

# Policy Inducement Effects in Energy Efficiency Technologies. An Empirical Analysis of the Residential Sector

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**Abstract** Energy efficiency technologies represent a key driver for the reduction of energy demand, leading to environmental and economic benefits. This aspect appears to be particularly relevant in the residential sector, where the demand for energy has not shown a decreasing trend over the last two decades. Our study provides a wide-ranging empirical analysis of the drivers of innovation in energy efficiency technologies by looking at the residential sector for a comprehensive panel of 23 OECD countries over the 1990–2010 period. It confirms the importance of adopting a systemic perspective when examining eco-innovation. In particular, the innovation system at both national and sectoral levels, together with the environmental and the energy systems, is found to have encouraged the propensity to innovate and significantly shaped the rate and direction of technical change in the residential sector. A general policy inducement effect is found to be relevant, but the size of its contribution for new energy efficient technologies changes if disaggregated policy instruments are factored in. We note a positive and significant impact driven not only by standard regulations but also by policies aimed at improving the level of consumer information and awareness. This evidence has noteworthy policy implications and suggests paths for the further development of research in this field.

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## 1 Introduction

Energy efficiency (EE) is one of the most effective means of achieving several goals, such as increasing energy security, fostering international cost competitiveness and reducing polluting emissions. In particular, achieving a more secure, sustainable and affordable energy system is a key challenge for future world development [18, 32, 33]. In this context, the availability and adoption of new energy-efficient technologies are a key driver for reducing overall energy demand as it influences the levels of EE. This aspect appears to be particularly relevant in the residential sector, where the demand for energy to power domestic appliances and equipment shows no sign of slowing but rather a trend of continuous growth over the last 20 years.

Understanding the determinants of the pace of inventions in this sector therefore appears to be an important step for the design of policies for fostering the generation and dissemination of environmental technologies aimed at increasing EE. However, the residential sector is a complex system in which several energy services are used, such as space heating, cooling systems, water heating systems, lighting and several electrical appliances. This implies that major research efforts are needed to properly map the evolution of technologies in this sector and to systematically collect information for specific policy strategies.

Given the limited number of studies that have analysed the drivers of innovation in this field, we propose a comprehensive analysis of the factors affecting the dynamics of EE technologies in the residential sector, with specific attention to the role played by public policies. In so doing, we seek to contribute to the relevant literature: (i) by including in the analysis the domain of electrical appliances which—although relatively unexplored—account for a large proportion of residential energy consumption in view of the great potential that comes with the multiplicative effect of each single appliance; (ii) by analysing the impact of the full array of policy instruments that are assumed to influence innovation activities; and (iii) by extending the country coverage of the empirical analysis to a large number of high-income OECD countries.

The rest of the paper is organised as follows. Section 2 shows the consumption patterns and the innovation dynamics in EE in the residential sector, to provide a better understanding of the energy-growth decoupling process that has occurred in most of OECD countries. Section 3 describes the data used for the econometric analysis, with a particular focus on policies, and Sect. 4 sets out the empirical strategy and presents the results of the model. Section 5 concludes with some policy implications and further research lines.

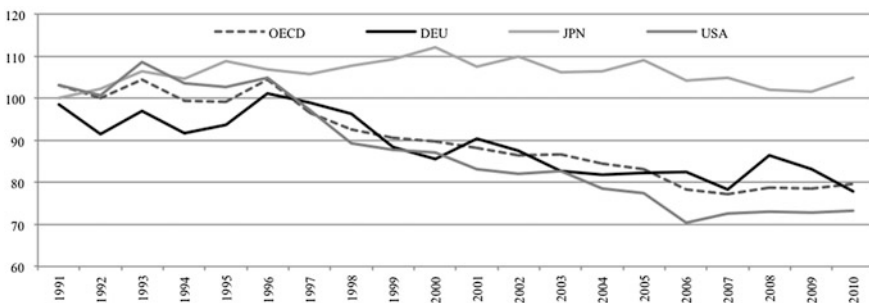
## 2 Consumption Patterns and Innovation Dynamics in Energy Efficiency for the Residential Sector

