applications. Experts of the Netherlands Patent Office consider the actual innovation to be taking place in Germany and do not assign such patents to the Netherlands. Without this information, one can easily overestimate the number of Dutch patent applications, especially since beginning 2000 this practice intensified. After sorting the patent applications and cleaning out the doubles, we counted the yearly number of Dutch patents applications in the period 1977-2006.

Subsequently, patents were grouped within 9 different groups of technologies for the ease of further analysis, see Table 2. These groups were matched for as much as possible with the environmental policies. Some further concessions were made to accommodate the specificities of the IPC classes. For instance, some technologies, such as heat pumps, heat and cold storage and cooling are extremely difficult to disentangle in the IPC classes and had to be bundled together in one group. The trade-off between technological structure, IPC structure and environmental policies resulted in 9 fields of technological applications presented in Table 2.

4.2 Patents trends

Figure 2 gives a general overview of the dynamics of patent applications by Dutch innovators for energy-efficient technologies in buildings. The mid-90s marks the beginning of a steady rise in the number of patent applications, which coincides with the intensification of the environmental policy, with many policy measures introduced around 1996-1997. More than half of all patents applications are concen-

Table 2: Technology groups in energy-efficient innovations in buildings

Technology group	Examples of specific technologies
Insulation and Energy demand reduction	Glazing, Window Frames, Insulation Materials, Floor and Roof Insulation, Insulation of pipes, Sun blinds, Warm Water Saving Devices
Heat Generation: HE-boilers	HE-boilers
Heat and Cold Distribution and CHP	Heat pumps, Heat and Cold Storage, Cooling, Heat Recovery, Heating Systems, Combined Heat and Power (CHP) or Cogeneration
Ventilation	Ventilation Technologies
Solar Energy and other RES	Thermal Solar Energy, Photovoltaic Energy (PV), Passive Solar Energy, Biomass, Geothermal Energy
Wind Energy and Fuel Cells (RES)	Wind Turbines, Fuel Cells
Lighting	LEDs, Fluorescent Lamps, Daylight Systems, Timed Lighting
Building Materials	Phase Change Materials, Timber Frames
Climate Control Systems	Tuning Indoor Climate System, Room Thermostat with Timer, Home Automation

trated in the technological area of lighting, mainly due to intensive innovative activity by Philips Figure 3 gives an overview of the most important areas of energy-efficient innovations in buildings in the Netherlands. High-efficiency boilers were invented in the Netherlands in the 1980s and therefore account for the second largest share of the patent applications. The group including Heat and Cold Distribution and CHP is the third largest group. Figures 6-8 in Appendix plots the evolution of patenting activities for each separate group of technologies related to improving energy-efficiency of buidings.

Figure 2: Number of patent applications by Dutch companies in energy-efficient innovations in buildings, 1977-2006

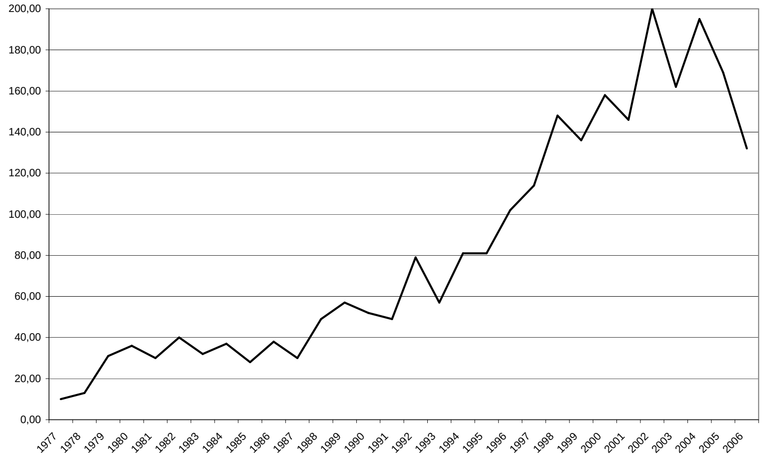


Figure 3: Total number of patent applications by Dutch companies in energy-efficient innovations in buildings, per field of application over 1977-2006

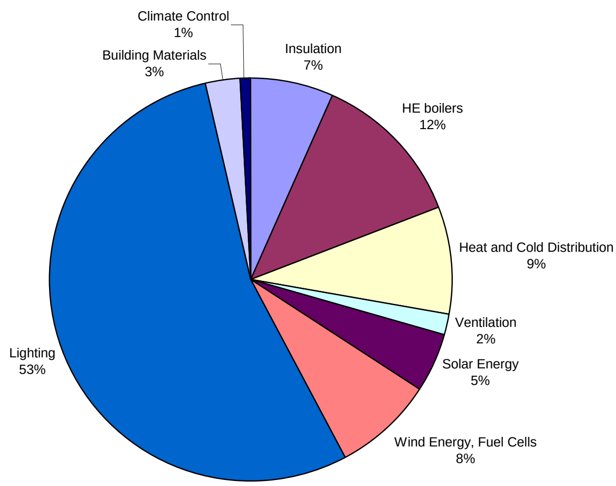


Table 3: Number of patent applications in energy-efficient innovations in buildings, 1978-2006

Technology group	Annual average per company	Annual average
Insulation and energy demand reduction	1,47	5,50
Heat Generation: HE-boilers	1,85	10,40
Heat and Cold Distribution and CHP	2,01	7,20
Ventilation	1,05	1,47
Solar Energy and other RES	1,53	3,77
Wind Energy and Fuel Cells (RES)	2,30	6,83
Lighting	21,41	44,97
Building Materials	1,06	2.20
Climate Control Systems	2,75	0,73

Lighting is also the most concentrated sector where the highest share of innovations is done by one company, as shown in Table 3. 63 companies applied for 1349 patents pertaining to the lighting technologies, with Philips responsible for the largest amount of applications - 1218. Without lighting an average number of patent applications per company is 1,75. The lowest is in ventilation with 42 companies making 44 patent applications in the 30 years from 1977 till 2006.

From an international perspective, the share of the Dutch energy-efficient innovations in buildings stayed around 5-6% of the worldwide, with a recent downward trend as shown in Figure 4.

