No 198

Home, green home
A case study of inducing energy-efficient innovations in the Dutch building sector

Joëlle Noailly, Svetlana Batrakova, Ruslan Lukach

CPB document

CPB Document

No 198
January 2010

Home, green home – A case study of inducing energy-efficient innovations in the Dutch building sector

Joëlle Noailly, Svetlana Batrakova, Ruslan Lukach

CPB Netherlands Bureau for Economic Policy Analysis
Van Stolkweg 14
P.O. Box 80510
2508 GM The Hague, the Netherlands

Telephone +31 70 338 33 80
Telefax +31 70 338 33 50
Internet www.cpb.nl

ISBN 978-90-5833-432-9

Abstract in English

This document provides a case study of policies aiming to foster technological innovations for 'green' buildings in the Netherlands. The study aims to provide 1) a detailed overview of the policy framework over the last thirty years, and 2) a picture of the level of innovations related to energy efficiency in buildings in the Netherlands. The analysis shows an intensification of environmental policy in the Dutch building sector in the mid-1990s, followed by a slight decline after 2001. A striking feature of environmental policy in this sector is the large number of policy programs implemented successively for short periods of time. This might affect the stability and continuity of the policy framework and be damaging for innovation. Faced with high levels of uncertainty about future policies, firms may prefer to postpone risky investments in innovative activities. Finally, governmental R&D support for green innovations in general remains very low in the Netherlands. Descriptive data on patenting activities show that Dutch firms file nowadays about 150 patents annually in the field of energy efficiency in buildings. The Netherlands have a clear comparative advantage in the field of energy-saving lighting technologies, mainly due to intensive patenting activities by Philips. High-efficiency boilers also represent a substantial share of Dutch innovation activities in this domain over the last decades. In many other fields (such as insulation, heat-pumps and co-generation, solar boilers, etc), however, Germany, Austria and Scandinavian countries rank much higher than the Netherlands.

Abstract in Dutch

Dit document analyseert het Nederlandse beleid om innovatie in 'groene' gebouwen te stimuleren. De studie heeft twee doelstellingen: 1) het schetsen van een gedetailleerd overzicht van het beleidskader over de laatste dertig jaar en 2) het presenteren van gegevens over het niveau van innovatie in deze sector. De analyse laat zien dat het beleid gericht op energie-efficiënte gebouwen halverwege de jaren 90 is toegenomen en na 2001 licht is afgenomen. Een opvallend kenmerk van het beleid in deze sector is het grote aantal beleidsinstrumenten dat is geïmplementeerd voor een relatief korte periode. Dit kan gevolgen hebben voor de stabiliteit en continuïteit van het beleid en kan nadelig zijn voor innovatie. Bedrijven die geconfronteerd zijn met veel onzekerheid over het toekomstige beleid, kunnen immers riskante investeringen in innovatie gaan uitstellen. Ten slotte blijken in Nederland publieke R&D-uitgaven voor groene innovatie in het algemeen relatief laag te zijn. Patentgegevens laten zien dat Nederlandse bedrijven rond 150 patenten per jaar indienen in technologieën voor energie-efficiënte gebouwen. Nederland heeft een sterk comparatief voordeel in energiebesparende verlichting, hoofdzakelijk door de intensieve innovatieactiviteiten van Philips. Daarnaast heeft Nederland een sterke positie in de Hr-ketel-technologie. In veel andere technologiegebieden (zoals isolatie, warmtepompen, zonneboilers enz.) behalen Duitsland, Oostenrijk en Scandinavische landen een hogere positie dan Nederland.

Contents

Preface		7
Summary		9
1	Introduction	13
2	Insights from the economic literature	15
2.1	Theoretical literature	15
2.2	Empirical evidence using patent data	17
3	Public policies promoting energy efficiency in the Dutch building sector	21
3.1	General trends	21
3.2	Specific environmental policy instruments	22
3.3	Innovation policy	24
4	Innovations for energy-efficient buildings	33
4.1	Construction of the patent dataset	33
4.2	Patenting activities in the Netherlands	35
	4.2.1 General trends	35
	4.2.2 Patents by technological field	36
	4.2.3 Innovating firms	37
4.3	International comparison	38
5	Conclusions and implication for policy	47
References		57

Preface

With climate change high on the policy agenda, many countries are developing policies to foster green innovations, as these innovations can greatly contribute to lower environmental impacts and to reduce the costs of emission reductions. This CPB document provides a case study of Dutch policies inducing technological innovations for ‘green’ buildings. In the Netherlands, where the building sector accounts for one third of carbon emissions, the government aims to halve the total energy use from buildings by 2030 compared to 1990 levels (Schoon en Zuinig, VROM 2007). This document discusses the evolution of the policy framework in this sector over the last thirty years and presents empirical evidence – using an unique patent dataset – on the level of innovation by Dutch firms related to energy efficiency in buildings.

This document was written by Joëlle Noailly, Svetlana Batrakova and Ruslan Lukach. The authors are grateful to Marcel Seip and Jos Winnink from the Netherlands Patent Office for their outstanding help in building the patent dataset and their valuable expertise on patent related questions. The authors also thank Suzanne Joosen, Anton Schaap and Frank Zegers from Ecofys for providing technical information on the relevant technologies. Albert Faber (PBL) and Ed Blankesteijn (SenterNovem) are also acknowledged for providing additional documents on the Dutch policy framework. In addition, this document benefited from comments from participants at seminars at the DIME Workshop on "Innovation, Sustainability and Policy" and at the Dutch Ministry of Economic Affairs. At last, the authors also thank Paul Koutstaal, Rob Aalbers, Bas ter Weel, Casper van Ewijk and Bas Straathof (CPB) for valuable comments. This study is part of the research project ‘Environmental Policy and Economics’ initiated by the Dutch Ministry of Economic Affairs.

This study is published together with a companion CPB Discussion Paper entitled "Improving energy efficiency in buildings: the impact of environmental policy on technological innovation" written by Joëlle Noailly, CPB Discussion Paper 137, which provides a quantitative analysis of the effects of policy instruments on technologial innovations aiming to improve the energy efficiency of buildings in a set of European countries.

Coen Teulings
Directeur CPB

Summary

Reducing emissions from buildings represents a direct and significant opportunity to help tackle climate change. The 160 million buildings in Europe absorb over 40% of final energy consumption and represent 40% of its carbon dioxide emissions. Hence, many countries have set ambitious targets to stimulate 'green' buildings. In the Netherlands where the building sector accounts for 33% of carbon emissions (Joosen et al., 2004), the government aims to halve the total energy use from buildings by 2030 compared to 1990 levels (Schoon en Zuinig, VROM 2007). A viable option to improve the energy efficiency of buildings is to foster technological change, as technological innovations can significantly contribute to lower the environmental impacts of buildings and to reduce the costs of emission reductions .

The current document provides a case study of policies inducing energy-efficient innovations in the Dutch building sector. The objective of the study is twofold. First, the study aims to provide a comprehensive overview of the relevant environmental and innovation policy instruments introduced by the Dutch government over the last thirty years. This overview allows to address some of the following questions: How did environmental policy related to energy efficiency in buildings evolve over the last decades? What are the main features of the policy framework – regarding the number, type and design of policy instruments? The second objective of this study is to provide a picture of how much innovation related to energy efficiency in buildings takes place in the Netherlands. To this end, the analysis uses an unique dataset of patent applications by Dutch firms. Some of the questions addressed here are: How did the level of innovation in this field evolve over the last decades? In which technological field do the Netherlands hold a comparative advantage? Where do the Netherlands stand in comparison to other countries?

A general result from the economic literature is that environmental policy has an impact on the rate and direction of technological change. A strong case has been made in the literature for the use of market-based instruments (e.g. taxes, subsidies) rather than command-and-control instruments (e.g. technology and performance standards) to induce innovation. Regardless the type of policy instruments, however, recent work emphasizes the importance of environmental policy design (e.g. in terms of flexibility, stability, targeting) on the incentives to innovate. In addition, recent theoretical work also advocates the implementation of a portfolio of policy measures, combining both environmental and technology policy instruments.

A historical review of policy initiatives inducing energy-efficient innovations in the Dutch building sector shows that Dutch environmental policy intensified in the mid-1990s and slowed down after 2001-2002. Subsidies and fiscal incentives have been widely used over the last thirty years, although there has been a diversification in the type of policy instruments since the mid-1990s, in particular with the introduction of the energy tax and the energy performance standard for buildings (EPN). A striking feature of environmental policy in this sector, however,

is the large number of different policy programs implemented successively for shorts periods of time. These frequent policy changes and revision of instruments might affect the stability and continuity of the policy framework. In turn, an unstable policy framework may have nefast consequences for innovation. When there is too much uncertainty about future policies, firms may prefer to postpone their long-term risky investments in innovative activities. Finally, R&D support for environmental innovations remains very low in the Netherlands. Government R&D expenditures on 'control and care of the environment' and 'production and rational utilization of energy' represent only a negligible share of total public R&D, namely: 1.2% and 2.2% of total government R&D spending in 2005, respectively. Expenditures related to energy efficiency in buildings represent about 10% of the total budget for energy R&D.

To describe the level of innovation in green buildings in the Netherlands, the analysis uses an unique dataset of patent applications by Dutch firms in specific technological fields, namely: insulation, high-efficiency boilers, heat and cold distribution (heat pumps and co-generation), ventilation technologies, solar boilers (and other renewables), lighting technologies, building materials and climate control technologies. Several experts from Ecofys and the Netherlands Patent Office have been involved in the process to help us identifying the relevant patents. Using this dataset, we find that Dutch firms file nowadays on average about 150 patents applications per year in technologies related to energy efficiency in buildings. This represents about 0.02% of all patenting activities in the Netherlands. The number of patents increased over the 1990s and stabilized after 2000. The Netherlands have a clear comparative advantage in the field of energy-saving lighting technologies. High patenting activities by Philips explain the predominance of the Netherlands in this field on the international market. High-efficiency boilers represent the second most important group of innovations in this field. Overall, however, other countries, notably Germany, Austria and Scandinavian countries exhibit higher levels of innovation than the Netherlands in a broader set of technologies. Correcting the number of patents per GDP unit, Germany appears to be in the top five of innovating countries in almost all technological fields. Sweden, Denmark and Austria are in the top five in half of the technology groups. The Netherlands rank first in lighting technologies and fourth in the field of high-efficiency boilers. For other technologies, the Netherlands fall outside the top five innovative countries.

This case study suggests several lessons for policies aiming to induce technological innovations. First, one of the basic lesson that follows from the literature is that, regardless of the type of instruments, the stringency of environmental policy matters for innovation. In the companion paper directly related to this study, Noailly (2009) finds evidence that countries with more stringent regulatory standards achieve higher levels of patenting activities than countries with less stringent regulations. A primary option for the government to stimulate energy innovation is thus to further increase the stringency of environmental policy. Second, since a confusing and frequently changing policy framework may come at the cost of innovation, the government has clear incentives to behave in a predictable manner and to commit itself to policies for a relatively long time period. Third, there is a case for policy options aiming to increase R&D support. Finally, since the costs of inefficient policies can be high, much can be gained by a proper evaluation of policy instruments. Such evaluation was not feasible in the building sector, mainly because many policy instruments were introduced almost simultaneously making it impossible to differentiate their impacts. Policy evaluations can be greatly facilitated by resorting more often to policy experiments. A simple policy experiment could be for instance to introduce a policy program first in one region before extending it to other regions.

1 Introduction

With climate change high on the list of public priorities, efforts to cut carbon emissions have moved to the foreground of many government agenda's. Reducing emissions from buildings, in particular, represents a direct and significant opportunity to help tackle climate change. The 160 million buildings in Europe absorb over 40% of final energy consumption and represent 40% of its carbon dioxide emissions. Most of the energy from buildings is used for space heating (57% of domestic consumption, 52% of non-residential building consumption) and water heating (25% of domestic consumption and 9% of non-residential use). Lighting accounts for up to 25% of emissions due to commercial buildings (ACE, 2004). Hence, many countries have set ambitious targets to stimulate 'green' buildings. In the Netherlands where the building sector[1] accounts for 33% of carbon emissions (Joosen et al., 2004), the government aims to halve the total energy use from buildings by 2030 compared to 1990 levels (Schoon en Zuinig, VROM 2007).

A viable option to improve the energy efficiency of buildings is to foster technological innovation. New buildings using advanced insulation technologies consume significantly less energy than existing buildings and the energy performance of boilers, heat-pumps and other heating systems is increasing rapidly.[2] Accordingly, the Dutch policy agenda has set specific goals with regard to green innovations in the building sector. Within the framework of the 'Energy Transition Platform for the building sector', the Dutch government has recently launched a large range of demonstration projects aiming to realize 5000 high energy performance buildings by 2012 and to develop energy neutral buildings by 2020 (VROM, 2009).

The current document provides a case study of policies inducing energy-efficient innovations in the Dutch building sector. The objective of the study is twofold. First, the study aims to provide a comprehensive overview of the relevant environmental policy instruments introduced by the Dutch government over the last thirty years. Historical overviews of Dutch environmental policy over such time frames are scarce in the literature. The present inventory allows to address some of the following questions: How did environmental policy related to energy efficiency in buildings evolve over the last decades? What are the main features of the policy framework – regarding the number, type and design of policy instruments? The descriptive analysis of Dutch environmental policy shows an intensification of environmental policy in the mid-1990s, followed by a slight decline after 2001. Overall, the policy framework is also characterised by the introduction of a large number of short-lived policy instruments and frequent policy changes. The lack of stability and continuity of environmental policy may be damaging for innovation, since uncertainty about future policies could slow down innovation efforts. Also, the

[1] The building sector includes residential and non-residential (commercial and industrial) buildings. The residential sector only refers to residential buildings.