### 2.1 Energy Consumption Trends and Energy-Growth Decoupling

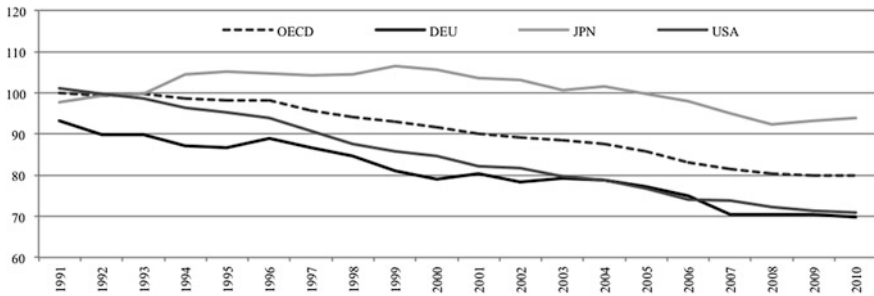
In the decades following the first oil shock energy consumption trends have changed substantially, due to several changes in energy policy and in consumption behaviour, especially in the developed world. Decreases in energy and carbon intensity can be detected in almost all sectors of the economy, and most strongly in the manufacturing industries. A look at the last two decades (1990–2010) reveals that there are some divergences, especially when the residential sector is considered. A comparison of indices taking 1990 as base year, using the ratio of total energy consumption to Gross Domestic Product (GDP) for selected OECD countries (Fig. 1) reveals that the average trend for OECD countries and the path for three major energy consumers (Germany, Japan and the US) are continuously decreasing over time, with the exception of Japan up to 2004. The residential sector shows, on average, similar dynamics for OECD economies, with increasing values for Japan and a less evident negative trend for Germany (Fig. 2). Index numbers based on the ratio of energy consumption in the residential sector to final household consumption expenditure reveal interesting differences from the previous overall trend, with the divergence between Japan and the rest of OECD countries appearing to be much wider.

This evidence provides an initial broad picture of cross-country specific features, indicating that some countries have made less effort to improve EE in the residential sector than in other sectors, while other countries have obtained particularly strong EE gains in this sector. There may be several reasons for these divergences.

An initial explanation is provided by different levels of stringency in residential sector EE policies adopted in OECD countries during the study period. Indeed, the number of policies increases substantially after the year 2000 (see Sect. 3), with



**Fig. 1** Energy intensity trends in the total economy, 1990–2010 (1990 = 100). *Source* own work based on IEA [34], World Bank [79]



**Fig. 2** Energy intensity trends in the residential sector 1990–2010 (1990 = 100). *Source* own work based on IEA [34], World Bank [79]

countries such as Japan, the United Kingdom and the US adopting more stringent, more pervasive policies only recently, while others such as Denmark, Finland and Germany have introduced a relatively smaller number of policies, but adopted them in the early 1990s. It is also worth noting that the effectiveness of environmental policies is closely related to the instruments adopted. Several differences arise when comparing for instance command and control with market-based instruments [6], with the latter being considered as cost effective as well as more suitable for pushing technological change [71].

As a matter of fact, this field of analysis requires a complex framework, where several driving factors may help to explain divergent performance trends, such as institutional and technological capabilities, as well as the more general innovation system at country level. It is also true that gains in resource efficiency must be strictly related to technological innovation, encouraging a large number of scientific contributions in an attempt to disentangle this issue.

## 2.2 *Eco-innovation and Energy Efficiency*

Broadly speaking, reduction of the overall residential energy demand can be thought of as a function of the level of EE, which in turns depends on the availability and adoption of new EE technologies such as intelligent building design and high-performance buildings including highly efficient heating, ventilation and water heating systems. In this regard the dynamics of the technologies used in the residential sector are a key issue.

Considering the strong linkage between the energy system, the environment and innovation processes, EE can be included in the broader framework of eco-innovation [47, 61]. In this chapter we are particularly interested in understanding how public policies may induce innovation efforts at country level. An examination of the growing literature on different technological environmental domains

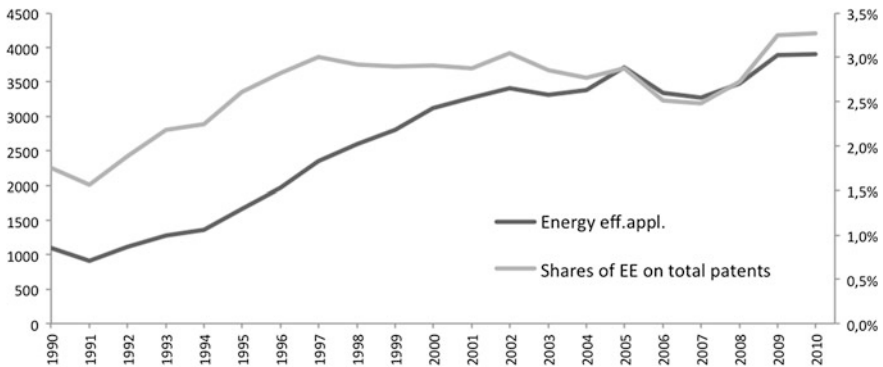
[4, 8, 10, 27, 31, 44, 46, 48, 53, 54, 62, 67] suggests that a patent-based analysis may be the most appropriate way to study innovation dynamics in this field, in view of the lack of specific data on efforts in research and development (R&D), especially in the private sector.