Figure 4: Share of Dutch patent applications in energy-efficient innovations in buildings in the world, 1977-2006

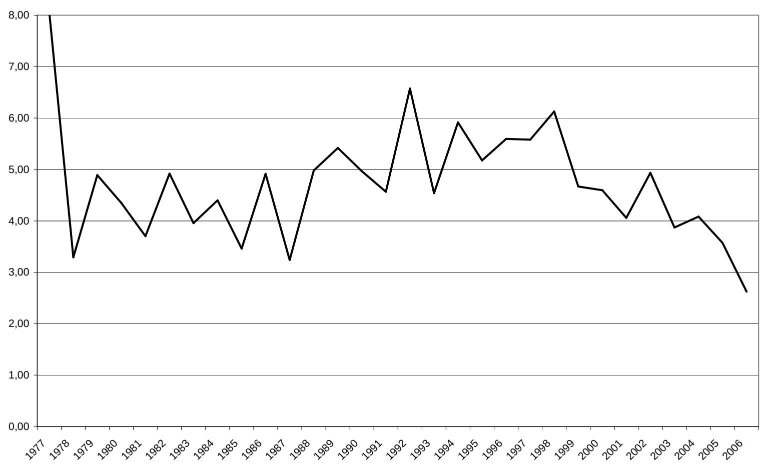


Table 4: Top ten patenting countries in energy-efficient innovations in buildings, 1977-2006

	Country	Annual average patent applications per GDP unit	Annual average patent applications
1	CH	2,66	5,53
2	NL	2,29	9,23
3	DE	2,26	43,50
4	LU	2,22	0,39
5	DK	2,18	3,19
6	SE	2,00	4,17
7	AT	1,47	3,07
8	FI	1,19	1,39
9	JP	1,08	34,57
10	NO	0,92	1,30

Compared to other countries, the Netherlands show significant patenting activity. Table 4 lists the top ten countries with the highest number of patent applications in energy-efficient innovations in buildings, averaged over the period of 1977-2006. Normalising the number of patent applications per GDP, it appears that the Netherlands is the second most patenting country in the sector. Other major innovating countries are Switzerland, Luxembourg, Germany, and Denmark. The strong position of the Netherlands, however, is mainly explained by the large number of patents in lighting. When we exclude lightings from the total number of patents, the Netherlands fall from the second to the eighth position in Table 4 (see table 12 in Appendix).

Table 5 gives the ranking of major innovating countries for each group of technology. The Netherlands stand in the middle range of innovative countries, with the exception of lighting technologies. Denmark ranks first in wind energy technologies and scores high in most technologies except lighting. Germany is also almost always in the top five innovative countries.

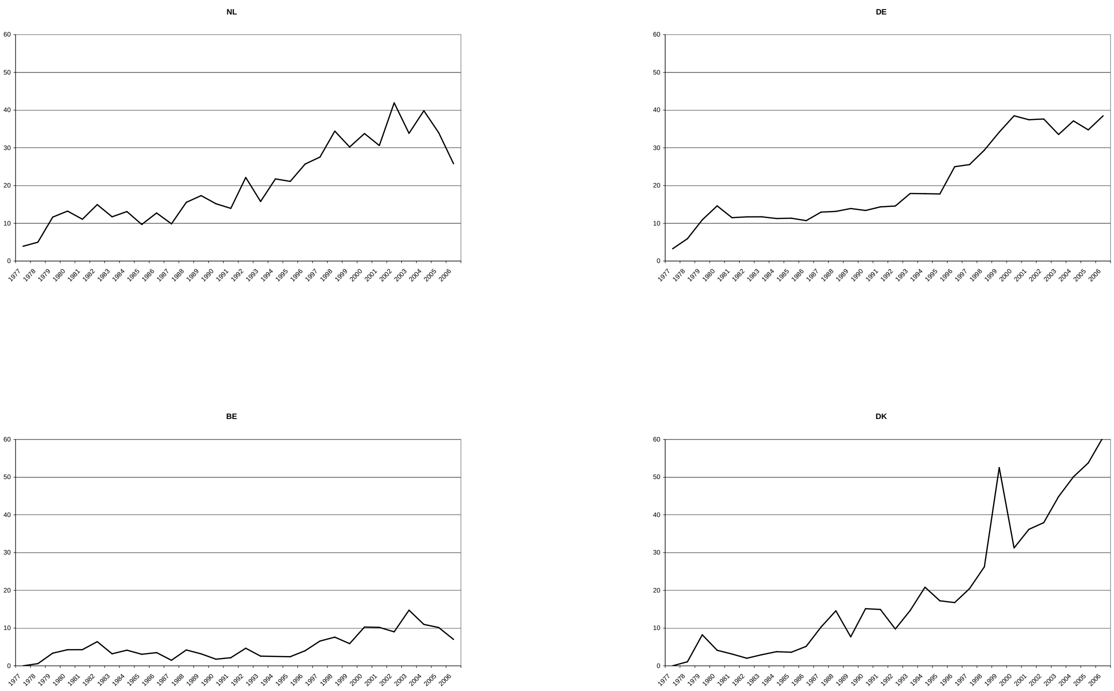
Figure 5 compares the evolution of technological innovations in energy-efficiency in buildings across several countries, namely the Netherlands, Germany, Belgium and Denmark. There is an increasing trend in all countries, although the trend is less marked in Belgium. Since we do not have information on foreign environmental policy, we cannot assess how much innovation patterns in Germany, Belgium and Denmark are related to national environmental policies. Figures 9 - 12 in Appendix plot the evolution of patenting activity for selected technologies in the Netherlands, Germany, Belgium and Denmark.