[2] According to a study by Ecofys (2009), replacing three-fourth of all high-performance boilers in the Dutch market by new hybrid air/water heat pumps could reduce CO_2 emissions in the residential sector by 20%.

simultaneous introduction of instruments makes it difficult to evaluate the effectiveness of policies.

The second objective of this study is to provide a picture of how much innovation related to energy efficiency in buildings takes place in the Netherlands. To this end, the analysis uses an unique dataset of patent applications by Dutch firms in specific technological fields, namely: insulation, high-efficiency (HE)-boilers, heat and cold distribution (heat pumps and co-generation), ventilation technologies, solar boilers and other renewables, energy-saving lighting technologies, building materials and climate control technologies. This dataset has been constructed for the present study. Several experts from Ecofys and the Netherlands Patent Office have been involved in the process to help us identify the relevant technologies and patents. This dataset allows to address questions such as: How did the level of innovation in this field evolve over the last decades? In which technological field do the Netherlands hold a comparative advantage? Where do the Netherlands stand in comparison to other countries? Descriptive data on patenting activities show that Dutch firms file nowadays about 150 patents annually in the field of energy efficiency in buildings. The Netherlands have a clear comparative advantage in the field of energy-saving lighting technologies, mainly due to intensive patenting activities by Philips. High-efficiency boilers also represent a substantial share of Dutch innovation activities in this domain over the last decades. In many other fields, however, Germany, Austria and Scandinavian countries rank much higher than the Netherlands.

This study is related to the work by Blok et al. (2004), who discuss the effectiveness of various environmental policy instruments to foster the adoption of energy-efficient technologies in the Netherlands. By contrast to their work, our study focuses specifically on technological innovation – and not adoption. In addition, while Blok et al. (2004) look at several policy instruments across various sectors, we only focus on one specific sector, namely the Dutch building sector. Finally, Blok et al. (2004) focus on a few policy instruments in isolation. Instead, in this study we describe the range of policy instruments and the policy framework over longer time frames.

In a companion paper directly related to this study, Noailly (2009) compares the impacts of three different policy instruments, namely energy standards, energy taxes and R&D support, on innovations aiming to improve energy efficiency in buildings in a set of European countries. The results of this empirical study are discussed in more details below. Due to data restrictions and identification issues an econometric estimation of the impact of environmental policy on innovations for the Netherlands only was not feasible.

The study is organized as follows. Section 2 briefly summarizes insights from the economic literature on induced innovation. Section 3 gives an overview of public policies inducing energy-efficient innovations in the Dutch building sector. Section 4 describes the data on technological innovations as measured by the number of patents by Dutch firms. Section 5 concludes and draws implications for policy.

2 Insights from the economic literature

Technological change has received much attention in the environmental economic literature. This section briefly summarizes some of the main insights on the effects of public policies to foster technological innovation. For a detailed overview of the literature, see Popp et al. (2009).

2.1 Theoretical literature

Environmental technologies are characterized by two types of market failures (Jaffe et al., 2005): 1) the environmental externality, and 2) the innovation externality. The environmental externality relates to the fact that firms do not have incentives to minimize the external costs of pollution, since the consequence of pollution are not borne by the firm itself but by third parties. Similarly, since most of the benefits from environmental innovations are a public good, firms also have insufficient incentives to innovate in cleaner technologies.[3] The innovation externality, instead, stems from the public good nature of knowledge. Since innovating firms cannot prevent other firms from benefiting from their new knowledge, firms have low incentives to invest in new technologies (Martin and Scott, 2000). These two market failures – the environmental and the knowledge externalities – reinforce each other and decrease the likelihood that the rate of investment in the development and diffusion of technologies occurs at the socially optimal level.

There is an extensive literature on the role of environmental policy in fostering technological innovation.[4] This literature stems from the induced innovation hypothesis (Hicks, 1932) which states that when a factor price increases, firms will develop technologies that aim to reduce this factor. Therefore, if environmental policy increases the price of energy, profit-maximizing firms will have incentives to innovate in energy-saving technologies. The standard theoretical model assumes that firms' incentives to innovate depend on (Milliman and Prince, 1989; Fischer et al., 2003): 1) abatement costs, i.e. the costs of pollution control (equipment and operation costs); technological change is typically assumed to reduce these costs.[5], 2) associated transfers, i.e. emission taxes or subsidies but also royalties and 3) spillover or imitation costs, due to the

[3] In some cases, there might be private benefits for the firms to innovate. For instance, when energy prices are high, the firms may have incentives to innovate in energy-saving technologies. However, incentives given by energy prices may not be large enough to internalise the externalities. Environmental policy can thus correct for this.

[4] Beside environmental policy, there are other factors driving technological innovations. The environmental economic literature acknowledges for instance the role of 'autonomous' (i.e. non-endogenous) energy efficiency technological improvements.

[5] In recent years, this result has been challenged (Baker et al., 2008; Bauman et al., 2008). Baker et al. (2008) discuss the fact that technical change may also increase marginal abatement costs. This is likely to occur for many improvements in intermediate technologies, which have lower emissions that business-as-usual technologies but will be substituted away in the case of very high abatement for instance when carbon prices are very high. For instance, a firm using gas-fired electricity generation which wants to achieve higher levels of abatement may substitute toward a lower carbon alternative such as nuclear.

inability of innovators to fully appropriate the rents from innovation.[6] Accordingly, the firm will set the optimal amount of R&D such that marginal costs of innovation are equal to marginal benefits. Theoretical models aiming to rank the different policy instruments according to their innovation-stimulating effect have often yielded ambiguous conclusions. Ulph (1998) finds no straightforward ranking between taxes of standards, due to the presence of two competing effects: environmental regulations increase costs and thus increases the incentives to invest in R&D, but also reduce output, and thereby decrease R&D incentives. In addition, Fischer et al. (2003) find it difficult to find an unequivocal ranking between pollution taxes and permits. Rather, they show that the performance of instruments depends on innovator's ability to appropriate spillover benefits of new technologies, the costs of innovation, environmental benefit functions and the number of firms producing emissions. Overall, however, market-based instruments (taxes, tradable permits, subsidies) are often preferred over command-and-control instruments (performance and technological standards). This is mainly because with market-based instruments firms get a financial reward for performing beyond the target, while this is not the case with command-and-control instruments. Requate (2005) reviews 28 different studies and concludes that "it seems 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 that command and control policies." (Requate, 2005, p.193).

Recently, some of the core assumptions of the theoretical models have been challenged. Bauman et al. (2008) show that when innovation leads to an increase (and not a decrease as typically assumed) in marginal abatement costs, command-and-control instruments may provide stronger incentives for innovation than economic instruments. This is likely to be the case for process innovations, in particular.[7] For instance, if a plant plans to reduce emissions by shutting down temporarily, it will forego more output (and profit) when it is using a more efficient boiler. The assumption of profit-maximizing firms making optimal R&D decisions has also been challenged. Porter and Van der Linde (1995) argue that command-and-control instruments might be better able to force boundedly rational firms to modify their 'routines' and thereby to foster creativity and innovation (see also Jaffe et al. (2002) for a discussion).

Finally, in recent years, the environmental economic literature has studied the effectiveness of combining environmental and innovation policy. Theoretical work and models tend to suggest that these policies work best when used in tandem. Fischer (2008) finds that R&D government support in emission control is only effective if at least some moderate environmental policy is in place to encourage the adoption of these technologies. Fischer and Newell (2008) also find that an optimal portfolio of policies, including emission pricing and R&D subsidies, achieve

[6] Fischer et al. (2003) extent the basic model of Milliman and Prince (1989) to assume weak appropriation of innovation rents by firms.

[7] See also Amir et al. (2008).

emission reductions at a lower cost than any single policy. The combination of the environmental and knowledge externalities suggests that policymakers need to implement corrective measures for both types of market failures (Jaffe et al., 2005). Public policies can then combine standard policy instruments, such as carbon tax and emission trading, with specific R&D measures focused on energy and the environment. In a recent paper, Acemoglu et al. (2009) develop a theoretical framework to study the effects of different types of policies on innovation, growth and environmental resources. They find that optimal policy should always include both a 'carbon tax' to control current emissions and R&D subsidies to influence the direction of research towards clean technologies. As long as the dirty technology enjoys an installed-based advantage, innovations will tend to work in favour of further improvements in the dirty technology. The path of innovations is then locked-in into dirty technologies. Acemoglu et al. (2009) argue, therefore, that high initial clean-innovation R&D susbsidies are needed next to high carbon pricing to redirect market forces towards clean technologies. These R&D subsidies can be reduced over time as the market for clean technologies grows and private innovations continue to generate further clean technologies.

2.2 Empirical evidence using patent data

In recent years, many studies have investigated empirically the impact of environmental policy on innovation. These econometric studies face several methodological challenges. First, since data on environmental R&D are generally not available, there has been some discussion on how to measure technological innovation. In recent years, patent data have become very popular simply because they provide a rich set of information and are becoming increasingly available. Hence, in this review we focus specifically on these studies using patents data.[8] A second challenge in these studies is to find an indicator of the stringency of environmental policy.[9] A few studies use data on Pollution Abatement Cost Expenditures (PACE), measuring expenditures for achieving compliance, to capture the stringency of environmental policy. A main problem with this measure is that it might suffer from endogeneity issues, since these expenditures tend to reflect the industry response to environmental policy (Rennings, 2000). Jaffe and Palmer (1997) find a significant correlation at the industry level between PACE and general R&D expenditures, but not with patents. Looking more specifically at environmental patents, Lanjouw and Mody (1996) find a positive effect of PACE on patenting. More recently, Hascic et al. (2008) estimate the effects of PACE on environmental innovations (air pollution, water pollution, waste disposal,

[8] As an alternative to patents, Jaffe and Palmer (1997) use (general) R&D expenditures and Newell et al. (1999) use data on the introduction of new products.

[9] Ideally, one would like to use data on the shadow prices of policies, i.e. the costs of environmental regulation imposed on firms as reflected in new technologies adopted (costs of compliance less energy-saving benefits from the adoption of the new technology). These data, however, are not available.

noise protection and environmental monitoring) for a panel of 16 countries between 1985 and 2004. They find that private expenditures on pollution control lead to higher innovation, but not government expenditures.

Other studies have looked at specific instruments. De Vries and Withagen (2005) and Dekker et al. (2009) model the stringency of environmental policy using dummy variables controlling for the enforcement of international environmental protocols for SO_2 emissions reductions. Looking at patents applications of 15 countries over 1970-1997, Dekker et al. (2009) find that international environmental protocols foster technological innovations and knowledge transfers. Popp (2006) looks at the effects of national regulatory standards on patents data for NO_x and SO_2 abatement technologies in the US, Japan and Germany over the 1970-2000 period. He finds that innovation is largely affected by domestic (but not foreign) regulation. Popp (2002) finds evidence that the filing of US patents is sensitive to changes in relative energy prices in particular between 1970 and 1994. High energy prices over the period contributed to foster innovation in fuel cells and in the use of waste as fuel or for heat production.

Finally, only a few papers have compared the impact of alternative – environmental and technology – policy instruments on innovation. These types of studies are scarce since estimating the differential impact of policy instruments implies high data requirements (Vollebergh, 2007). Studying the case of renewable energy, Johnstone et al. (2009a) use data on six different policy types, namely R&D support, investment incentives, tax incentives, tariffs incentives (feed-in tariffs), voluntary programs, obligations and tradable certificates for a panel of 25 countries over the 1978-2003 period. Their dataset includes continuous variables for three types of policy measures, namely R&D support, feed-in tariffs and renewable energy certificates. For other policy types, they use dummy variables to capture the introduction of the measures. Their results show that quantity-based policy instruments (obligations, tradable quotas) are most effective in stimulating innovations that are closely competing with fossil fuels, such as wind energy. More targeted subsidies, such as feed-in tariffs, are most effective for innovations in more costly technologies such as solar energy. Finally, for the specific case of energy efficiency in the building sector, Noailly (2009) in a companion paper related to this study estimates the impact of three main types of policy instruments – regulatory energy standards in building codes, energy taxes and specific governmental energy R&D expenditures – on patenting activities. The estimates for seven European countries over the 1989-2004 period imply that a strengthening of 10% of the minimum insulation standards for walls would increase the likelihood to file additional patents by about 3%. In contrast, energy prices have no significant effect on the likelihood to patent. This result is mainly explained by very low energy prices over the 1989-2004 period. Another potential explanation is the fact that economic incentives may have a lower effect in the building sector than in other sectors, due to the presence of split-incentives of principal-agent types of issues.[10] Governmental energy R&D support has a small positive significant effect on patenting activities.

At last, there is some scarce empirical evidence that the design – more than the type – of policy instruments matters for innovation. Johnstone and Hascic (2008) find that the flexibility of policy instruments, i.e. whether the instruments offer many options for achieving compliance or not, can help to create broader markets for innovation. In particular, environmental patents of countries with 'flexible' policy regimes are more internationally diffused (i.e. tend to be filed in a larger number of countries) than patents of countries with a less flexible policy regime. They argue that regulations that tend to be too prescriptive, such as technology-standards, can result in fragmented technology markets with a high level of national specialisation. Here again, the design of instruments (flexibility) matters more than the type (command-and-control or market-based). Well-designed performance standards can present the same advantages as market-based instruments. Finally, Johnstone et al. (2009b) find that uncertain and unstable environmental policy can serve as a brake on innovation. They use responses from CEO's in a survey from the World Economic Forum to measure the continuity and stability of environmental policy in different countries. Using patent data, they present preliminary evidence supporting the hypothesis that environmental policy uncertainty can result in less innovation in environmental technologies. For a given level of average policy stringency, the more 'unstable' a policy regime, the less innovation takes place.