Despite some major limitations, the use of patent data is widespread in the literature on the economics of innovation (see [2, 3, 13, 24, 25, 42, 49, 50, 52, 64, 66, 74, 75]). Indeed, patents provide a wealth of public information on the nature of inventions and applicants for rather long time series, indicating not only the countries where inventions are produced but also where new technologies are used and derive from. Patent data frequently represent the direct result of R&D processes, a further step toward the final output of innovation that is useful knowledge through which firms are able to generate new profit sources. Moreover, patent applications are usually filed early [24], hence they can be interpreted not only as a measure of innovative output but also as a proxy for innovation-related activity [68]. Besides this, it is worth noting that patent data are subject to an extensive process of updating of their information content, which is continuously enriched by national and international patent offices. In addition, EE technologies are only partially and roughly represented in the set of international patent classifications.

An initial contribution to fill this gap is provided by Noailly and Batrakova [57], who analyse the building sector for a limited number of countries. They use patent applications per year in selected areas of environmental technologies in buildings, classified by applicant country and priority date. In order to identify the relevant patents, they refer to technical experts, providing IPC classes related to specific technologies together with a list of keywords for describing the state-of-the-art of EE technologies in the building sector. Although this paper provides an important contribution in mapping EE technologies, it does not consider the important domain of domestic electrical appliances, which account for a large proportion of final energy consumption and have a very high potential impact in terms of EE gains thanks to the multiplier effect derived from their widespread distribution [32]. This gap has been partially filled by the recent Cooperative Patent Classification (CPC), a collaboration between the European Patent Office (EPO) and the World Intellectual Property Office (WIPO), which now includes specific patent classes for EE, also including four domestic electrical appliances.<sup>1</sup> In particular, for patents related to buildings, we adopt the methodology based on keywords developed by Noailly and Batrakova [57], extending the search to 23 OECD countries and 21 years. In our paper, we also take into account EE patents for domestic electrical appliances, following the recent paper by Costantini et al. [16], which provides a comprehensive, up-to-date contribution in mapping this technological domain (including also the new EE classes based on the CPC-Y02 classification) while maintaining the same patent search methodology as for the previous sectors. As a result, we obtain a set of 55,261 patent applications related to EE technologies in different residential sectors, using a homogeneous extraction methodology. Once patent data were

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<sup>1</sup> In particular, freezers, refrigerators, washing machines and dishwashers.



**Fig. 3** Trends in EE patents in absolute numbers and as a proportion of total patents at EPO (1990–2010). *Source* own work based on EPO [19]

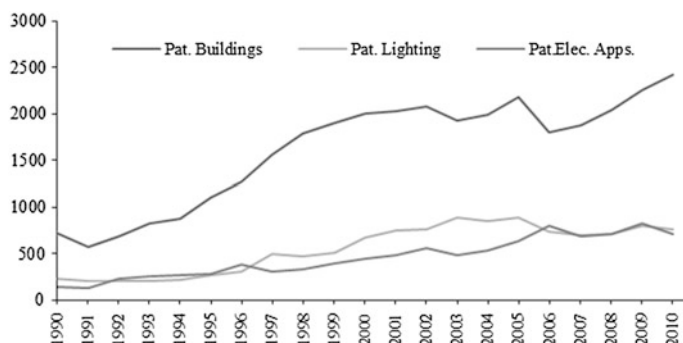
extracted using the Thomson Reuters Core Patents search engine, the patent count was calculated and sorted by application date,<sup>2</sup> with duplicates being dropped to avoid prevent double counting of patents. Finally, the whole technological domain was divided into three sub-domains: building, lighting and large residential appliances (see Sect. 3). A complete list of keywords is provided in Table 6a, b in the Appendix. For a comprehensive description of the data extraction methodology, see Noailly and Batrakova [57] and Costantini et al. [16].

### 2.3 Trend in Energy Efficiency Patents

The number of patents for EE residential technologies increased dramatically in the period 1990–2010. Figure 3 depicts the trends of EE patents in the residential sector and the proportion of the total patents registered at EPO that they represent in the same period for the countries listed in Table 7. Despite a slight decrease between 2005 and 2007, which mirrors a general slump in patenting activity, EE patents show constant growth. After 2007, EE patenting activity increased again, more strongly than in the past, most likely due to the increasing application of EE regulations in each country (e.g. the implementation of EE Action Plans, EEAPs, in the European Union).

The growing trend is also confirmed by the sectoral analysis shown in Fig. 4 for the three sub-sectors of EE residential technologies considered, namely buildings, lighting and large electrical appliances. In the case of buildings the increase in patenting activity was particularly strong, especially in the period 2006–2010. It is

<sup>2</sup> Specifically the “early application date” document field. Moreover, only application codes A1 and A2 are considered in order to capture the most innovative inventions.



**Fig. 4** Trends in EE patents at EPO in the three sub-domains (1990–2010). *Source* own work based on EPO [19]

worth noting that patents for highly efficient appliances are not affected by the general downturn in patenting activity in 2005: they maintained constant growth over the entire period analysed. In terms of sectoral contributions, patents for buildings account for the most EE technologies, followed by lighting and electrical appliances, both of which make moderate contributions to the total number of EE patents filed. Adding up all the patents in the entire period, buildings account for 73 % (33,973 applications), lighting for 21 % (11,699 applications) and electrical appliances for 17 % (9,619 applications).