Table 5: Top ten patenting countries in the period 1977-2006 per technology area, based on the number of patent applications per unit of GDP

Insulation and Demand Driven Energy Saving			HE-boilers		Heat and Cold Distribution and CHP	
1	LU	5,41	CH	5,57	SE	3,80
2	CH	4,09	DE	3,53	CH	3,67
3	AT	3,59	SE	2,95	DK	3,12
4	DK	3,52	NL	2,74	DE	2,82
5	DE	3,24	AT	2,31	LU	2,20
6	SE	2,84	DK	1,87	FI	2,03
7	NO	2,25	FR	1,72	NL	1,93
8	FI	2,17	LU	1,38	JP	1,85
9	FR	1,49	IE	1,29	AT	1,82
10	NL	1,44	IT	1,27	NO	1,40
Ventilation			Solar Energy and other RES		Wind Energy and Fuel Cells	
1	SE	1,42	LU	4,37	DK	6,65
2	FI	0,81	CH	2,33	DE	3,85
3	CH	0,78	DE	1,56	JP	3,72
4	DK	0,67	AT	1,16	CH	2,90
5	DE	0,40	SE	1,14	CA	2,13
6	NL	0,37	AU	1,12	SE	1,69
7	NO	0,32	NL	0,98	NL	1,61
8	KR	0,31	NO	0,88	US	1,35
9	AU	0,25	DK	0,79	FI	1,21
10	LU	0,24	FI	0,73	NO	1,13
Lighting			Building Materials		Climate Control Systems	
1	NL	44,97	CH	2,18	DK	0,88
2	DE	70,23	SE	2,15	SE	0,51
3	CH	4,43	LU	2,04	DE	0,50
4	JP	65,50	FI	1,68	CH	0,37
5	AT	4,60	AT	1,14	GB	0,27
6	SE	3,13	DK	1,13	AT	0,21
7	LU	0,23	AU	1,02	FR	0,19
8	GB	13,33	NZ	0,92	NL	0,18
9	DK	1,53	DE	0,91	IE	0,17
10	US	87,23	NO	0,87	US	0,16

The table gives the average number of patents applications over the 1977-2006 period, normalised per unit of GDP (in trillions of US dollars, using 2000 prices and PPP).

Figure 5: Number of patent applications in energy-efficient innovations in buildings, corrected for GDP.



Several things are left for further analysis. We intend to look at a cooperation between countries in the patenting and innovating activities. We further intend to correct the average number of patent applications by overall patenting activity of the country over the period 1977-2006. At a later stage we will also look at the number of patent applications registered with the Netherlands Patent Office, because these applications would mostly represent inventions done by small- and medium-sized business and smaller companies might show a stronger response to policy measures.

5 Empirical methodology and results

5.1 Empirical methodology and descriptives

In this section we estimate the effect of environmental policy on the number of patents in the field of energy-efficiency in buildings. Since we are interested in estimating patent counts, which are nonnegative integers, we must formulate an estimation model which satisfies this integer restriction.

In order to assess the impacts of the determinants on the number of patent applications, the discreteness of this variable has to be taken into account. For instance, because of difficulties and uncertainty inherent to R&D activities, firms do not always apply for patents and, hence, a zero value is a (very common) natural outcome of this variable. Because of this property, the use of conventional linear regression models may be inappropriate. The reasons are that some basic assumptions such as the normality of residuals or the linear adjustment of data are no longer fulfilled. The usual way to deal with the discrete nonnegative nature of the dependent variable is to consider the simple *Poisson regression model* ((Cameron and Trivedi, 1998), p. 279).

Let Y_i be a dependent variable, which represents the number of patents (or patent applications) of firm i, where $i = 1,...,N$. The $y_{i,t}$s are assumed to be independent observations of firm i's number of patents (patent applications) and it is assumed that this number follows a Poisson distribution with parameter $\lambda_{i,t}$. Parameters $\lambda_{i,t}$ are assumed to depend on the set of independent variables, or

$$\lambda_{i,t} = \lambda(\mathbf{x}'_{i,t}\beta),$$

where $\mathbf{x}_{i,t}$ represents the set of explanatory variables for firm i at period t, β is the vector of corresponding unknown coefficients, which are to be estimated. The Poisson regression model is specified as

$$\Pr(Y_i = y_{i,t}) = \text{Poisson}(\lambda_{i,t}) = \frac{\exp(-\lambda_{i,t})\lambda_{i,t}^{y_{i,t}}}{y_{i,t}!}, \tag{1}$$
$$y_{i,t} = 0,1,2,... \text{ for } \forall i,t,$$

where we assume an exponential mean function for $\lambda_{i,t}$

$$\lambda_{i,t} = \exp(\mathbf{x}'_{i,t}\beta).^4 \tag{2}$$

In this specification, the estimation of the *Poisson count data model* is robust to distributional misspecification. Given $\lambda_{i,t} = \exp(\mathbf{x}'_{i,t}\beta)$, the maximum likelihood (ML) estimates of the Poisson model are consistent, even if the assumption of the Poisson process cannot be applied (Cameron and Trivedi (1998), Ch. 3).

An important property of the Poisson model is that its (conditional) mean and (conditional) variance are equal, or

$$E(y_{i,t}|\mathbf{x}_{i,t},\beta) = Var(y_{i,t}|\mathbf{x}_{i,t},\beta) = \lambda_{i,t} = \exp(\mathbf{x}'_{i,t}\beta). \tag{3}$$

[4] This exponential mean function is introduced to assure the nonnegativity of the conditional mean (variance) of the dependent variable.

In other words, the Poisson model implies the presence of heteroskedasticity in the model.

For interpreting the coefficients of the Poisson estimation, we consider from (3) that

$$\frac{\partial E(y_{i,t}|\mathbf{x}_{i,t},\beta)}{\partial x_{j,i,t}} = \exp(\mathbf{x}'_{i,t}\beta) \times \beta_j.$$

This means that the corresponding regression coefficient represents a proportional change in $E(y_{i,t}|\mathbf{x}_{i,t},\beta)$ of β_j with respect to a unit change in $x_{j,i,t}$.