[10] The builder (agent) decides on the energy efficiency level of a building, while the consumer living in the building (principal) is the one actually paying the bill.

3 Public policies promoting energy efficiency in the Dutch building sector

This section describes the evolution of public policies related to energy efficiency in the Dutch building sector over the last 30 years. Section 3.1 reviews the general trends in environmental policy. Section 3.2 describes the main policy measures related to energy efficiency in buildings. Section 3.3 reviews specific innovation policy.

3.1 General trends

There is a close correlation between the stringency of environmental policy and the level of environmental awareness in the public opinion. The 'greener' the public opinion, the more the government tends to spend on environmental protection and vice versa. As an illustration, Figure 3.2 plots the evolution of membership at 'Natuurmonumenten', a leading environmental organization in the Netherlands, and the evolution of the share of environmental expenditures in total governmental expenditures over the 1990-2007 period.[11]

Environmental awareness increased in the mid-1990s due to growing fears of greenhouse effects and rising economic growth (Van Zanden and Verstegen, 1993).[12] In parallel, governmental environmental expenditures also increased steadily over the 1990s. This period corresponds to the introduction of the three National Environmental Plans in 1989, 1993 and 1998. The interest for environmental issues fell slightly at the beginning of the year 2000, as shown by the slight drop in membership at Natuurmonumenten in Figure 3.2.[13] Yet, a decline in governmental environmental expenditures occurs only after 2002. Expenditures still increased between 2000 and 2002, due mainly to the increasing demand for green energy subsidized through an exemption of the energy tax (REB) and due to other fiscal measures (EIA and EPR). After 2002, governmental environmental expenditures decreased as the result of the suspension of several fiscal measures. The Dutch government justified the revision of these measures by a need towards greater efficiency of environmental policy. At last, climate change experiences a renewed interest in the media after 2005, notably with the broadcasting of the documentary *An*

[11] Data on environmental governmental expenditures have been compiled since 1990 by the Natuur- and MilieuCompendium. Public environmental expenditures include 1/ direct expenditures from the Ministry of Housing, Spatial Planning and the Environment (VROM) from functioning expenditures (personnel, computers) and programs expenditures (financing of waste disposal), 2/ direct expenditures with a clear environmental dimension from other departments (Ministry of Economic Affairs), 3/ tax expenditures, 4/ indirect environmental expenditures.

[12] A spectacular television campaign by Natuurmonumenten in 1992 also explains the strong rise in membership in this year.

[13] There is some additional evidence for the decrease in environmental awareness in this period. According to the Natuur- en Milieucompendium, the percentage of Dutch people who find the protection of nature as 'very important' drops from 1997 to 2001. Similarly, the volume of gifts and donations for environment and nature reaches a peak in 1999-2000 and drops slightly afterwards.

Inconvenient Truth by Al Gore and the publication of the *Stern Report on Climate Change*. The number of members at 'Natuurmonumenten' stops declining and reaches a stable level, while governmental expenditures on environment protection increase again slightly after 2005 and tend to stabilize afterwards.

3.2 Specific environmental policy instruments

Figure 3.2 gives an overview of policy measures related to improving energy efficiency in buildings over the last decades.[14] Although many of these policy instruments were not initially implemented with the objective of stimulating technological innovation, all these measures affect the development of new technologies. An energy tax makes it less profitable to invest in 'dirty' technologies, while a subsidy for energy-efficient technologies and an energy standard for buildings increase the market size for these types of technologies. The abbreviations used in Figure 3.2 are reported in Table 5.1 in the Appendix. This historical overview has been constructed by consulting a large range of policy documents.[15] Some of the main recent instruments, such as the Energy Performance Norm (EPN) and the energy tax (REB) are described briefly in Table 3.1. According to an evaluation by Joosen et al. (2004), the energy tax has had the largest impact on reducing CO_2 emissions in the building sector over the 1995-2002 period. Figure 3.2 shows the year of introduction and removal of every instrument, but not the years of revision or reforms of the policy measures. The EPN was for instance strengthened at several occasions since 1996 and the EIA was also revised in 2001.

Several features emerge from the historical overview given in Figure 3.2. First, environmental policy in the building sector follows as expected the general trends described in Section 3.1. There is an intensification of environmental policy in the mid-1990s, as shown by the increase in the number of policy measures in this period. In 1996-1997, several major instruments (REB, EPN, EIA) are introduced almost simultaneously. The mid-1990s also mark a clear shift away from direct subsidies towards a broader portfolio of instruments (including taxes and energy performance standards). In particular, the introduction of the EPN and REB in 1996 represents an important step towards more flexible types of instruments. The EPN replaces previous technology standards (setting for instance a minimum on the level of insulation of a buildings) by an energy performance standard (the energy performance of a building can be improved through a broad range of technologies) . After 2001-2002, several fiscal measures are removed or revised (notably EIA in 2001, EPR in 2003, REB in 2004).

[14] The overview is as comprehensive as possible given the policy documents available.The overview does not include measures specific to energy-saving measures for appliances, since we do not look at technological innovations for home appliances. The overview also exclude information instruments, such as information campaigns to increase consumer's awareness.

[15] See for instance Oudshof et al. (1997), Heijnes and De Jager (1999), Joosen et al. (2004).

A second feature of this general picture of environmental policy in the Dutch building sector is the large number of short-term policy initiatives. Over the 1980s and 1990s, a large number of different subsidy programs were implemented successively for short periods of time. This improves slightly after the mid-1990s, since most of the instruments introduced in that period are still in place today (although these instruments have also been frequently revised in the last decade). As an illustration, Table 3.2 compares the number and average length of financial policy measures (taxes and subsidies) introduced over the 1991-2005 period in the residential sector across several countries. The Netherlands introduced 16 financial instruments over the 1991-2005 period, compared to 10 in Germany and only 4 in Denmark and Austria. On average, financial policy instruments in the Netherlands were removed after 7.2 years, against 13.5 years in Austria and 7.7 years in Denmark and Germany.

A large number and frequent changes of policy instruments might affect the transparency and stability of environmental policy. In turn, an unstable policy framework may have nefast consequences for innovation. Since investments in R&D tend to be large and irreversible, firms may prefer to wait until future costs or benefits of developing new technologies are known. When there is too much uncertainty about future policies, firms will postpone their long-term risky investments in innovative activities.[16] Some first empirical evidence on the negative effect of policy instability has been given by Johnstone et al. (2009b), as discussed in Section 2. Table 3.2 gives the scores of various countries at the Environmental Policy Transparency and Stability Index developed by the World Economic Forum and as reported in Johnstone et al. (2009b). The index reflects how CEO's in every country perceive the stability of environmental policy in general. The Netherlands reach a score of 5.38, on a scale from 1 (confusing) to 7 (transparent and stable), which is far better than countries as China (3.75) and Russia (3.23) but also better than a large range of developed countries such as the United States (4.85) or UK (5.23). Yet, the Netherlands score below Scandinavian countries, Germany, Austria and Switzerland, which exhibit a high level of transparency and stability of environmental policy.

Since a confusing and frequently changing policy framework may come at the cost of innovation, the government has clear incentives to behave in a predictable manner and to commit itself to policies for a relatively long time period. Different policy instruments may send different signals to firms about the permanence of the instruments. Barradale (2008) shows for instance that investors in the renewable energy sector perceived that regulatory standards were more likely to stay in effect long enough to influence long-term investment decisions than depreciation rules, tax credits, feed-in tariffs or production subsidies.

At last, another feature of environmental policy in the Dutch building sector is that many

[16] The role of uncertainty on long-term investments has been studied in the option value literature. See Pindyck, 2007 for a general discussion of the role of uncertainty in environmental economics.

important instruments were introduced simultaneously. This makes it very difficult to evaluate the effectiveness of the different measures. In econometric modelling, this leads to identification issues and high data requirements (Vollebergh, 2007). In particular, the EPN, EIA/EINP and REB were all introduced within a few years for similar environmental goals. Within the specific field of energy efficiency in buildings, they all target the same technologies, making it empirically difficult to estimate a differential impact. Nevertheless, evaluating the effectiveness of policies is important since the costs of inefficient policies can be very high. This raises the question of how the design of policies could be improved to facilitate subsequent evaluation. One option is to use policy experiments to gather knowledge about the effectiveness of instruments. Yet, as noted by Vollebergh (2007), policy experiments remain non-existent in the domain of environmental policy. The central idea of a policy experiment consists in measuring the differential impacts between a group of individuals of firms participating into the policy programme (the 'treated' group) and a very similar group of individuals or firms not-participating in the programme (the 'control' group). There are several ways to design policy experiments (see Cornet and Webbink (2004) for a discussion). As an example, a simple policy experiment could be to implement the policy first in one region of the country before extending it to other regions.

3.3 Innovation policy

Innovation policy – in the form of government R&D support for environmental innovation – can be a complementary instrument alongside environmental policy. In the Netherlands, government R&D expenditures on 'control and care of the environment' and 'production and rational utilization of energy' represent only a negligible share of total public R&D, namely: 1.2% and 2.2% of total government R&D spending in 2005, respectively (Eurostat, 2008).[17] [18] In addition, these shares have been decreasing over the 2000-2005 period by 18.1% and 7.3%, respectively.[19]

Government R&D support for environmental innovation can take either the form of direct financing of R&D by research organisations or subsidies to private sector R&D.

Public expenditures on energy R&D

In the Netherlands, public energy research is conducted by various research and academic institutes (50% of budget), universities (10%) and companies (40%). The Ministry of Economic Affairs finance energy R&D up to 90% of the total budget mainly in demonstration projects

[17] Eurostat uses GBAORD (Government Budget Appropriations or Outlays on R&D) data. This data is split according to'socio-economic objectives' (NABS Classification). These include the two groups of interest here: NABS03: 'control and care of the environment' and NABS05: 'production, distribution and rational utilisation of energy'. These groups do not include research financed from general university funds (NABS09).

[18] Average shares over EU-27 are 2.7% and 4.9%, respectively.

[19] By contrast, the annual average growth rates in the EU-15 over the same period were of 14.2% and 0.8% respectively.

through the existing Energy Transition program and the Innovation Agenda. Data on government energy technology R&D expenditures are collected by the International Energy Agency. Figure 3.3 gives the evolution of the total budget on energy R&D since the end of the 1970s. There is a clear declining trend over the period. In 2006, the budget for energy R&D falls to about 150 million euro.

The IEA data also include specific expenditures related to energy efficiency in buildings, covering the following categories: space heating and cooling, ventilation and lighting control systems, low energy housing design, new insulation and building materials, thermal performance of buildings and domestic appliances. In 2006, about 10% of the total energy R&D budget, so about 13 million euro, was spent on energy efficiency for buildings. This share increased slightly in the first half of the 1980s, declined until the mid-1990s and rose again after 1995 to reach a peak in 1999 and again in 2006 as shown in Figure 3.3.

Subsidies for energy R&D through the WBSO

The R&D Promotion Act (Law on the Stimulation of Research and Development - WBSO), introduced in 1994, provides a fiscal incentive for companies, knowledge centres and self-employed persons who perform R&D. Companies can get part of the wages of R&D personnel reimbursed by the Dutch government.[20]

Energy projects represent less than 10% of all WBSO projects. The share of energy projects has been slightly increasing from 6.2% in 2000 to 8.6% in 2005 (SenterNovem, 2007). Among these energy WBSO projects, projects related to energy efficiency in buildings represent 14% of firms' private spending on R&D (see Table 3.3). This share has increased over the 2000-2005 period, mainly due to a increasing number of innovation projects in the field of lighting technologies (SenterNovem, 2007). Finally, energy R&D is mainly conducted by large companies with more than 250 employees, which tend to be overrepresented in this sector.[21]

To sum up, the share of R&D expenditures spent on energy innovations in buildings has recently increased, both in public energy R&D expenditures and in projects financed by the WBSO. Yet, overall R&D support for environmental innovations remains very low in the Netherlands and represents a negligible share of governmental R&D support. As discussed in Section 2, there are theoretical arguments and empirical evidence underlying the importance of R&D subsidies for environmental innovations. For the case of energy efficiency in buildings, Noailly (2009) also finds a positive significant relationship betwen specific public R&D spending and the probability

[20] In general, the part covered by the Dutch government correspond to about 20% of the total wage costs (wage costs correspond in turn to about 60% of the total research costs). Firms get 40% of the costs reimbursed up to a threshold of 90756 euro, and 13% above this threshold.

[21] Large companies represent 65% of all private investment in energy WBSO projects, against 50% in all WBSO projects.

to patent in this field. This gives some support for policy options aiming to increase R&D sopport.

Here again, however, this raises the question of evaluating the effectiveness of different innovation policy programs. A common problem is the issue of ‘additionality’ of R&D subsidies, i.e. the fact that public money is given away to (‘free-riding’) firms that would have performed R&D even in the absence of subsidies. Jaffe (2002) gives several examples on how to design policy experiments for innovation subsidy schemes, hence allowing to compare the effects between a ‘treated’ group and a ‘control’ group. One way to do this is to create a threshold in the selection criteria for the subsidy. For instance, when only proposals above a certain quality are granted, it is then possible to compare the effects of the subsidy on the group just above the threshold (the treated group) and the group just below the threshold (the control group). Another option is to allocate the limited budget available for a subsidy scheme by using a lottery among all applicants (Cornet and Webbink, 2004).