### 3 Innovation Drivers in Residential EE Technologies: The Empirical Framework

A large body of literature has sought to identify the main forces pushing and supporting eco-innovation, using both theoretical and empirical models. Such analyses suggest that a systemic approach is an appropriate way to study the determinants of introduction and the patterns of dissemination of eco-innovation [17, 30, 73], as it sheds light on the relevance of both demand-pull and supply-push forces and on the primary role played by public policies in this context [31, 55, 69]. From a general point of view, Coenen and Díaz López [12] clearly emphasise that a systemic approach is necessary in eco-innovation studies whatever theoretical framework is adopted. Regardless of whether technological innovation systems, socio-technical systems or sectoral systems of innovation make up the analytical setting of the analysis, private efforts in innovation, technological and institutional capabilities and different public support policies should be accounted for in an integrated manner.

Building on this comprehensive approach, the empirical analysis proposed seeks to take into account the different forces that shape the rate and direction of eco-innovation in the sector considered. In particular the dependent variable,

represented by the count of patent applications at the EPO by 23 countries over the period 1990–2010, is regressed against a set of explanatory variables referring to innovation, market, institutional, energy and environmental systems. The groups of explanatory variables are as follows.

*The Innovation System* There is a large strand of literature on the role of national and sectoral innovation systems [59]. Recently, the innovation process as a whole has been interpreted as the result of complex relationships between different actors, including not only market players but also private and public institutions, government interventions and intangible elements such as spillover effects and tacit knowledge flows. In this study, we particularly stress the role of public policies in inducing innovation in EE, but other general aspects of the innovation system are also taken into account. First, we test efforts and the capability to innovate at country level—proxying the knowledge stock via national gross expenditure in R&D (GERD), which includes expenditure by business enterprises, higher education institutions, the government and private non-profit organisations (data taken from OECD Main Science and Technology Indicators, [63]). Besides this, sectoral features of the energy-technology system also have to be considered. Indeed, the energy sector is characterised by certain specific aspects that affect the performance of technological improvements such as slow response to stimuli to innovate due to high capital intensity, longevity of capital stock, time needed for learning and experimentation, clustering and spillovers [72, 80]. In the light of this, we also test the sectoral knowledge stock for energy, proxied by specific expenditure in R&D on EE, using data provided provided by the IEA [36].

We assume that technological knowledge operates cumulatively, and can thus be added up over time. On the other hand, knowledge is subject to deterioration as it becomes obsolete [20] and should be discounted to take this effect into account. The literature suggests a knowledge depreciation rate of between 10 and 40 % per annum (see [7, 22, 26, 55]). We have decided to apply a moderate decay rate of 15 %<sup>3</sup> considering the high level of “inertia” that characterises the energy technology system. In order to build up the national and sectoral knowledge stocks, we follow the Perpetual Inventory Method suggested in OECD [60] as follows:

$$\text{Stock}_{\text{R\&D}} = \sum_{s=0}^t \left\{ \text{R\&D}_{i,s} \cdot e^{[-\gamma(t-s)]} \right\} \quad (1)$$

where  $\gamma$  indicates the discount rate,  $i$  indexes countries and  $s$ ,  $t$  index time. All values, for both GERD and R&D in EE, are converted into constant US dollars at 2010 levels.

*The Market System* Market effects in spurring innovation have been extensively analysed in economics, dating back to the seminal work by Hicks [29] which gave prices the role of a driving force for more efficient input substitution in which part

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<sup>3</sup> As a sensitivity analysis, we also tested different discount rates (specifically 10 and 20 %), but they did not affect our results significantly.



of the process relies on innovation. Here we adopt an extensive interpretation of price-induced effects, extending the framework to government intervention in an attempt to control market prices. Indeed, it is worth noting that although the final substitution stimulus is related to price, the latter can be divided into two components referring to different innovation drivers. The final price influencing the substitution effect often includes government market instruments such as taxes or incentives, which we call the “public” component. Apart from taxes or subsidies, the rest of the price represents the pure market component, which is assumed to be affected only by market forces and not by public intervention.