We apply a Poisson probability regression models using count data on the number of patents in energy-efficiency technologies in buildings. We estimate the following equation:

$$NPATENTS_{i,t} = \beta_1 POLICY_{i,t} + \beta_2 CONTROLS_{i,t} + \varepsilon \tag{4}$$

where $i = 1 \dots 9$ are the different technological fields related to energy efficiency in buildings as given in Table 2, and $t = 1978 \dots 2007$ indexes the years. $NPATENTS$ gives the number of patent applications filed with the EPO and WIPO by Dutch companies, $POLICY$ is a set of variables describing environmental policy measures over the period and $CONTROLS$ are a set of control variables explaining patenting activity. This set of control variables includes a time trend to control for unobservable variation over time. We also include energy prices. Energy-efficient innovations in buildings will tend to become more profitable as the prices for energy used in buildings rise. Therefore, we expect to find a positive relationship between energy prices (gas or electricity prices) and incentives to innovate in energy-efficiency in buildings. We obtained data on gas and electricity prices for households (excluding taxes) in the Netherlands over the 1978-2008 period from the International Energy Agency. Finally, we also include governmental energy R&D expenditures. Government expenditures on energy R&D reflect the national R&D capacity of the country. These data were obtained from IEA. We use the total R&D expenditures specific to renewable energy for two of our technology groups, namely ‘solar energy and other RES’ and ‘wind energy and fuel cells’. We use R&D expenditures on energy efficiency for all the other technology groups. We expect to find a positive effect of R&D expenditures on the number of patents.

Regarding our environmental policy variables, we define in a first step each policy measure by a dummy variable, which takes value 0 prior the introduction of the measure and 1 thereafter. In a second step, we group policy measures in 6 different types: subsidies, standards, fiscal incentives, tax, voluntary

Table 6: Descriptive Statistics

	Mean	Std. Dev.	Min	Max	Obs
Number of patents per technology group	9.51	18.88	0.00	140	261
Gas prices households (eur/unit)	0.26	0.72	1.36	4.80	261
Electricity prices households (eur/unit)	0.09	0.01	0.07	0.12	261
Energy efficiency R&D (billions USD, 2005 prices and PPP)	0.06	0.02	0.04	0.88	234
Renewable energy R&D (billions USD, 2005 prices and PPP)	0.04	0.01	0.03	0.08	234
Main policy measures (dummies)					
REB (energy tax)	0.42	0.49	0	1	279
EPN (energy performance standard)	0.42	0.49	0	1	279
MAP (subsidy)	0.34	0.47	0	1	279
EIA (fiscal incentives)	0.39	0.49	0	1	279
EINP (fiscal incentives)	0.19	0.40	0	1	279
MJA (voluntary agreement)	0.61	0.49	0	1	279
Types of policy measures (number)					
all measures	8.40	4.55	1	16	279
subsidies	2.85	1.34	0	6	279
standards	2.00	0.81	1	3	279
fiscal incentives	1.58	1.20	0	5	279
tax	0.42	0.49	0	1	279
voluntary agreements	0.90	0.82	0	2	279
R&D support	0.65	0.74	0	2	279

agreements and R&D support. Table 6 gives the descriptive statistics.

Subsidies, standards and fiscal incentives have been the most widely used policy measures over the period. On average the technology field of high-efficiency boilers counts the highest number of policy measures (9) over the period, while the field of wind energy and fuel cells presents the lowest number of policy measures (7.7).

5.2 Estimation results

Our analysis is limited by several factors. Firstly, since for now we conduct the analysis for one country only, the size of the sample is very limited (9 technologies over 30 years). Secondly, as explained in Section 3 the history of environmental policy in the Netherlands is characterised by a large mix of policy measures, in particular after 1996 where performance standards, energy tax and fiscal incentives were introduced almost simultaneously. Since these measures also affect all technology groups, it is very difficult to disentangle one measure from the other. Thirdly, again given the small range of observations we cannot estimate how the effectiveness of environmental policy varies per technology group. These limitations restrict the issues that we can address empirically. Nevertheless, at this stage of our analysis, we can present some preliminary results on the importance of environmental policy next to other factors on innovative activities in the Netherlands.

In a first step, we present estimation results on the general impact of environmental policy on innovation in energy-efficiency technologies in buildings. These results are presented in Table 7.

In column (1) we simply include a dummy variable for the period 1996-2008, representing the period with a clear intensification of Dutch environmental policy. In column (2) of Table 7, we capture the effects of environmental policy through dummy variables corresponding to different time intervals. We include a dummy for the 1989-1996 period characterised by a large range of subsidies schemes and a dummy for the period after 1996, characterised by a broader mix of instruments with the simultaneous introduction of the REB, EPN and other important fiscal incentives. In column (3) of Table 7 we capture the intensification of environmental policy by a dummy for the 1996-2008 period and add controls for electricity prices[5] and energy R&D expenditures. In column (4) we measure the intensity or stringency of environmental policy by using a general policy variable, namely the total number of policy measures over the period. Finally, in column (5) just as Johnstone et al. (2008) we construct another indicator of environmental policy intensity by conducting a principal component analysis. Principal component analysis is a statistical technique used for data reduction. It helps reduce the number of variables in an analysis describing a series of uncorrelated linear combinations of the variables that contain most of the variance. In this case we only keep the first component (which explains about 50% of the total variance). In all our specifications, we find a positive effect of environmental policy on the number of patent applications. Depending on the specification, the effect is significant at the 1%-10% level. Energy prices have a positive effect on the number of patent applications, but the effect is not significant in certain specifications. R&D expenditures also have a positive effect. Including fixed effects to correct for technology-specific effects does not affect our results. Since lighting technologies represent a large part of patenting activities in the Netherlands, excluding them from our estimations has some consequences for our results, namely we find less robust results given our small sample size. In general, given the small number of observations, we should interpret these preliminary results with caution. We still intend

[5]Results using gas prices are reported in Table 13 in Appendix

Table 7: Estimation results of Poisson model, Dependent variable = number of patent applications

	(1)	(2)	(3)	(4)	(5)
Environmental Policy variables					
Dummy period 1996-2006	0.409***	0.814***	0.202**		
	(0.082)	(0.140)	(0.090)		
Dummy period 1989-1995		0.331***			
		(0.094)			
Total number of policy measures				0.029*	
				(0.015)	
Principal component variable					0.096***
					(0.024)
Other controls					
Time trend	0.056***	0.041***	0.073***	0.068***	0.044***
	(0.005)	(0.007)	(0.006)	(0.010)	(0.011)
Electricity prices households			4.966	5.579*	6.550**
			(3.154)	(3.121)	(2.952)
Energy R&D expenditures			7.110***	6.909***	6.838***
			(1.378)	(1.414)	(1.379)
Constant	-110.285***	-79.409***	-143.531***	-134.236***	-86.041***
	(10.296)	(13.470)	(12.970)	(19.083)	(21.339)
Observations	261	261	234	234	234
Log likelihood	− 2307	− 2300	− 1791	− 1792	− 1786

*/**/*** refers to significance at the 1/5/10% level respectively. Standard errors are given in brackets.
The dependent variable is the number of patents by Dutch applicants in a given technology area.
Excluding the time trend in columns (3)-(5) gives similar qualitative results.