Figure 3.1 Evolution of environmental awareness and environmental governmental expenditures in the Netherlands, 1990-2007

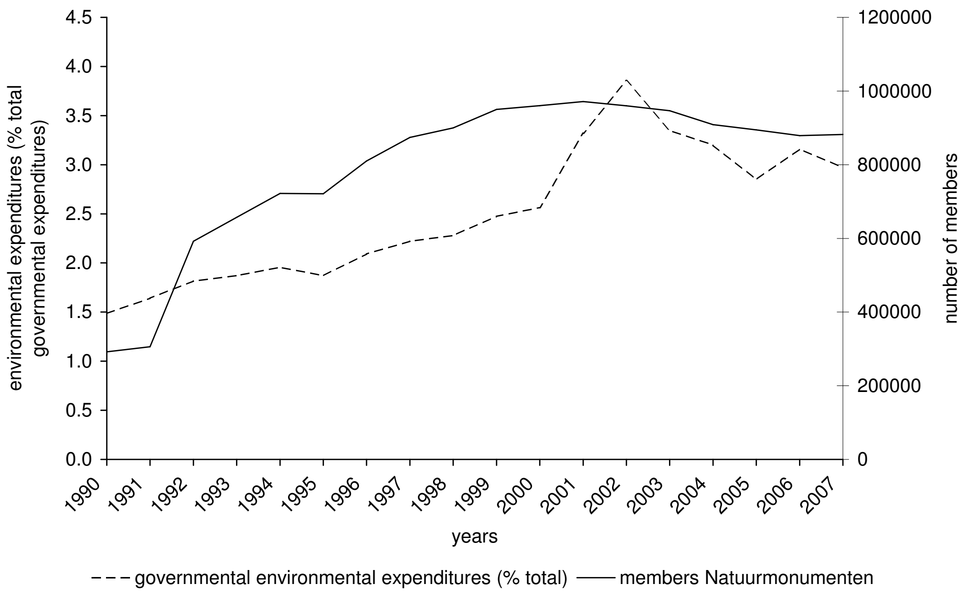


Table 3.1 Description of the main policy instruments

Type	Name	Description	Contribution to CO_2 emissions reductions [a]
Standards and norms	Energy Performance Norm (EPN) 1996-present	The EPN relies on the calculation of the energy performance coefficient (EPC) of the building, which includes all energy features of the building itself as well as the efficiency of its installation. The EPC is bounded to a certain maximum, such that a lower coefficient means better energy efficiency. When first introduced in 1996, the maximum value of the EPC for residential buildings was of 1.4. This maximum EPC was subsequently strengthened to 1.2, 1.0 and 0.8 in 1998, 2000 and 2006 respectively. Next to residential buildings, there are also specific EPCs for different types of non-residential dwellings.	0.3 - 0.5
Taxes	Regulatory Energy Tax (REB) 1996-present (called EB after 2004)	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. Originally, the tax was levied on the consumption of 'grey' energy only, i.e. gas and electricity produced from fossil fuels. From 2004 on, the tax exemption for green energy has been removed. The tax has been regularly increased over the years.	0.9 - 3
Fiscal incentives	VAMIL 1991-present	The VAMIL program allows an accelerated depreciation of investments in environmentally-friendly technologies, resulting in lower interest payments and improved liquidity for firms.	0.1-0.7 (EIA/EINP/VAMIL)
	EIA 1996-present	The EIA program 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 a yearly basis. Figure 5.1 in Appendix gives the evolution of the number of applications for EIA for a selected set of technologies relevant for energy efficiency in buildings. A large number of applications concerned Heat and Cold distribution technology (heat pumps and CHP). The Energy List was revised in 2001 and the number of eligible technologies was restricted. The revision aimed to improve the efficiency of the program and to limit the percentage of free-riders. The EINP program is the equivalent of EIA for the non-profit sector.	
Subsidies	MAP 1991-2000	The Environmental Action Plan (MAP): MAP-I (1991-1993), MAP II (1994-1996) and MAP-III (1997-2000) provided subsidies for various energy-saving equipment and appliances in residential and non-residential buildings. According to Joosen et al. (2004), MAP contributed greatly to the development of high-efficiency boilers and energy-saving lightings.	0.7-0.9
	EPR 2002-2003	The Energy premium for existing dwellings subsidised the advice given to improve the energy efficiency of a house and partially financed the energy-saving measures. In 2003, a large number of appliances were removed from the list.	0.2
Voluntary agreements	MJA 1992-present	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.	0.1

[a] Based on the calculations by Joosen et al. (2004). Contribution to CO_2 emissions reductions over 1995-2002 (Mton).

Figure 3.2 An overview of policy measures inducing energy-efficient innovations in buildings, 1977-2006

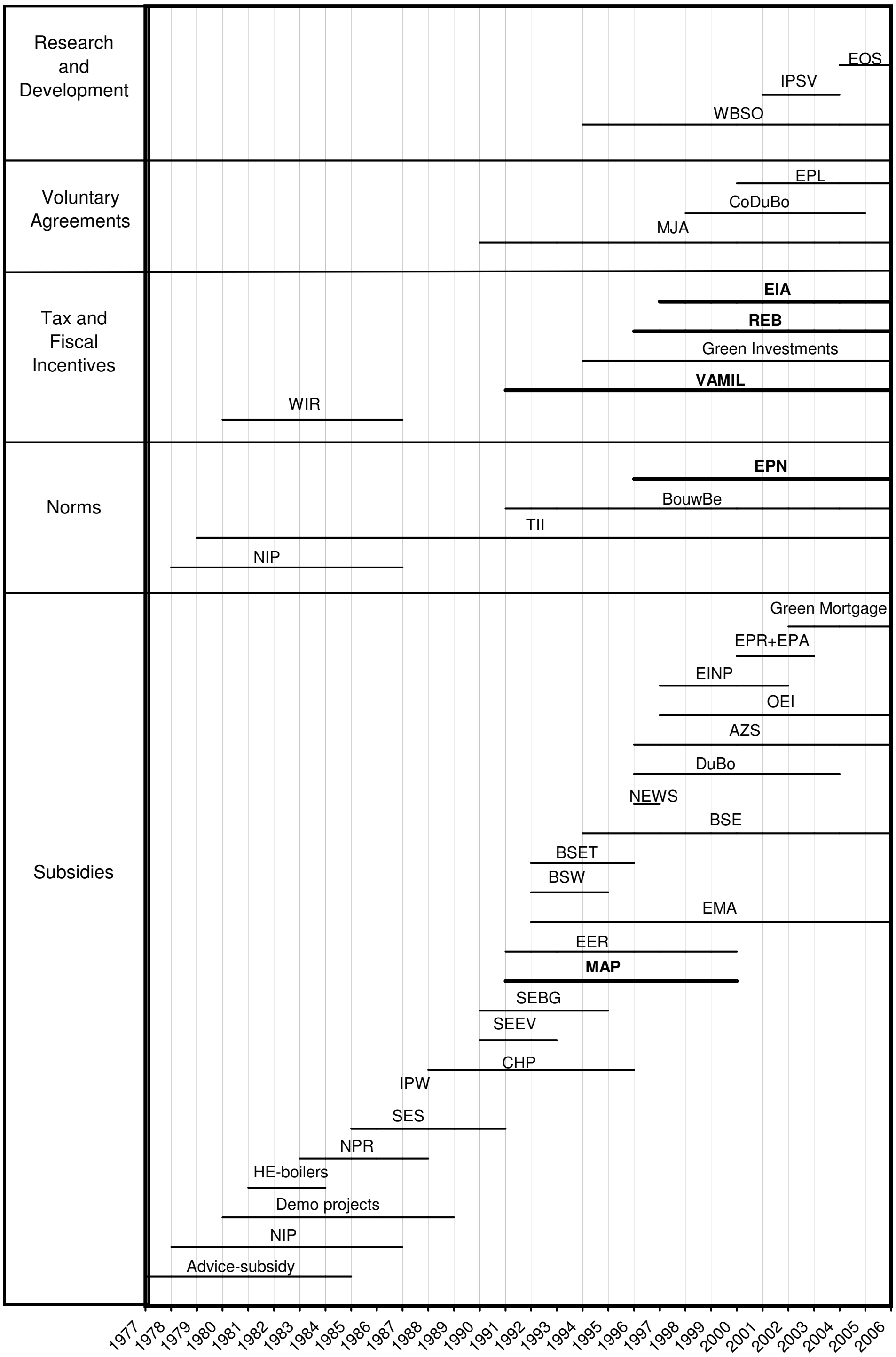


Table 3.2 Number and average length of financial instruments introduced in the residential sector over the 1991-2005 period

	(1) Number of financial instruments	(2) Average length of financial instruments
Austria	4	13.5
Denmark	4	7.7
Germany	10	7.7
Netherlands	16	7.2

Columns (1) and (2) report the number of and average length (in years) of financial policy instruments (tax, subsidies, fiscal incentives) promoting energy efficiency in the residential sector introduced over the 1991-2005 period. Source: MURE database (www.mure2.com). See Table 5.2 in Appendix for a detailed overview of the measures.

Table 3.3 Stability of environmental policy regimes

Country	WEF Stability index
Sweden	6.02
Finland	5.98
Switzerland	5.95
Singapore	5.93
Denmark	5.73
Norway	5.65
Austria	5.63
Germany	5.57
Netherlands	5.38
Japan	5.33
Canada	5.25
UK	5.23
France	5.18
Tunisia	5.14
Australia	5.08
New Zealand	5.03
United States	4.85
Belgium	4.48
Spain	4.45
Italy	4.03
China	3.75
India	3.75
Russian Federation	3.23

The table reports the indicator of the stability of environmental policy as assessed by the respondents at the World Economic Forum survey, 2001-2006. The scale of the Environmental Policy Transparency and Stability Index range from 1 (=confusing and frequently changing) to 7 (= transparent and table). Johnstone et al. (2009b)

Figure 3.3 Government energy R&D budgets, Source: IEA

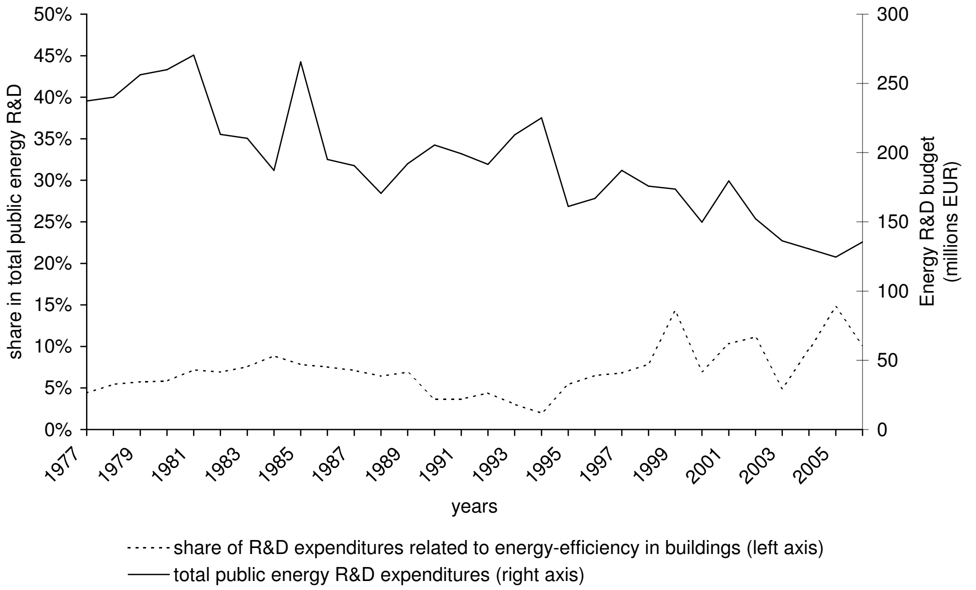


Table 3.4 Distribution of WBSO energy projects per energy field

	2000	2003	2004	2005
Share energy projects in WBSO	6.2%	9.1%	9.0%	8.6%
Total R&D costs on energy projects	163.7	247.9	251.8	247.6
- of which publicly financed	16.7	26.8	28.7	26.7
- of which privately financed	147	221.1	223.1	220.8
Share private financing per energy field				
Energy efficiency				
- in buildings	10%	12%	13%	14%
- in industry	43%	29%	28%	26%
- in transport	7%	7%	6%	7%
- in others	4%	4%	8%	7%
Energy generation	14%	12%	12%	11%
Renewable energy	12%	10%	11%	12%
Fossil fuels	10%	25%	24%	24%

The share of private financing is calculated as the total costs of the WBSO projects (60% personnel costs, 40% other costs) minus the public financing part (percentage fiscal advantage WBSO x 81% of personnel costs).