Many papers have tested the effectiveness of the price-inducement effect (see [9, 67, 76], among the others), and have found prices to play a significant, positive role in inducing input substitution through innovation, particularly over the long run. In the specific sector of EE, few studies have tried to analyse the relationships between prices and EE innovation. Jaffe and Stavins [39] focus their empirical analysis on the adoption of technologies, comparing the effects of energy prices, building codes and adoption subsidies on the average EE level in home construction in the US over the period 1979–1988. They find that energy taxes have a positive but relatively small impact on technology dissemination, but that subsidies have a stronger positive effect. By contrast, building code requirements (a form of direct regulation by technology standards, measured by using dummy variables) are found to have no effect. The paper by Newell et al. [56] is the only one that focuses specifically on home appliances. By evaluating the impact of energy prices and regulatory standards on the introduction of new home appliances (e.g. gas water heaters and air conditioners) in the US between 1958 and 1993, it confirms the price-inducement hypothesis, finding that falling energy prices work against the development of energy-efficient appliances. Noailly [58] is the most recent study, and the only one related to EE innovation measured by patent data. It investigates the impact of alternative environmental policy instruments (regulatory energy standards in building codes, energy prices and specific governmental energy R&D expenditures) on energy-efficient technological innovations in the building sector. The study covers seven European countries over the period 1989–2004 and finds that, for the specific case of the building sector, regulatory standards have a greater impact on innovation than energy prices and R&D support.

In our analysis, the price effect considered is the price-tax bundle calculated as the ratio of the overall cost of energy taxation to the total cost of energy consumption as follows:

$$\text{Price – tax bundle}_{it} = \frac{\sum_{n=1}^3 (\text{tax}_{n,it} \cdot \text{ener\_cons}_{n,it})}{\sum_{n=1}^3 (\text{price}_{n,it} \cdot \text{ener\_cons}_{n,it})} \quad (2)$$

where  $n$  indexes diesel, electricity and gas. Price and tax rates are taken from IEA Energy Prices and Taxes Statistics [35], while data on energy consumption are taken from IEA Energy Balance Statistics [34]. All data refer strictly to the residential sector.

**Table 1** EE residential main target and specific sub-domains

Main target sub-domain	Specific sub-domains
<i>Buildings</i>	Building code
	Building type (residential only)
	Energy class
	Existing buildings
	New buildings
<i>Lighting</i>	Residential
<i>Residential appliances</i>	Computer
	Cooking & laundry
	Home entertainment
	Other
	Refrigeration
	Space cooling
	Space heating
	Standby
	Ventilation
	Water heating

Source IEA [37]

*The Institutional System* In this empirical framework, we describe the institutional environment in terms of the different public policies implemented at country level for this specific domain (Table 1).

Using policy data, we investigate the hypothesis that although many policy interventions were not initially implemented with the purpose of stimulating new EE technologies, they have all helped to encourage the complex process of innovation, in particular at the invention stage, through an inducement mechanism that we call the “policy-induced effect”. Policy data are taken from the IEA’s “Energy Efficiency Policy Database” [37], which provides comprehensive, up-to-date information on EE policies in seven demand sectors (buildings, commercial/industrial equipment, energy utilities, industry, lighting, residential appliances and transport) and on policy measures across these sectors in 23 OECD countries.<sup>4</sup>

Public regulations can be considered on the basis of various criteria (e.g. type of measure, target audience, effective enforcement year, jurisdiction, policy status, etc.). National and supranational policies—still in force or ended during the 1990–2010 period—are included in the analysis. In order to exclusively capture residential-related EE policies, public regulations are selected according to the three main residential target audiences offered by the IEA, namely “buildings”, “lighting”

<sup>4</sup> <http://www.iea.org/policiesandmeasures/energyefficiency/>.

and “appliances” (see Table 1). These residential-specific targets are separated from commercial-, industrial- and transportation-oriented policy measures using an ad hoc semantic methodology based on co-word analysis applied to the main description of the policy. Table 2 illustrates the six policy types and their related instruments which constitute public regulations. Each of the six policy types offered by IEA is considered.

At first glance, the trend in EE policies follows that of the patents filed. This similar trend is an important piece of initial empirical evidence and deserves further investigation. OECD policies adopted to improve EE in residential buildings, lighting and electrical appliances have multiplied dramatically over the past decade, and the instruments implemented have become increasingly heterogeneous. According to the IEA [33], new policies were put in place to strengthen building codes for new buildings in Canada, South Korea, Luxembourg, The Netherlands and the United Kingdom during 2011; building certification has also been implemented in EU Member States. Information on EE in existing buildings is systematically collected and reported in Canada, Germany, Japan, South Korea and New Zealand. Minimum Energy Performance requirements (MEPs) have been strengthened and extended to cover new appliances in many OECD countries. New MEPs and labelling for television sets, set-top boxes and digital television adaptors

**Table 2** Policy types and instruments

Policy type	Instrument
<i>Economic instruments</i>	Direct investment
	Fiscal/financial incentives
	Market-based instruments
<i>Information and education</i>	Advice/aid in implementation
	Information provision
	Performance label
	Professional training and qualification
<i>Policy support</i>	Institutional creation
	Strategic planning
<i>Regulatory instruments</i>	Auditing
	Codes and standards
	Monitoring
	Obligation schemes
	Other mandatory requirements
<i>Research, development and deployment (RD&amp;D)</i>	Demonstration project research programme
<i>Voluntary approaches</i>	Negotiated agreement (public-private sector)
	Public voluntary schemes
	Unilateral commitments (private sector)