Table 8: Correlation matrix between some major policy measures

	epn	reb	eia	einp	vamil
epn	1				
reb	1.0000	1			
eia	0.9351	0.9351	1		
einp	0.5765	0.5765	0.6164	1	
vamil	0.7222	0.7222	0.6754	0.4163	1

to perform robustness tests.

In a second step, we investigate the empirical issues related to estimating the differential impact of policy measures. The main difficulty we face is due to the high correlation between all the important policy measures introduced after 1996, namely EPN, REB, and EIA/EINP/VAMIL. This is likely to lead to multicollinearity problems in our estimations. Table 8 gives the correlation matrix between the main policy variables, defined as dummy variables. When we take the variation in intensity of EPN, REB and EIA into account, we are still left with some correlation issues, simply because the intensity of all these instruments increases over time, so that it is not possible to disantangle them from one another. We are currently investigating the possibility of looking at the variation in intensity of these policy measures per type of technology. For instance, it seems that not all the technologies listed in Table 2 have been implemented at the same time in the computation of the performance standard enacted by EPN (e.g photovoltaics and solar energy entered in 2001). Also, the impact of EIA (measured for instance in terms of applications) differs across technology groups. Even though this might give us more variability, it may still not be enough to capture the differential impact of policies in a one country setting.

Since for now we only conduct the analysis for the Netherlands, we cannot draw conclusions on the differential impacts of diverse types of policy measures. In particular, since the energy tax (REB) and the energy performance standard (EPN) have been introduced simultaneously, we cannot estimate whether tax measures provide more incentives for innovation than command-and-control measures.

6 Conclusions and future work

In this paper we aimed to look at the links between environmental policy and innovations in energy-efficient technologies in buildings, measured by patents data. We conducted the analysis for one country only, namely the Netherlands. The most substantial part of this analysis consisted of identifying the relevant technologies and the relevant patents. In a first step, we obtained help from technical experts to identify the relevant technologies. These experts also provided us with an extensive list of keywords. In a second step, we worked together with the Netherlands Patent Office to build specific queries for our patent search. These queries were based on both IPC classes and keywords search. In the end we were able to investigate the innovation activity of Dutch firms for nine different technology groups, including for instance insulation, high-efficiency boilers, solar energy and lighting.

Descriptive data on patents show a regular growth in patenting activities of Dutch firms in technologies related to improving energy efficiency of buildings, with an acceleration in the second half of the 1990s. The Netherlands present a clear specialisation pattern in lighting technologies, mainly due to intensive innovative activity by Philips. Excluding lighting technologies, the Netherlands drop from the second position in terms of innovations in energy efficiency in buildings to the eighth position. Yet, the Netherlands also performs relatively well in other fields such as high-efficiency boilers. Internationally, the Netherlands also score low with regards to innovations in insulation and energy demand reduction and building materials.

The evolution of innovations is compared with changes in the policy framework. While the 1980s were characterised by a large range of subsidy programs, Dutch environmental policy shows a clear shift towards a broader mix of policy measures from the mid 1990s on. In 1996, two major policy measures were introduced simultaneously, namely an energy tax (REB) and an energy performance regulation for buildings (EPN).

The preliminary empirical results find that environmental policy has a positive impact on innovations in energy-efficient technologies in buildings. Yet, given that we only look at one single country, we face some restrictions in the number of empirical issues that we can address. In particular, we cannot disantangle the differential impact of policy measures. In further work, we aim to extend the analysis to several countries. The main challenge in a multi-countries analysis will be to collect data on national environmental policy related to energy efficiency in buildings. In particular, we should focus on countries with a different timing of introduction of policy measures – especially with regard to standards and taxes.

Appendix

Table 9: Abbreviation list for environmental policies in the Dutch built environment/building sector in 1977-2008

Abbreviation	Full name	Time period
Advice-subsidy	Advice-subsidy for energy saving / Advies-subsidie energiebesparing	1977-1985
AZS	Subsidies for active solar-thermal systems / Subsidieregeling Actieve Zon-thermische Systemen	1996-present
BSE	Subsidies for energy programmes / Besluit Subsidies Energie	1994 - present
BSET	Subsidies new energy-saving technologies / Besluit subsidie nieuwe energiebesparende technieken	1992-1996
BSW	Subsidies for wind energy / Besluit Subsidies Windenergie	1992- 1995
Demo	Subsidy to support demo-projects of rational energy use in the built environment / Regeling Steun Proefprojecten Rationeel Energieverbruik Gebouwde Omgeving	1980-1989
DuBo	Sustainable Building / Tijdelijke stimuleringsregeling Duurzaam Bouwen	1996-2000
EER	Programme to promote energy-saving in governmental buildings / Programma Energie Efficiente Rijksgebouwen	1991-2000
EIA	Energy Investment Allowance / Energie Investeringsaftrek	1997-present
EINP	Energy Investment Allowance for non-profit organisations / Energie Investeringsaftrek voor de non-profit sectoren	1997-2002
EMA	Subsidies for energy-saving and environmental advice / Energiebesparings- en milieuadvies subsidieregeling	1992-1998 and 1998-present
EOS	Energy Research Subsidy / Energie Onderzoek Subsidie	2004-present
EPL	Energy Performance of a building site / Energie Prestatie op Locatie	2000-present
EPN	Energy Performance Norm / Energie Prestatie Norm	1996 - present
EPR+EPA	Energy premium for existing dwellings and Energy Performance Advice / Energie Premie Regeling en Energie Prestatie Advies	2000-2003 / 2000-present
Green Investments	Green Investments / Regeling Groen Beleggen	1994-present
Green Mortgage	Green Mortgage / Groene hypotheek	2002-present
IPW	Programme Wind energy / Integraal Programma Windenergie	1986-1990
Law energy saving equipment	Law on energy saving equipment / Wet energiebesparing toestellen	1986-present
MAP	Environmental Action Plan / Milieu Actie Plan	1991-2000
MJA	Long-Term Agreements / Meerjarenafspraken	1990-present
NEWS	Subsidies new energy-efficient combinations with CHP systems / Subsidieregeling nieuwe energie-efficiente combinaties met W/K systemen	1996-1997
NIP	The National Insulation Programme / Het Nationale Isolatie Programma	1978-1987
NPR	Energy efficient non-profit sector / Regeling Energiebesparing nonprofitsector	1983- 1988
Promotion CHP	Promotion of CHP (Combined Heat and Power, also known as Cogeneration) / Stimuleringsregeling WKK (Warmte-Kracht-Koppeling)	1988-1996
REB	Regulatory Energy Tax / Regulerende Energie Belasting	1996 - present
SEBG	Subsidy regulation for energy saving in existing buildings / Subsidieregeling voor energiebesparing bestaande gebouwen	1990-1995
SEEV	Subsidies for other energy efficient equipment / Subsidieregeling voor energiezuinige en emissie-arme verwarmingstoestellen	1990-1993
SES	Subsidies for energy saving and renewable energy / Steunregeling Energiebesparing en Stromingsenergie	1985-1991 and 1992-1994
Subsidies for boilers	Subsidies for high-efficiency boilers / Subsidie aanschaf HR-ketel of economizer	1981-1984
TII	Thermal Insulation Index / De thermische isolatie-index van gebouwen	1979-present
VAMIL	Regulation for accelerated depreciation of investments in environmentally-friendly technologies / Regeling Willekeurige Afschrijving Milieu-investeringen	1991 - present
WBSO	Research and Development (Promotion) Act / Wet Bevordering Speur- en Ontwikkelingswerk	1994 - present
WIR	Law on Energy Investment Support / Wet Investerings Rekening	1980-1987