4 Innovations for energy-efficient buildings

4.1 Construction of the patent dataset

This section describes the construction of the dataset on environmental patents related to energy efficiency in buildings. We use patent counts to measure innovations related to energy efficiency in buildings. There is substantial evidence and a growing consensus in the literature that patent counts provide a good indication of innovation activity (OECD, 2009). Patents have a close (if not perfect) link to invention. Patents are strongly correlated with other indicators of innovative activity such as R&D expenditures or new product introductions (Griliches, 1990; Comanor and Scherer, 1969; Hagedoorn and Cloodt, 2003). In addition, patents provide a lot of information on the technological content, the inventor or the geographical location. For these reasons, patents have become extensively used in recent years in empirical work related to technological innovation. Working with patents requires, however, careful interpretation. Not all inventions are patented, as for strategic reasons firms may prefer not to disclose some valuable information in a patent. Also, the value of patents is very heterogeneous: only few patents will lead to successful commercial applications, while many will in the end never be used. Finally, patents reflect the actual 'invention' and are thus more likely to reflect product and end-of-pipe technologies, rather than process innovations. The *OECD Patent Manual* provides a useful description of existing patent systems, as well as guidelines on how to work with patent data (OECD, 2009).

Patents are granted by national offices in individual countries. Protection is then valid in the country granting the patent. If an inventor wants protection in other countries, he must file applications at the relevant national offices or by using the Patent Cooperation Treaty (PCT).[22] Next to patents filed at national offices, inventors can also file directly so-called European patents (EP) or international patents (WO) patents which give protection directly in a bundle of countries. An EP patent granted by a national patent office in Europe gives automatic protection in all member states of the European Patent Convention or Patent Cooperation Treaty. A WO patent is granted by the World Intellectual Property Organization (WIPO) and gives protection in the countries chosen by the applicants. Under PCT a patent can be protected in any of the 139 contracting states. These EP and WO patents have become increasingly popular over time and are nowadays standard.

The difference between patents filed at national offices and patents filed as EP or WO patents often reflect the value of the innovation. Applying for an EP or WO patent involves considerable costs and time. Firms will thus file as an EP/WO patent inventions that they consider as important and deemed to be profitable and applicable in other countries. In addition, for an EP/WO patent to be granted it has to go through an examination procedure. By contrast, patents

[22] In Europe, the European Patent Office also processes national applications.

applications filed at the Netherlands Patent Office (NPO) may be of lower value or quality than patents filed directly at EPO. There are two reasons for this: 1) filing a patent at the NPO is not very costly so that anyone can simply file a patent even though there are no commercial application, 2) there are no controls on the patents being filed at NPO, the only way to figure out if a patent has already been filed is during a law court. Nevertheless, these innovations may be worthwhile to look at in particular if they concern small and middle-size companies who are mainly active on the Dutch market.

In this study, we use EPODOC – the internal database of the EPO – to extract domestic and EP/WP patents applications from Dutch firms. Domestic applications are only available in a digital format from 1992 on, while EP and WO patent applications are available over the 1977-2006 period. We count the number of patent applications[23] per year in selected areas of environmental technologies in buildings classified by applicant country and priority date.[24]

To identify the relevant patents we used the help of technical experts from Ecofys and from the Netherlands Patent Office. Technical experts from Ecofys, a company offering research and consultancy services in the field of sustainable energy, 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 and keywords describing the technologies. Using this list of technologies, the International Patent Classification (IPC) codes 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 a challenging task since energy-efficient technologies in buildings touch upon a large number of diverse IPC classes. Patents on insulation, for instance, can be found in the IPC section of Fixed Construction, Chemistry and Metallurgy, Mechanical Engineering, as well as Performing Operations/Shaping (see Table 5.3 in Appendix). 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. The patent experts performed some extra checks on the dataset. [25]

[23] Patent applications are better suited to appraise the volume of inventive activity than granted 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 (Schmookler, 1954)

[24] We use the applicant's country of residence rather than the inventor's country of residence. This implies that patent counts include patents from filials of Dutch multinationals located abroad. Innovation from Philips in China is thus included in the dataset. Dutch inventors working for a foreign firm are, however, not considered (as would be the case if patent counts are classified by inventor's country). When sorting data per applicant's country of residence, one should keep in mind that: 1) multinational firms may have affiliates specialised in patent filing located in certain countries for fiscal reasons (this is in particular the case for Luxembourg) 2) countries with a high level of internationalisation of research activities will have a high number of patents (OECD, 2009).

[25] The following corrections were performed: 1) if a domestic patent was later filed as a EP patent, only the domestic patent was kept, 2) when a EP patent was later filed via PCT, only EP patents were kept – under the PCT, an inventor also features as an applicant in the patent information, which would lead to many double counting of patents. 3) if several EP patents with the same restricted family number contained exactly identical invention, only one was kept. 4) specificities of patenting activity by Dutch multinationals was accounted for. For instance, 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

Subsequently, patents were grouped within 8 different groups of technologies for the ease of further analysis, see Table 4.1. Some 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.

Table 4.1 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
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

4.2 Patenting activities in the Netherlands

4.2.1 General trends

Figure 4.1 gives the evolution of patenting activities by Dutch firms in the domain of energy efficiency in buildings over the 1992-2006 period, including both domestic and EP/WO patent applications.[26] The number of patents applications increases over the 1990s from about 50 patents per year at the beginning of the 1990s to about 150 patents per year after 2000. This represent about 0.02% of all patenting activities in the Netherlands.[27] The number of patents increases a few years before the simultaneous introduction in 1996 of the Energy Performance Norm (EPN) and the energy tax (REB). Innovation activities tend to stabilize after 2000 with the exception of a peak in 2004. After 2004, the number of patents falls back to 2001 levels. Looking at the distribution of domestic versus EP/WO patent applications, Figure 4.1 shows that

applications. In that case, 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.

[26] The data do not include domestic patent applications which were later filed as an EP/WO patent to avoid double counting.

[27] Since 2000, Dutch applicants file about 8000 patents per year as shown in Figure 4.1.

some substitution is taking place between domestic and EP/WO patents. The number of domestic applications at the Netherlands Patent Office declines after 1997, as these patents tend to be substituted away by EP/WO patents.

4.2.2 Patents by technological field

Figure 4.2 gives the distribution of patents by field of technology. Lighting technologies represent one-third of all patent applications over the 1992-2006 period. Insulation, HE-boilers and Heat and Cold distribution account for 21%, 18% and 11% of all energy patents in the Dutch building sector, respectively. There is an important difference, however, when we look at the source of patents filing as shown in Table 4.2. Insulation and HE-boilers technologies are highly represented in domestic patent applications. They represent 31% and 24% of all energy patents for buildings filed at the NPO. By contrast, lighting technologies represent 60% of all EP/WO patents in the field. The prominence of lighting technologies is mainly explained by large innovation activities by Philips. HE-boilers are the second most important technological field, representing 15% of EP/WO patents in this field.

Table 4.2 Distribution of patent applications per technological field and filing source

	Annual average NPO	Annual average EP/WO	Share in total NPO	Share in total EP/WO
Insulation and energy demand reduction	25.57	5.50	31%	7%
HE-boilers	19.07	10.40	24%	15%
Heat and Cold distribution and CHP	10.85	7.20	14%	10%
Ventilation	5.21	1.47	6%	1%
Solar energy and other RES	10.21	3.77	12%	5%
Lightings	5.71	44.97	7%	60%
Building materials	4.78	2.20	5%	2%
Climate control	0.57	0.73	1%	0%

All NPO patent applications over the 1992-2006 period.
All EP/WO patent applications over the 1977-2006 period. Here, the EP/WO patents also include domestic patents later filed as EP/WO patents.

Figure 4.3 plots the evolution of the number of patents for the main technological fields, while Figures 4.4 and 4.5 show the evolution of NPO and EP/WO patents on separate graphs. Several trends emerge from these figures. The technologies reach maturity in different years. Patenting activities in insulation, mainly domestic patent applications, reach a peak in 1997 and decline afterwards. Innovations in HE-boilers reach a peak around the year 2000 (both in domestic and EP/WO patent applications) and decline afterwards, with the exception of a peak in 2005. For Heat and Cold distribution (heat pumps and CHP), patenting activities tend to fluctuate over the years. After a slow increase, the number of patents stabilizes after 1999. Solar energy and other renewables are also characterized by many fluctuations. After being popular at the beginning of the 1980s, patents in this field increase until 1998, followed by a small decline (in particular in domestic applications) afterwards. After 2003, there is a renewed interest for solar technologies. Finally, patenting activities in lighting technologies increase sharply after 1997 (in particular in EP/WO types of patents) and reach a peak after 2003. The years of maturity of the different technologies are in line with the evolution in other countries. Noailly (2009) plots the same evolution of patents for a set of nine European countries. In all countries, patents in HE-boilers, insulation and heat and cold distribution all reach maturity at the end of the 1990s, while lighting technologies tend to reach maturity a few years later.

4.2.3 Innovating firms

As stated earlier, multinationals play an important role in Dutch innovation activities. Table 4.3 lists the top five of firms filing the largest number of EP/WO patents per technology group. As expected, large multinationals such as Philips, Shell and AKZO Nobel rank high. Organisations financed on public funds such as TNO and ECN are also active is certain fields, such as Heat and Cold distribution and solar energy. Table 4.4 reports the annual average number of firms filing patents in every technological group. The largest number of innovating firms is found in the field of HE-boilers, with about 10 innovating firms per year. Each firm patents on average 1 patent per year. As expected, there is a high level of concentration in the field of lighting technologies.

4.3 International comparison

This section compares the innovating activities of the Netherlands with other countries. Again, we only focus on the number of EP/WO patent applications across different countries, since these reflect the most valuable innovations (worth protection in a large set of countries and subject to strict examination by the EPO). Major innovating countries in energy-efficient technologies in buildings are Germany, the United States, Japan, France and the Netherlands.[28] Table 4.5 gives the top ten innovating countries over the eight technological fields. Germany accounts for 22% of all EP/WO patents in energy efficiency technologies in buildings. The Netherlands rank at the fifth position and account for 5% of energy patents in this field, which is relatively high for a small country. The strong position of the Netherlands, however, is mainly explained by the large number of patents in lightings technologies due to large innovation activities by Philips. When we exclude lightings technologies from the total number of patents, the Netherlands fall from the fifth to the eighth position.

Correcting patenting activities by unit of GDP, the Netherlands rank at the second position as shown in Table 4.6. Other top innovating countries are Switzerland, Germany and Scandinavian countries. Similar results emerge from Table 4.7, which gives the number of patent applications per unit of R&D expenditures for a set of European countries. This allows to compare the productivity of patenting activities accounting for countries' differences in innovation effort. With about 10 energy patents per R&D unit, the Netherlands achieve a higher innovation output per dollar of R&D expenditures than Germany, Austria and Scandinavian countries. Again, the high productivity of inventive activity in the Netherlands is mainly explained by the field of lighting technologies. Looking at the productivity of the Netherlands in other technological fields, the picture is more mixed. In the field of HE-boilers, Austria and Germany achieve more patents per dollar of R&D expenditure than the Netherlands. In the field of Heat and Cold distribution, Denmark, Germany, Austria and Finland also achieve higher inventive productivity than the Netherlands. Overall, in all other fields besides lighting technologies, the Netherlands tend to reach a middle-range position in Europe. Austria, Germany and Scandinavian countries produce more innovation per R&D unit across a broader range of technologies. This picture is confirmed in Tables 4.8 and 4.9, which give the ranking of major innovating countries for each group of technology. Germany is in the top five of innovating countries in almost all technological groups. Sweden, Austria and Denmark are in the top five in about half of the technology groups. The Netherlands rank first in lighting technologies and fourth in HE-boilers technologies. For other technologies, the Netherlands fall outside the top five of innovating countries.

[28] We only look at applications at the European Patent Office and at the WIPO. Patents from European countries are thus overrepresented. By contrast, the United States and Japan also file a large range of patents at the US Patent Office and Japanese Patent Office.

Figure 4.1 Total number of patents applications from Dutch applicants, 1992-2006

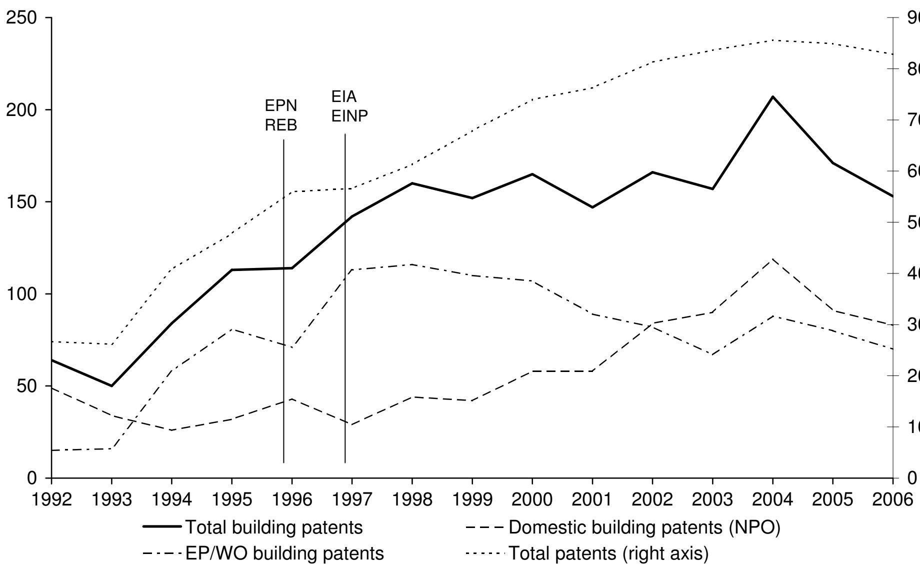


Figure 4.2 Share in total patents (NPO+EP/WO) 1992-2006, per technology field

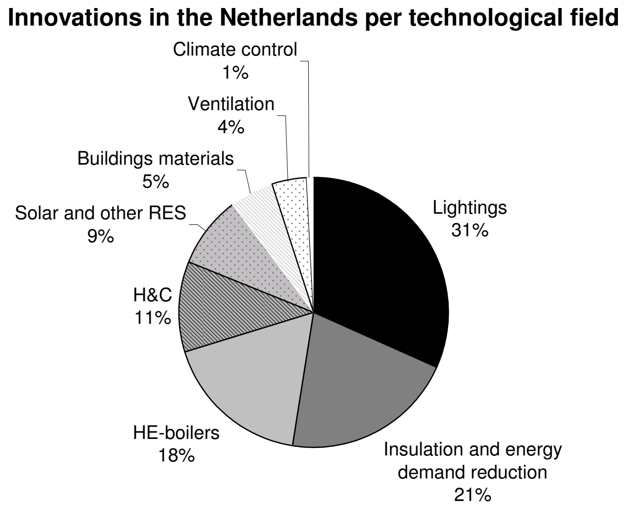


Figure 4.3 Total number of patents applications from Dutch applicants, 1992-2006, per technology field