Source IEA [37]

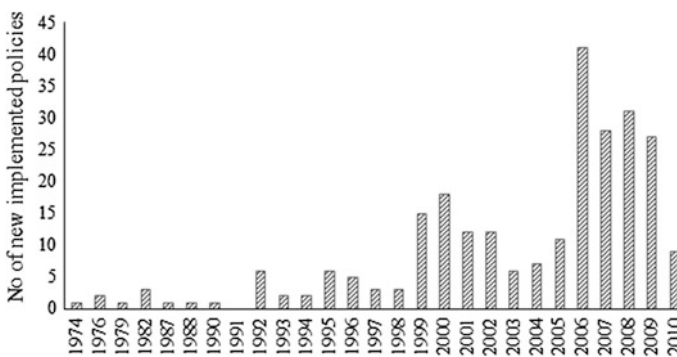
have been introduced in Australia, Canada and Japan, and numerous standby power requirements, planned in 2009, have been fully implemented. Moreover, most OECD countries continue to phase out inefficient incandescent lamps. Canada, Japan, the Netherlands, the United Kingdom and the US have also supported international efforts to stimulate adoption of higher-efficiency alternatives to fuel-based lighting in off-grid communities in developing countries.

Although OECD countries have a strong tradition of promoting EE (dating back to the two oil crises of the 1970s), residential-related EE regulations have been consistently promoted only since the early 1990s. Considering the 23 OECD countries analysed as a whole, 253 different policies can be identified for the 1974–2010 period, 245 of which have been implemented since the 1990s (Fig. 5).

The first major peak in residential-related policy implementation occurred at the turn of the millennium (15 new regulations in 1999 and 18 in 2000), though 2006, with 41, was the year with the most policies implemented. After 2006, government law-making in residential-related EE continued to be significant until 2009, with an average of more than 25 new regulations per year. In 2010, there was a slowdown, with only nine new regulations implemented.

There has been an interesting trend in the policy framework of public regulations in OECD countries over the last two decades. Policy packages have become more heterogeneous, and have shown an increasing level of diversity in terms of both the instruments implemented and the targets at which they have been aimed.

Figure 6 provides a chronology of the introduction of alternative policy types in the OECD countries analysed. Each point in the scatter plot represents the year in which a specific policy type was first introduced in the country indicated. As expected, policy types were first implemented at different times. The countries analysed seem to have preferred first to implement regulatory instruments (e.g. codes and standards, obligation schemes). Then economic instruments (e.g. direct investment, fiscal/financial incentives) and information and education instruments (e.g. performance labelling) are further implemented in the 1990s. Policy support



**Fig. 5** Overall residential-related EE policies in wealthy OECD countries (1974–2010). *Source* own work based on IEA [37]

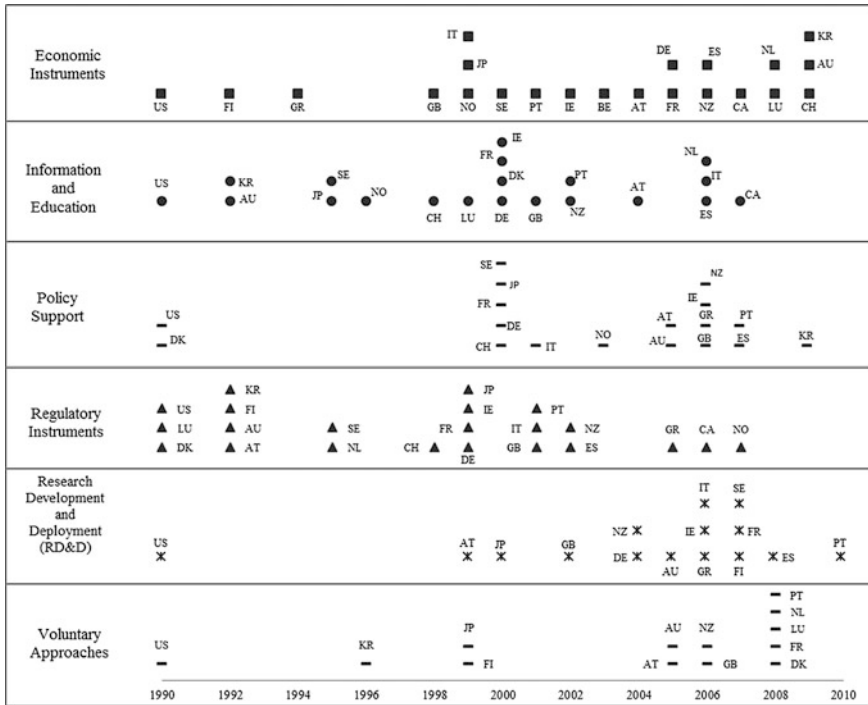


Fig. 6 First implementation of residential-related EE policies in 23 OECD countries by type. Source own work based on IEA [37]

tools, research, development and deployment (RD&D) instruments and voluntary approaches however, with the exception of the US (where they were all implemented in the 1970s) and Denmark (which implemented policy support instruments during the 1980s) were first implemented only during the 2000s. Since the mid-2000s, the entire package of residential-related EE policy types has been in force in most of the countries analysed. As a result, the level of policy heterogeneity has increased significantly.