Figure 6: Number of patent applications per year, Netherlands in: (a) Lighting, (b) HE boilers, (c) Wind Energy

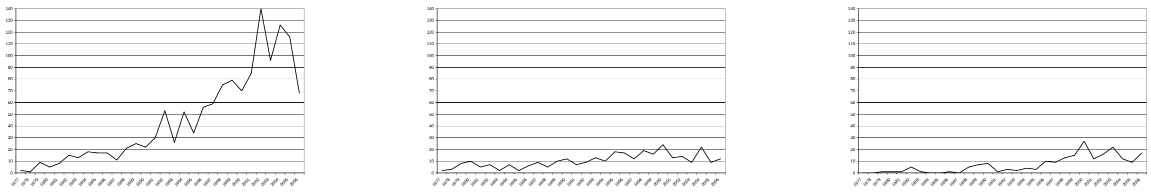


Figure 7: Number of patent applications per year, Netherlands in: (a) Ventilation, (b) Building Materials, (c) Climate Control Systems

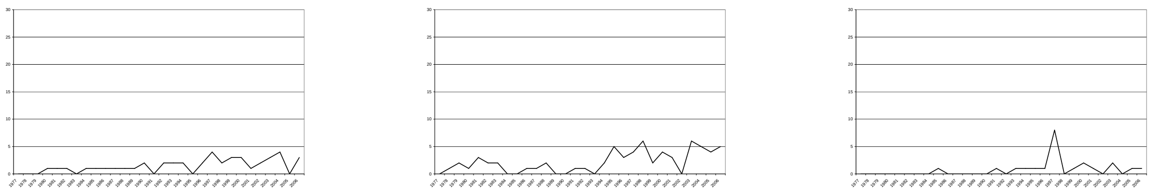


Figure 8: Number of patent applications per year, Netherlands in: (a) Insulation and Demand Driven Energy Saving, (b) Heat and Cold Distribution and CHP, (c) Solar Energy and other RES

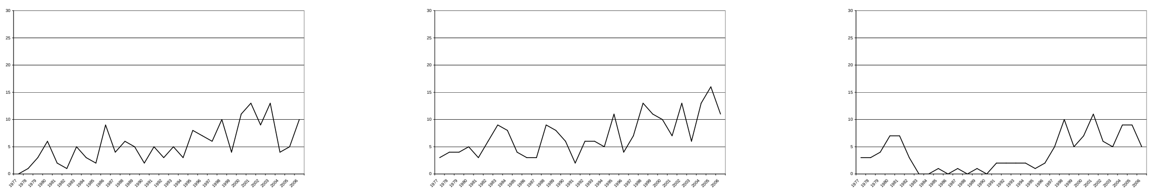


Table 10: Queries for energy-efficient innovations in buildings, Insulation and energy demand reduction

Insulation and Demand Driven Energy Saving			General IPC	Sub-classes	Keywords
Heat saving	Glass				
		double-glazing	E06B	3/24, 3/64 3/66, 3/67	
		high performance glazing	E06B	3+	high perform+ OR insulat+ OR low energy
		low-e coating	C03C	17/00, 17/36	low e
		vacuum glazing	E06B	3/67F	vacuum
		translucent insulation (aerogel)	E06B		aerogel
	Window frames				
		vinyl window frames	E06B	3/20	
		window frames with thermal break	E06B	1/32, 3/26	thermal break
	Insulation material	general	E04B	1/74,1/76	
		foams	E04B		polyurethane OR PUR OR polystyrene OR EPS OR XPS OR heavy gas+ OR pentane OR insulat+
		cavity wall insulation materials	E04B		flax OR straw OR (sheep+ AND wool)
	Floor insulation	foil with air cushions	E04F	15/18	
		shells	E04F		sea shell
	Roof insulation	general	E04D	11+	insulat+
		green roof	E04D	11+	green roof
		thatched roof	E04D	11+, 9+	thatch+
	Insulation of pipes		F16L	59/14	
Water saving	Water-saving devices		F24H		water AND (sav+ OR recover+)
			F16K	1+	water AND (sav+ OR recover+)
			E03C	1+	water AND (sav+ OR recover+)
Cooling reduction	Sunblinds	sunblinds	E04F	10+	
		reflecting, sunproof or heat resistant glass	C03+		glass AND (reflect+ OR sunproof OR heat resist+)
			E06B	3+	glass AND (reflect+ OR sunproof OR heat resist+)
			B32B	17+	glass AND (reflect+ OR sunproof OR heat resist+)