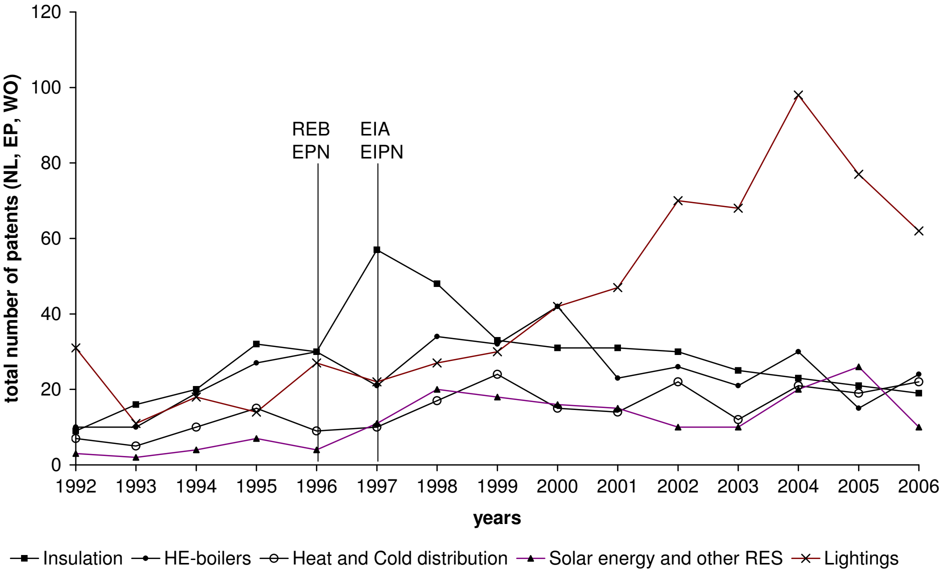


Figure 4.4 Evolution of the number of patents per technological field: a) NPO patents, 1992-2006, b) EP/WO patents (including initial NPO applications later filed as EP/WO), 1977-2006

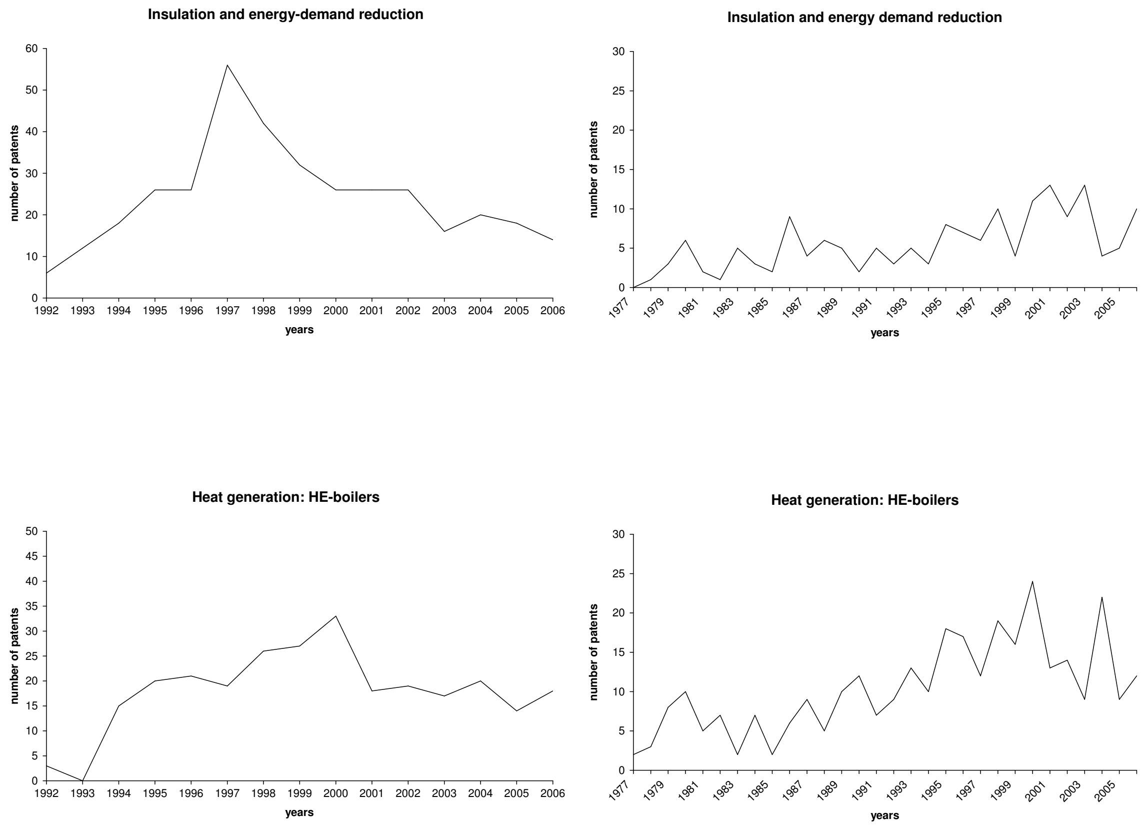
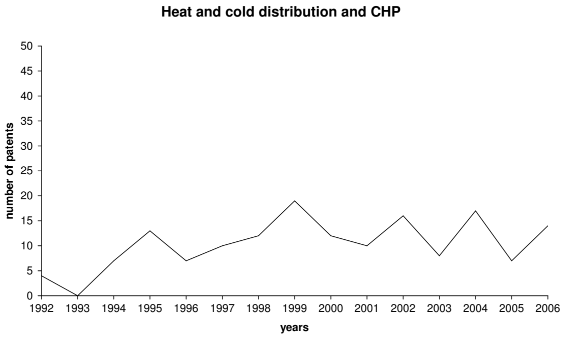
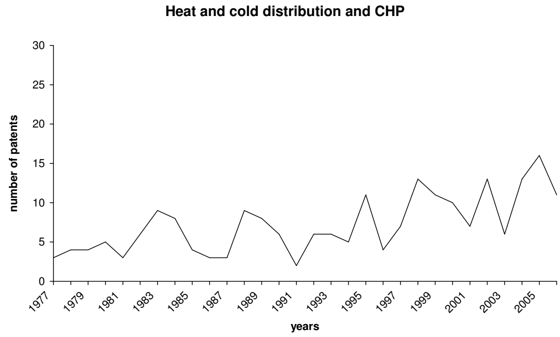
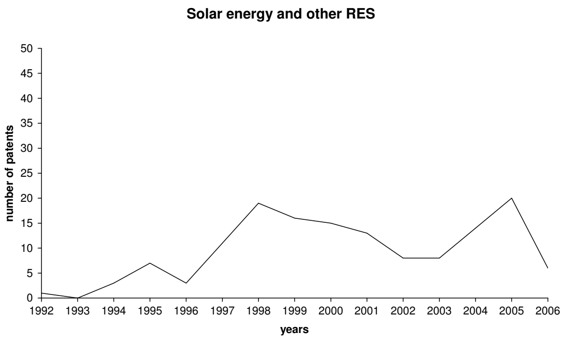
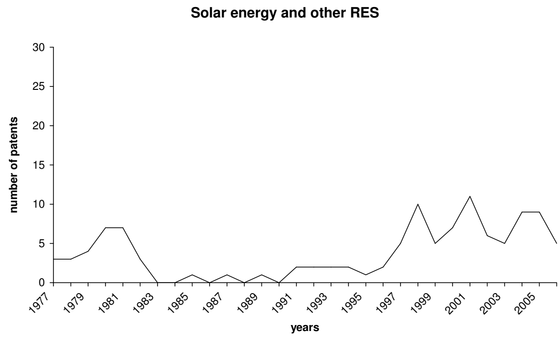


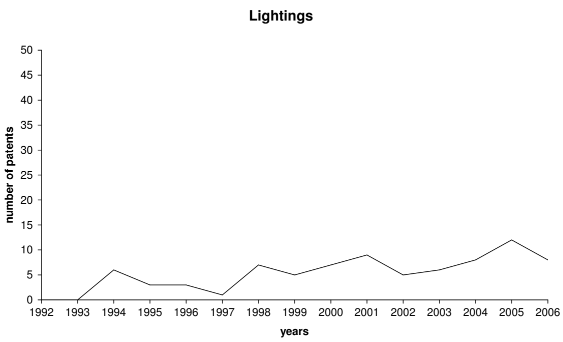
Figure 4.5 Evolution of the number of patents per technological field: a) NPO patents, 1992-2006, b) EP/WO patents (including initial NPO applications later filed as EP/WO), 1977-2006, (continued)











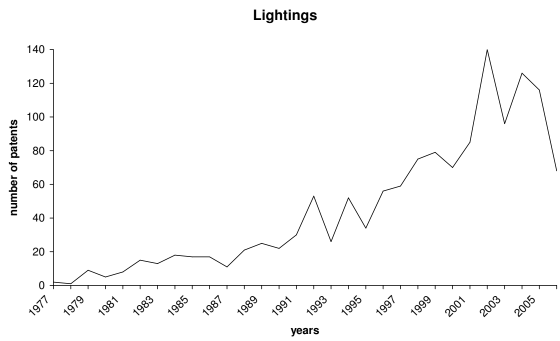


Table 4.3 Top innovating Dutch companies per technology group

Technology	Patent applicant	Total number of patents 1977-2006
Insulation and energy-demand reduction	MADO NEDERLAND	9
	KONINKLIJKE PHILIPS ELECTRONICS NV	9
	HUNTER DOUGLAS	9
	SHELL GROUP	6
	ISOBOUW SYSTEMS BV	4
HE-boilers	HONEYWELL BV	20
	SHELL GROUP	20
	KONINKLIJKE PHILIPS ELECTRONICS NV	19
	GASTEC TECH BV	10
	VAILLANT BV	10
Heat and Cold distribution and CHP	KONINKLIJKE PHILIPS ELECTRONICS NV	22
	AKZO NOBEL NV	15
	SHELL GROUP	12
	TNO	11
	VAILLANT BV	7
Ventilation	KONINKLIJKE PHILIPS ELECTRONICS NV	4
	STORK GROEP	2
	GASTEC TECH BV	2
	INNOSOURCE B V	2
	BAAS LAURENS JAN	2
Solar energy and other RES	KONINKLIJKE PHILIPS ELECTRONICS NV	22
	AKZO NOBEL NV	7
	ECONCERN BV	4
	INVENTUM B V	4
	ENERGIEONDERZOEK CENTRUM NEDERLAND (ECN)	3
Lightings	KONINKLIJKE PHILIPS ELECTRONICS NV	1543
	FLOWIL INT LIGHTING	40
	HUGHES AIRCRAFT CO	11
	NXP BV	3
Building materials	JAMES HARDIE INT FINANCE BV	3
	TNO	3
	BALLAST NEDAM GROEP NV	2
	ECOTHERM BEHEER B V	2
	LENTEN HENDRIK	2
Climate control systems	KONINKLIJKE PHILIPS ELECTRONICS NV	20
	WHIRLPOOL EUROP	1
	FERRO TECH BV	1
	RETTIG ICC B V	1
	FERRO ELECTRONIC BV	1

Table 4.4 Average number of innovating firms filing EP/WO patents, 1977-2006

Technology	Average number of firms 1977-2006	Average number of patents per firm 1977-2006
Insulation and energy demand reduction	5.10	1.07
Heat generation: HE-boilers	9.13	1.18
Heat and Cold distribution and CHP	5.97	1.39
Ventilation	1.67	0.82
Solar energy and other RES	3.27	1.17
Lightings	3.80	14.80
Building materials	2.30	0.78
Climate control systems	0.57	0.82

Table 4.5 Top ten patenting countries in energy-efficient innovations in buildings (EP/WO patent applications), 1977-2006

Country	Total number of patents 1977-2006	Share in total 1977-2006	Annual average
Germany	9348	22%	311.6
United States	8615	21%	287.2
Japan	5653	14%	188.4
France	2589	6%	86.3
Netherlands	2287	5%	76.2
United Kingdom	1891	5%	63.1
Italy	1577	4%	52.6
Switzerland	1302	3%	43.4
Sweden	1011	2%	33.7
Korea	932	2%	31.1

Including EP/WO patents which were first filed as a domestic application.

Table 4.6 Top 10 patenting countries in innovations in buildings (EP/WO patent applications) per unit of GDP, 1977-2006

Country	Annual average per unit of GDP	Annual average
Switzerland	21.06	43.4
Netherlands	18.98	76.23
Luxembourg	16.92	2.99
Germany	16.5	311.6
Sweden	16.28	33.7
Denmark	13.01	18.5
Austria	12.38	25.6
Finland	9.52	10.96
Norway	7.15	9.9
France	6.55	86.3

The table gives the annual average number of patents applications for energy-efficient innovations in buildings during 1977-2006, classified by applicant country, and normalized by country's GDP (in trillions of US dollars using 2000 prices and PPP. Source: OECD).
Fiscal regulations make it attractive for firms to file applications in Luxembourg. This may explains the high ranking of the country.