Figure 7 plots the level of each of the six policy types implemented over the period from 1990 to 2010. Regulatory instruments, information and education and economic instruments are the most widely used policy types. However, the implementation of policy support tools, RD&D instruments and voluntary approaches increases considerably from the mid-2000s onward. As mentioned above, all six policy types have significantly and persistently increased since the mid-2000s and have been implemented simultaneously in almost all the countries analysed. Indeed, the number of multi-instrument policies has recently increased greatly in the OECD area. The same consideration is also evident with respect to residential-related EE targets, which have shown continuous growth and increasing co-occurrence in recent years (see Fig. 8).

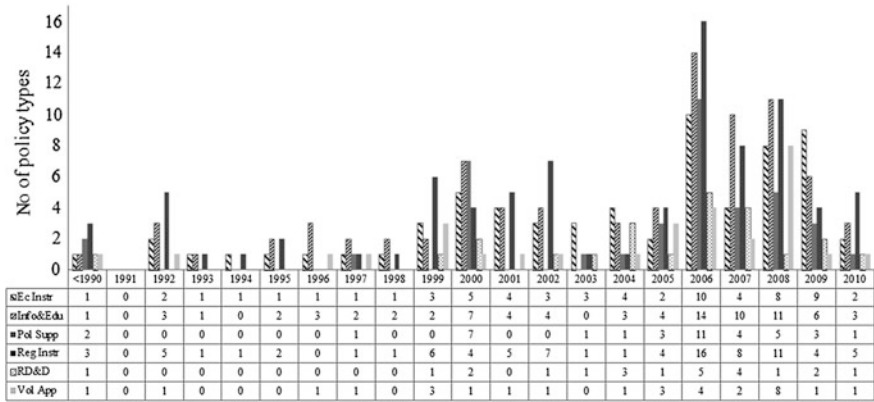


Fig. 7 Number of policies by instrument type (1990–2010). Source own work based on IEA [37]

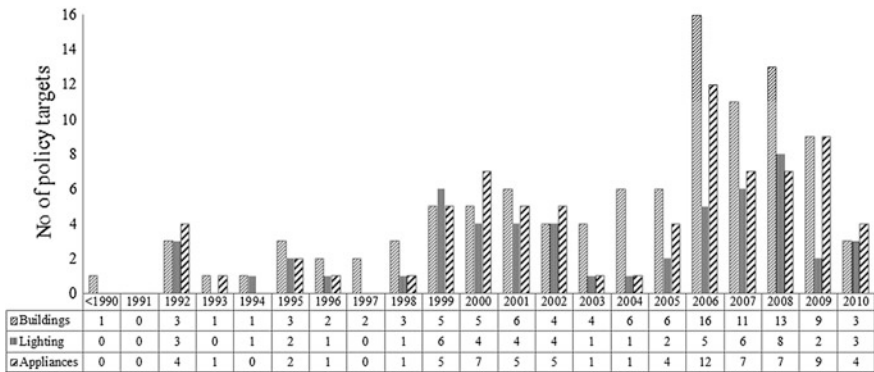


Fig. 8 Number of policy instruments by target sub-domains (1990–2010). Source own work based on IEA [37]

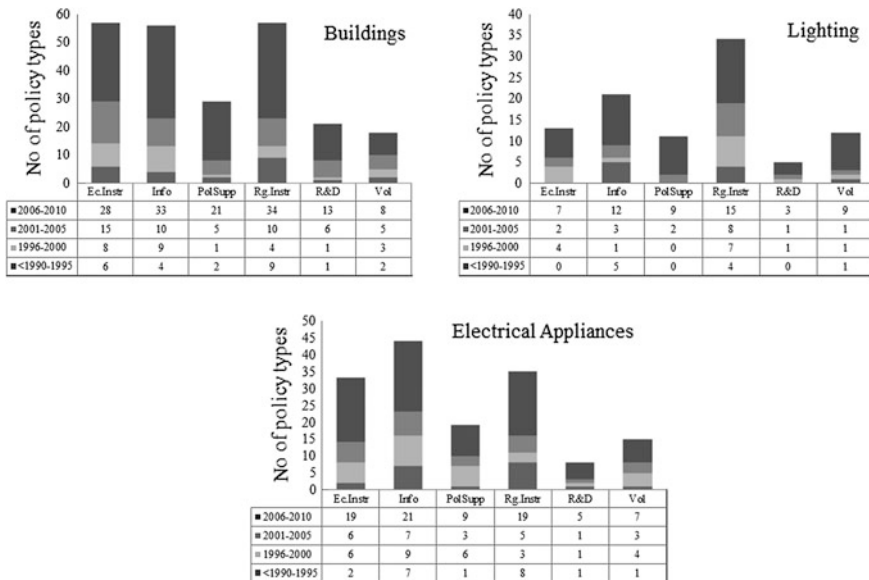
Building-related regulations, the most widely disseminated residential-related policy interventions over the period analysed, are characterised by the large-scale introduction of economic, regulatory and information and education instruments. Notwithstanding, lighting and appliance-related regulations have both more than doubled since 2006. For lighting-related policies, regulatory instruments seem to be preferred, while information and education tools, such as residential performance labelling, are the most widely implemented policy instruments in appliance-related regulations. Nevertheless, as stressed above, there have been dramatic increases in all six policy types in all the policy target areas analysed since the mid-2000s, more and more in co-occurrence with other instruments.