Table 11: Queries for energy-efficient innovations in buildings, Wind Energy and Fuel Cells

Wind Energy and Fuel Cells	General IPC	Sub-classes	Keywords
Wind Energy	F03D		
Fuel Cells	H01M	8+	

Table 12: Top ten patenting countries in energy-efficient innovations in buildings, 1977-2006, without lighting

	Country	Patent applications per GDP unit	Patent applications
1	CH	2,73	5,67
2	LU	2,35	0,41
3	DK	2,33	3,40
4	DE	2,10	40,16
5	SE	2,06	4,30
6	AT	1,40	2,88
7	FI	1,23	1,42
8	NL	1,23	4,76
9	NO	0,98	1,38
10	JP	0,96	30,71

Figure 9: Number of patent applications per year, corrected for GDP. Lighting technologies

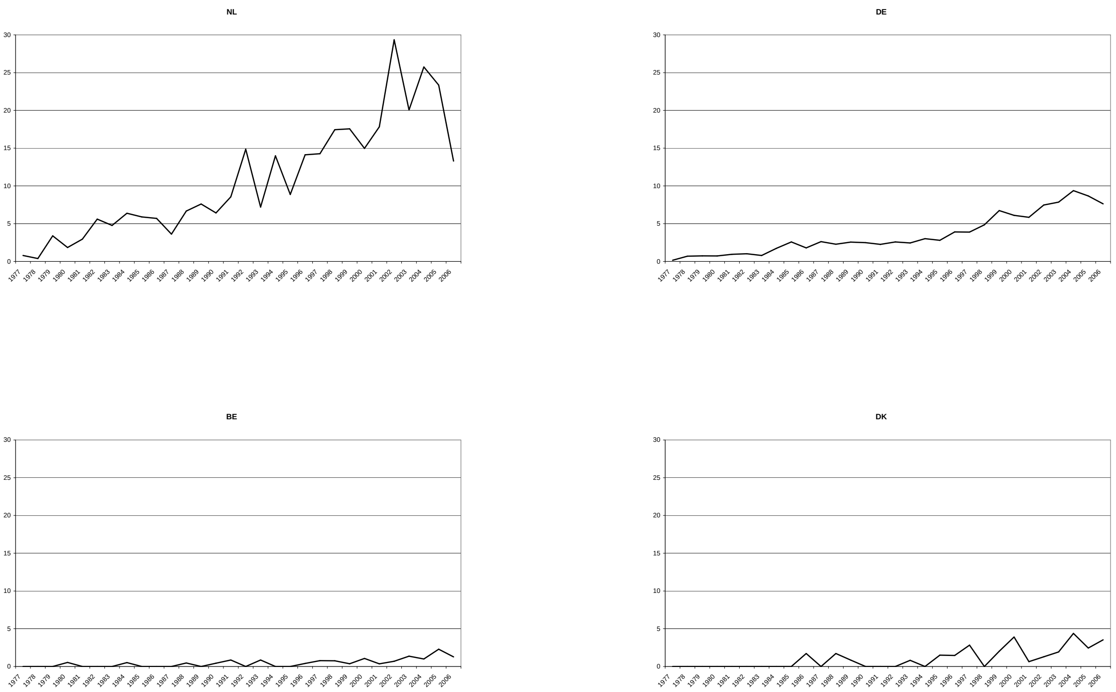


Table 13: Estimation results, specifications including gas prices

	(3)	(4)	(5)
Environmental Policy variables			
Dummy period 1996-2006	0.255***		
	(0.084)		
Dummy period 1989-1995			
Total number of policy measures		0.039***	
		(0.015)	
Principal component variable			0.119***
			(0.026)
Other controls			
Time trend	0.069***	0.062***	0.030**
	(0.007)	(0.010)	(0.013)
Gas prices households	0.264	0.285	1.463*
	(0.703)	(0.708)	(0.769)
Energy R&D expenditures	6.650***	6.284***	6.749***
	(1.374)	(1.389)	(1.379)
Constant	-136.496***	-122.379***	-57.961**
	(13.743)	(19.389)	(25.553)
Observations	234	234	234
Log likelihood	− 1792	− 1793	− 1786

*/**/*** refers to significance at the 1/5/10% level respectively. Standard errors are given in brackets.
The dependent variable is the number of patents by Dutch applicants in a given technology area.
Excluding the time trend in columns (3)-(5) gives similar qualitative results.

Figure 10: Number of patent applications per year, corrected for GDP. Solar Energy and other RES