Table 4.7 Number of EP/WO patent applications per dollar of R&D expenditures

Country	Total	Insulation	HE-boilers	H&C	Ventilation	Solar	Lightings	Build Mat	Climate Control
Austria	7.90	2.38	1.47	1.16	0.06	0.71	1.31	0.75	0.14
Belgium	2.64	0.84	0.61	0.33	0.06	0.19	0.33	0.25	0.05
Germany	7.42	1.49	1.58	1.26	0.19	0.62	1.66	0.42	0.23
Denmark	7.29	2.08	0.99	1.65	0.42	0.44	0.56	0.73	0.47
Finland	4.89	1.11	0.62	1.06	0.44	0.38	0.45	0.85	0.04
France	3.17	0.73	0.85	0.59	0.11	0.21	0.41	0.19	0.10
United Kingdom	2.77	0.41	0.55	0.56	0.10	0.17	0.59	0.24	0.16
Ireland	4.38	0.47	1.30	1.03	0.08	0.45	0.68	0.26	0.16
Netherlands	10.96	0.80	1.48	1.05	0.22	0.48	6.55	0.32	0.11
Norway	5.05	1.51	0.63	1.03	0.26	0.57	0.42	0.62	0.05
Sweden	5.45	0.90	1.03	1.18	0.52	0.35	0.57	0.75	0.20

Gross domestic expenditures on R&D, in billions USD using PPP and 2000 prices. Source: OECD.

Table 4.8 Top ten patenting countries in the period 1977-2006 per technology area, based on the number of EP/WO patent applications per unit of GDP

Country	Annual average per GDP unit	Annual average
Insulation and energy-demand reduction		
Luxembourg	5.41	1.07
Switzerland	4.09	8.47
Austria	3.59	7.33
Denmark	3.52	4.87
Germany	3.24	61.03
Sweden	2.84	5.80
Norway	2.25	3.10
Finland	2.17	2.47
France	1.49	20.03
Netherlands	1.44	5.50
HE-boilers		
Switzerland	5.57	11.47
Germany	3.53	65.33
Sweden	2.95	6.17
Netherlands	2.74	10.40
Austria	2.31	4.63
Denmark	1.87	2.73
France	1.72	22.17
Luxembourg	1.38	0.27
Ireland	1.29	1.13
Italy	1.27	17.60
Heat and Cold Distribution and CHP		
Sweden	3.80	7.97
Switzerland	3.67	7.53
Denmark	3.12	4.53
Germany	2.82	52.47
Luxembourg	2.20	0.43
Finland	2.03	2.30
Netherlands	1.93	7.20
Japan	1.85	58.20
Austria	1.82	3.70
Norway	1.40	1.97
Ventilation		
Sweden	1.42	2.90
Finland	0.81	0.97
Switzerland	0.78	1.57
Denmark	0.67	0.93
Germany	0.40	7.33
Netherlands	0.37	1.47
Norway	0.32	0.40
Korea	0.31	2.70
Australia	0.25	1.07
Luxembourg	0.24	0.07

Table 4.9 Top ten patenting countries in the period 1977-2006 per technology area, based on the number of EP/WO patent applications per unit of GDP (continued)

Country	Annual average per GDP unit	Annual average
Solar Energy and other RES		
Luxembourg	4.37	0.57
Switzerland	2.33	4.80
Germany	1.56	28.57
Austria	1.16	2.33
Sweden	1.14	2.33
Australia	1.12	5.20
Netherlands	0.98	3.77
Norway	0.88	1.17
Denmark	0.79	1.10
Finland	0.73	0.80
Lightings		
Netherlands	10.78	44.97
Germany	3.55	70.23
Switzerland	2.08	4.43
Japan	2.07	65.50
Austria	2.06	4.60
Sweden	1.49	3.13
Luxembourg	1.28	0.23
United Kingdom	1.04	13.33
Denmark	1.03	1.53
US	1.02	87.23
Building Materials		
Switzerland	2.18	4.40
Sweden	2.15	4.37
Luxembourg	2.04	0.33
Finland	1.68	1.97
Austria	1.14	2.40
Denmark	1.13	1.53
Australia	1.02	4.70
New Zealand	0.92	0.80
Germany	0.91	17.30
Norway	0.87	1.20
Climate Control Systems		
Denmark	0.88	1.27
Sweden	0.51	1.03
Germany	0.50	9.33
Switzerland	0.37	0.73
United Kingdom	0.27	3.50
Austria	0.21	0.47
France	0.19	2.57
Netherlands	0.18	0.73
Ireland	0.17	0.13
US	0.16	13.53

5 Conclusions and implication for policy

This study provides a case study of policies inducing energy-efficient innovations in the Dutch building sector. Technological innovations with respect to insulation technologies, high-efficiency boilers or energy-saving lightings can greatly contribute to reduce carbon emissions from buildings. There is thus a great interest in understanding the role of public policies in stimulating energy innovations.

A general result of the economic literature is that environmental policy has an impact on the rate and direction of technological change. A strong case has been made in the literature for the use of market-based instruments (e.g. taxes, subsidies) rather than command-and-control instruments (e.g. technology and performance standards) to induce innovation. Regardless the type of policy instruments, however, recent work emphasizes the importance of environmental policy design (e.g. in terms of flexibility, stability, targeting) on the incentives to innovate. In addition, recent theoretical work also advocates the implementation of a portfolio of policy measures, combining both environmental and technology policy instruments.

A historical review of policy initiatives inducing energy-efficient innovations in the Dutch building sector shows that Dutch environmental policy intensified in the mid-1990s and slowed down after 2001-2002. Subsidies and fiscal incentives have been widely used over the last thirty years, although there has been a diversification in the type of policy instruments since the mid-1990s, in particular with the introduction of the energy tax and the energy performance standard for buildings (EPN). A striking feature of environmental policy in this sector, however, is the large number of different policy programs implemented successively for shorts periods of time. These frequent policy changes and revision of instruments might affect the stability and continuity of the policy framework. Finally, R&D expenditures for environmental innovations in general and for energy innovations in buildings in particular are relatively low in the Netherlands

Regarding the level of innovation, Dutch firms file on average about 150 patents applications per year in technologies related to energy efficiency in buildings. The Netherlands have a clear comparative advantage in the field of energy-saving lighting technologies. High patenting activities by Philips explain the predominance of the Netherlands in this field on the international market. Yet, although Philips benefits from Dutch innovation policy, a large part of these patenting activities are likely to be driven by developments on the international market rather than by national environmental policy. High-efficiency boilers represent the second most important group of innovations in this field. Overall, however, other countries, notably Germany, Austria and Scandinavian countries exhibit higher levels of innovation than the Netherlands in a broader set of technologies.

This case study suggests several lessons for policies aiming to induce technological innovations. First, one of the basic lesson that follows from the literature is that, regardless of the type of instruments, the stringency of environmental policy matters for innovation. In the companion paper directly related to this study, Noailly (2009) finds evidence that countries with more stringent regulatory standards achieve higher levels of patenting activities than countries with less stringent regulations. Although the cross-country study does not find any significant effect of energy prices on innovation, this is mainly due to very low energy prices over the 1990s. A primary option for the government to stimulate energy innovation is thus to further increase the stringency of environmental policy.

Second, there is some growing evidence that the design of policy instruments is of great importance for the effectiveness of policies. As underlined in this study, Dutch environmental policy has been relatively unstable over the last decades. Such instability might slow down innovation efforts. Indeed, firms making plans for long-term R&D investments may prefer to wait until more is known about the potential future costs and benefits – depending on future policies – of these investments. Obviously, policy changes may be necessary for some good reasons, for instance when additional information becomes available. Nevertheless, the government should be aware that such changes come at a cost. Different policy instruments may send different signals to firms about the permanence of the instruments. For instance, regulatory standards or taxes are less likely to be affected by governmental budget constraints than subsidies. The overall conclusion is that the government should behave in a predictable manner in order to induce technological innovation.

Third, there is some room to increase R&D support. There are many theoretical arguments and empirical evidence in the literature for combining stringent environmental policy with R&D subsidies.

As a final remark, we want to stress that, although it was our primary objective when we started this study, an econometric estimation of the impact of environmental policy on energy-efficient technological innovations in the Dutch building sector was not feasible. Since several important measures were introduced almost simultaneously, identifying the differential impact of each measure on innovation would require a large range of data, which cannot be obtained in a single-country setting. In general, there are many opportunities to gather knowledge about the effectiveness of environmental policy instruments by implementing policy experiments. A simple policy experiment could be to first introduce a policy program in one region before extending it to other regions. Also, subsidy schemes can be designed in such a way to facilitate evaluations, for instance by introducing a threshold in the selection criteria for granting the subsidy. Since the costs of inefficient policies can be high, much can be gained by a proper evaluation of policy instruments.

Appendix

Tables

Table 5.1 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
BouwBe	Building decree / Bouw Besluit	1991-2002 / 2002-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
CoDuBo	Voluntary agreements social housing corporations / Convenant duurzaam bouwen	1998-2005
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
IPSV	Innovation Programme Urban Renewal / Innovatie Programma Stedelijke Vernieuwing	2001-2004
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
OEI	Optimal Energy Infrastructure / Optimale Energie Infrastructure	1997-present
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

Table 5.2 Financial instruments introduced in the 1991-2005 period in the Netherlands, Germany, Austria and Denmark

Policy measures	Starting Year	Ending Year
Netherlands		
EIA	1997	present
REB	1996	present
Green Inv	1994	present
Green Mort	2002	present
EPR+EPA	2000	2003
OEI	1997	present
AZS	1996	present
DuBo	1996	2004
NEWS	1996	1997
BSE	1994	present
BSET	1992	1996
BSW	1992	1995
EMA	1992	present
MAP	1991	2000
SEBG	1990	1995
SEEV	1990	1993
Germany		
KfW Housing modernisation programme	1990	2004
On-site energy advice (Vor-Ort-Beratung)	1991	present
100-million-DM programme for renewables	1994	1998
Ecological Bonus Programme for owner-occupied homes	1996	2002
KfW CO2 Reduction Programme (KfW-Programm zur CO2-Minderung)	1996	2004
Ecological Tax Reform	1999	present
100 000 Roofs Solar Power Programme (100 000-Dächer-Solarstrom-Programm)	1999	2003
Renewable Energies Programme (Marktanreizprogramm für erneuerbare Energien)	1999	present
KfW CO2 Building Rehabilitation Programme (KfW-CO2-Gebäudesanierungsprogramm)	2001	present
Austria		
Personal income tax deduction for energy saving investments	1991	present
Housing support scheme	1991	present
Grants for renewable energy	1992	present
Energy Taxes	1996	present
Denmark		
Grant for energy saving measures for pensioners' dwellings	1993	2003
Agreement on efficient windows	2004	2006
Grants for connection of houses built before 1950 to district CHP systems	1993	2002
Grants for Energy Savings Products for Household	1998	present
Electricity Saving Trust	1997	2007
Carbon Dioxid tax	1998	present

Table 5.3 Queries for energy-efficient innovations in buildings, Insulation and energy demand reduction

Insulation and energy demand reduction			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 5.4 Queries for energy-efficient innovations in buildings, High-Efficiency Boilers

High-Efficiency Boilers	General IPC	Sub-classes	Keywords
HE-boilers	F23D	14+	
	F24D	1	low
	F24D	3+, 17+	
	F24H, excluding F24H7+		

Table 5.5 Queries for energy-efficient innovations in buildings, Heat and Cold Distribution and CHP

Heat and Cold Distribution and CHP	General IPC	Sub-classes	Keywords
Heating Systems	F24D	5+, 7+, 9+, 10+, 11+, 13+, 15+, 19+	
Storage heaters	F24H	7+	
Heat exchange	F28F	21+	
Cooling	F25B	1+, 3+, 5+, 6+, 7+, 9+, 11+, 13+, 15+, 17+	
CHP (Cogeneration)	X11-C04 R24H240/04 (ICO code)		

CHP/Cogeneration codes are taken from the Thomson patent database - the World Patent Index (WPI). In case of CHP the classification in the WPI is better than the IPC. The extra ICO code makes sure additional applications in cogeneration from the EPODOC are addedd to the list.