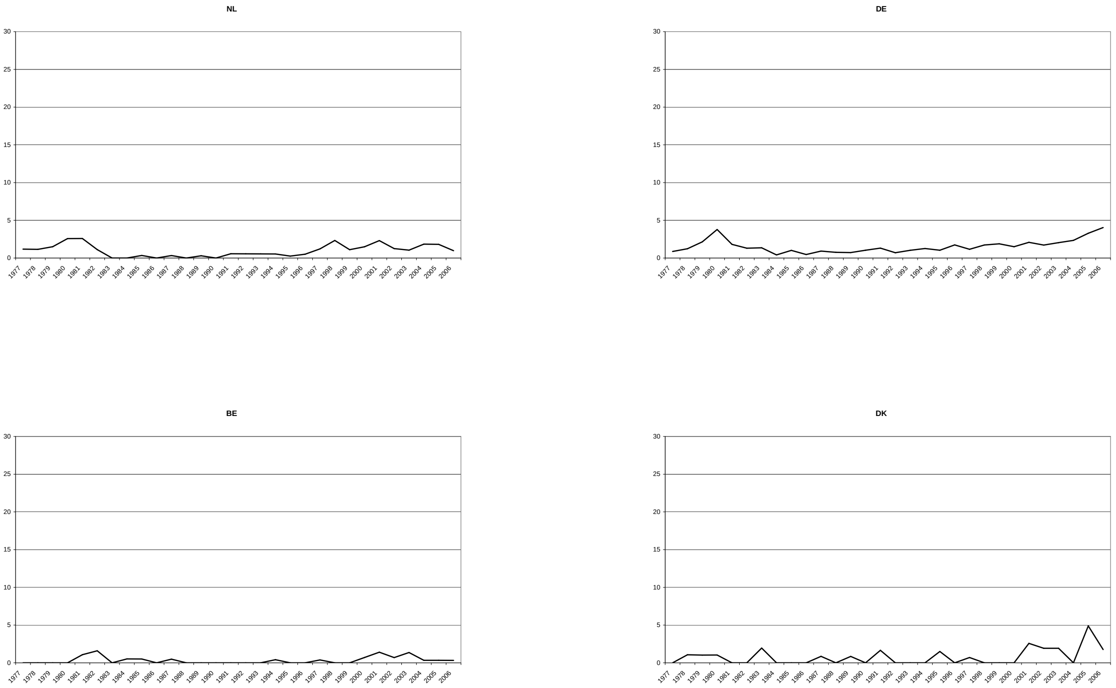


Figure 11: Number of patent applications per year, corrected for GDP. Insulation and Demand Driven Energy Saving technologies

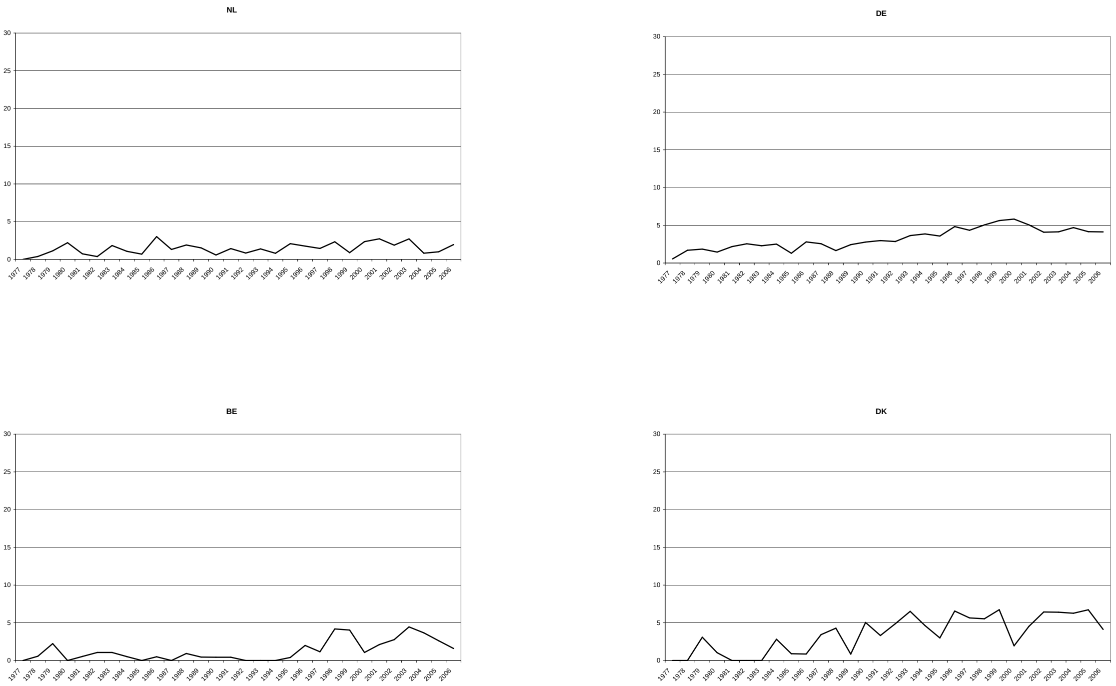
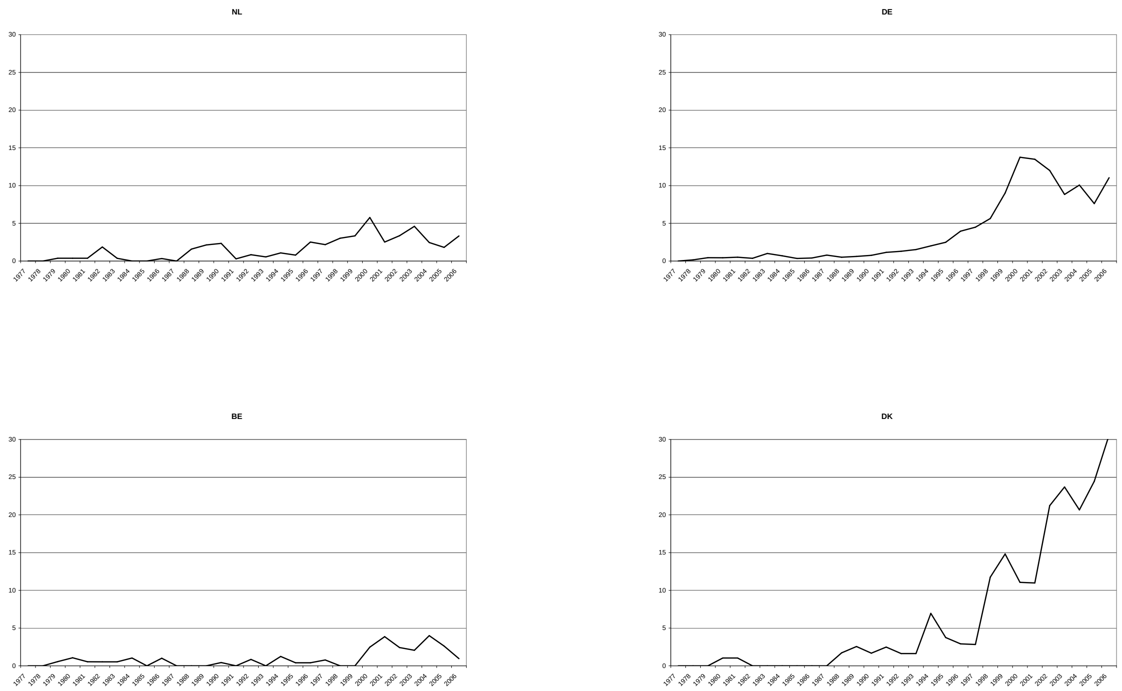


Figure 12: Number of patent applications per year, corrected for GDP. Wind Energy and Fuel Cells



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