Table 5.6 Queries for energy-efficient innovations in buildings, Ventilation

Ventilation	General IPC	Sub-classes	Keywords
Ventilation	F24F	7+	

Table 5.7 Queries for energy-efficient innovations in buildings, Solar Energy and other Renewables (RES)

Solar Energy and other RES	General IPC	Sub-classes	Keywords
Solar Energy	F24J	2+	
	H01L	31/042, 31/058	
	H02N	6+	
Biomass	F24B		wood+
Geothermal	F24J	3+	

Table 5.8 Queries for energy-efficient innovations in buildings, Lighting

Lighting	General IPC	Sub-classes	Keywords
Lighting	F21S		not vehicle, not aircraft
	F21K	2+	not vehicle, not aircraft
	H01J	61+	not vehicle, not aircraft
	F21V	7+	house or home or building
LED	H01L	33/00+	light and LED
	H05B	33+	light and LED

Table 5.9 Queries for energy-efficient innovations in buildings, Building Materials

Building Materials	General IPC	Sub-classes	Keywords
Construction structures	E04B	1+	building+ or house+
Materials	C09K	5+	building+ or house+

Table 5.10 Queries for energy-efficient innovations in buildings, Climate Control Systems

Climate Control Systems	General IPC	Sub-classes	Keywords
Control of temperature	G05D	23/02+	
Electric heating devices	H05B	1+	

Figure 5.1 Number of EIA applications per type of technology 1997-2006. Source: own computations using yearly EIA reports

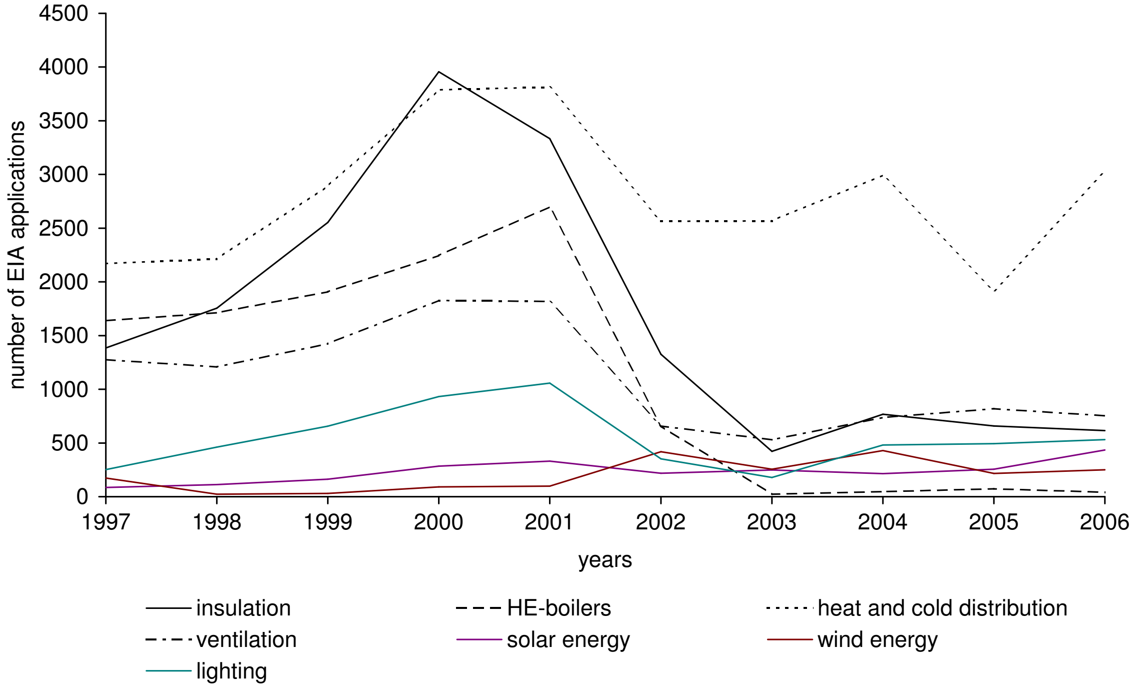
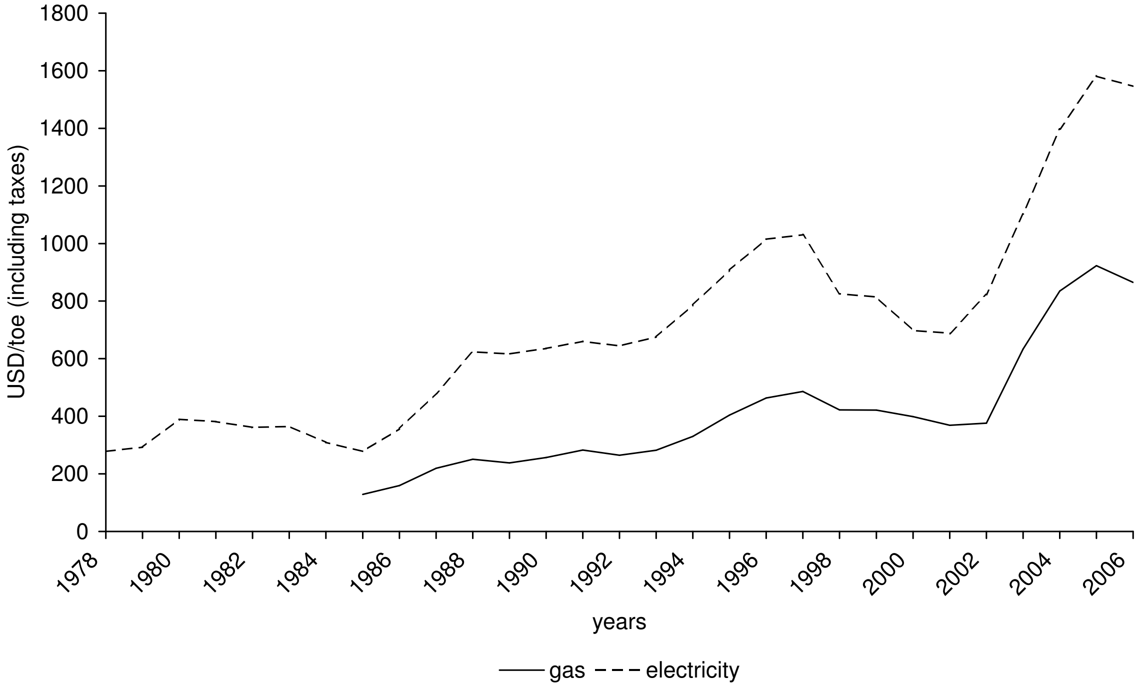


Figure 5.2 Evolution of energy prices in the Netherlands. Source: IEA



References

ACE, 2004, Briefing on the energy performance of buildings directive, Association for the Conservation of Energy.

Acemoglu, D., P. Aghion, L. Bursztyn and D. Hemous, 2009, The environment and directed technical change, NBER Working Paper 15451.

Amir, R., M. Germain and V. van Steenberghe, 2008, On the impact of innovation on the marginal abatement cost curve, *Journal of Public Economic Theory*, vol. 10, no. 6, pp. 985–1010.

Baker, E., L. Clarke and E. Shittu, 2008, Technical change and the marginal cost of abatement, *Energy Economics*, vol. 30, no. 6, pp. 2799–2816.

Barradale, M., 2008, Impact of policy uncertainty in renewable energy investment: Wind power and PTC, in *US Association for Energy Economics Working Paper 08-003*.

Bauman, Y., M. Lee and K. Seeley, 2008, Does technological innovation really reduce marginal abatement costs? Some theory, algebraic evidence and policy implications, *Environmental and Resource Economics*, vol. 40, no. 4, pp. 507–527.

Blok, K., H. de Groot, E. Luiten and M. Rietbergen, 2004, *The effectiveness of policy instruments for energy efficiency improvements in firms*, Kluwer Academic Publishers.

Comanor, W.S. and F.M. Scherer, 1969, Patent statistics as a measure of technical change, *Journal of Political Economy*, vol. 77, no. 3, pp. 392–398.

Cornet, M. and D. Webbink, 2004, Lerend beleid: het versterken van beleid door experimenteren en evalueren, CPB Document 48.

Dekker, T., H. Vollebergh, F. de Vries and C. Withagen, 2009, How international environmental agreements trigger knowledge transfers: Evidence from SO2 protocols, VU University Amsterdam.

Ecofys, 2009, Energiebesparing- en CO2-reductiepotentieel hybride lucht/water warmtepomp in de bestaande woningbouw, Ecofys report.

Eurostat, 2008, Government budget appropriations or outlays on R&D data 2007, Statistics in focus 29/2008.

Fischer, C., 2008, Emissions pricing, spillovers and public investment in environmentally friendly technologies, *Energy Economics*, vol. 30, no. 2, pp. 142–162.

Fischer, C. and R. Newell, 2008, Environmental and technology policies for climate mitigation, *Journal of Environmental Economics and Management*, vol. 55, no. 2, pp. 142–162.

Fischer, C., I. Parry and W. Pizer, 2003, Instrument choice for environmental protection when technological innovation is endogenous, *Journal of Environmental Economics and Management*, vol. 45, no. 3, pp. 523–545.

Griliches, Z., 1990, Patent statistics as economic indicators: A survey, *Journal of Economic Literature*, vol. 28, no. 4, pp. 1661–1707.

Hagedoorn, J. and M. Cloodt, 2003, Measuring innovative performance: Is there an advantage in using multiple indicators?, *Research Policy*, vol. 32, pp. 1365–1379.

Hascic, I., N. Johnstone and C. Michel, 2008, Environmental policy stringency and technological innovation: Evidence from patent counts, paper presented at the European Association on Environmental and Resource Economists, Gothenburg, Sweden, June 26 2008.

Heijnes, H. and D. de Jager, 1999, *Inventarisatie milieu- en energiesubsidies 1985-1998*, Ecofys, Utrecht.

Hicks, J., 1932, *The theory of wages*, MacMillan, London.

Jaffe, A., 2002, Building program evaluation into the design of public research support programs, *Oxford Review of Economic Policy*, vol. 18, no. 1, pp. 22–34.

Jaffe, A., R. Newell and R. Stavins, 2002, Technological change and the environment, *Environmental and Resource Economics*, vol. 22, pp. 41–69.

Jaffe, A., R. Newell and R. Stavins, 2005, A tale of two market failures:technology and environmental policy, *Ecological Economics*, vol. 54, pp. 164–174.

Jaffe, A. and K. Palmer, 1997, Environmental regulation and innovation: a panel data study, *Review of Economics and Statistics*, vol. 79, pp. 610–619.

Johnstone, N. and I. Hascic, 2008, Environmental policy design and the fragmentation of international markets for innovation, Available at $http : //papers.ssrn.com/sol3/papers.cfmabstract_id = 1370339$.

Johnstone, N., I. Hascic and D. Popp, 2009a, Renewable energy policies and technological innovation: Evidence based on patent counts, *Environmental and Resource Economics*, vol. forthcoming.

Johnstone, N., I. Hascic and P. Scapecchi, 2009b, Environmental policy stability and innovation in environmental technologies, Available at $http : //papers.ssrn.com/sol3/papers.cfmabstract_id = 1370336$.

Joosen, S., M. Harmelink and K. Blok, 2004, Evaluatie van het klimaatbeleid in de gebouwde omgeving 1995 - 2002, Ecofys Publication.

Lanjouw, J. and A. Mody, 1996, Innovation and the international diffusion of environmentally responsive technology, *Research Policy*, vol. 25, pp. 549–571.

Martin, S. and J. Scott, 2000, The nature of innovation market failure and the design of public support for private innovation, *Research Policy*, vol. 29, no. 4-5, pp. 437–447.

Milliman, S.R. and R. Prince, 1989, Firm incentives to promote technical change in pollution control, *Journal of Environmental Economics and Management*, vol. 17, pp. 247–265.

Newell, R., A. Jaffe and R. Stavins, 1999, The induced innovation hypothesis and energy-saving technological change, *Quarterly Journal of Economics*, vol. 114, no. 3, pp. 941–975.

Noailly, J., 2009, Improving energy-efficiency in buildings: The impact of environmental policy on technological innovation, CPB Discussion Paper 137.

OECD, 2009, *Patent Statistics Manual*, OECD Publishing.

Oudshof, B., M. Arentsen, S. Nonhebel and W. Biesiot, 1997, Analyse en evaluatie van beleidsinstrumenten voor energiebesparing, IVEM.

Pindyck, R., 2007, Uncertainty in environmental economics, *Review of Environmental Economics and Policy*, vol. 1, pp. 45–65.

Popp, D., 2002, Induced innovation and energy prices, *American Economic Review*, vol. 92, no. 1, pp. 160–180.

Popp, D., 2006, International innovation and diffusion of air pollution control technologies: the effects of NOX and SO2 regulation in the US, Japan, and Germany, *Journal of Environmental Economics and Management*, vol. 51, pp. 46–71.

Popp, D., R. Newell and A. Jaffe, 2009, Energy, the environment, and technological change, NBER Working Paper 14832.

Porter, M.E. and C.M. van der Linde, 1995, Toward a new conception of the environment competitiveness relationship, *Journal of Economic Perspectives*, vol. 9, no. 4, pp. 97–118.

Rennings, K., 2000, Redefining innovation – eco-innovation research and the contribution from ecological economics, *Ecological Economics*, vol. 32, pp. 319–322.

Requate, T., 2005, Dynamic incentives by environmental policy instruments: A survey, *Ecological Economics*, vol. 54, pp. 105–126.

Schmookler, J., 1954, The level of inventive activity, *The Review of Economics and Statistics*, vol. 36, no. 2, pp. 183–190.

SenterNovem, 2007, Energieonderzoek in Nederland. Energietechnologie projecten in de WBSO 2003 tot en met 2005, SenterNovem.

Ulph, D., 1998, Environmental policy and technological innovation, in C. Carraro and D. Siniscalaco, eds., *Frontiers of Environmental Economics*, Edward Elgar, Cheltensham, UK.

Vollebergh, H., 2007, Differential impact of environmental policy instruments on technological change: A review of the empirical literature, Tinbergen Institute Working Paper.

Vries, F. and C. Withagen, 2005, Innovation and environmental stringency: The case of sulfur dioxide abatement, centER Discussion Paper, No 18.

VROM, 2009, Innovatieagenda energie – gebouwde omgeving, Ministry of Housing, Spatial Planning and the Environment.

Zanden, J. van and S. Verstegen, 1993, *Groene geschiedenis van Nederland*, KNAW, Het Spectrum.