Country-level analysis shows that the EU-15 group of countries have implemented the largest number of residential-related EE public regulations. This is particularly evident since the mid-2000s, with 81 new policies. The crucial years are 2006, 2007 and 2008, with 27, 19 and 19 new policy interventions, respectively. The US maintains a consistently high level of implementation of regulation from the 1970s to the mid-2000s, with major increases in 2008 and 2009. By contrast, implementation of regulations in Japan peaked in the period 1995–2000, slowed down in the early 2000s and picked up again in 2006. As stressed above, these trends are also characterised by significant changes in specific policy mixes. All the countries analysed have shifted over time to higher levels of heterogeneity in their policies, increasingly implementing both multi-target and multi-instrument policies. This is particularly evident for the EU and the US, which employ the highest number of policy instruments in all the policy target areas analysed (see Fig. 9).

In the econometric model we shape the institutional framework by building a discrete variable as the stock of EE policies, calculated as the cumulative number of policy instruments in force at time  $t$  in country  $i$ , as follows:

$$KPOL_{it} = \sum_{s=1}^t POL_{is} \tag{3}$$

dividing by six policy instrument types and three policy sub-domains as specified in Tables 1 and 2. This modelling choice allows us to consider for each year the



**Fig. 9** Country-specific policy activity, per type and target sub-domains (1990–2010). *Source* own work based on IEIEA [37]

whole range of policies still in force at time  $t$ . This shows not only a single impulse depending on whether or not EE measures are in place, but also a qualification of the strength and complexity of the overall institutional system.

*The Energy System* EE performance can affect all the components of the energy system, enabling it to become more efficient ([21], among others). Indeed, EE technologies can be found throughout energy technologies, on the both the energy production and consumption sides. Moreover, EE performance can be affected by the characteristics of the energy system itself. For instance, a shortfall in energy generation in a given country might lead to higher levels of generation and adoption of EE technologies to counterbalance the suboptimal supply of energy. In such endogenous mechanisms, the evaluation of the energy system as a whole appears crucial, especially in a panel setting.

A recent study has developed the concept of an “energy-technology innovation system” (ETIS), defined as “the application of a systemic perspective on innovation to energy technologies comprising all aspects of energy systems (supply and demand); all stages of the technology development cycle; and all innovation processes, feedbacks, actors, institutions, and networks” [22], p. 139. Such a system relies on the role of innovation for improving overall EE but is strictly related to specific contexts and incentive structures, which means that the processes and mechanisms at work within the system must be taken into account, including the roles of private actors, networks and institutions.

In the light of this, we identify a set of variables in an attempt to capture some intrinsic characteristics of the energy system of a country, and more precisely the following:

- The level of energy independence. The mechanisms at work here are based on the hypothesis that if a given country is a net energy exporter, then it is most likely rich in energy supplies and less pressed to innovate in EE technologies. In other words, the greater the energy abundance, the lower the stimulus is to make the national energy system more efficient through the adoption and generation of technology.
- The effect of major additional non-coal energy sources such as nuclear power plants. Nuclear energy accounts for a significant proportion of energy production in many countries and an extra source of energy that might contribute to reducing effort in EE gains. Moreover, the presence of nuclear power plants reflects long-term national energy strategies, since their construction implies that a long time is needed to obtain returns on investments. This variable is expected to have a positive impact in countries that have a low level of nuclear power production.
- The level of energy intensity, to check out the overall efficiency of a system, which is also an indicator for evaluating different national energy strategies. According to Patterson [65], there are different indicators for assessing aggregate efficiency in the energy system. We use energy consumption divided by the



level of population, but we are well aware that although this indicator is widely used, it is not exempt from bias.<sup>5</sup>

In the empirical model, we combine the effects of the presence of nuclear power generation with the level of energy intensity by interacting these two variables.

*The Environmental System* Public intervention to reduce pollution and improve the environment has been thoroughly justified in standard environmental economic theory, which starts by assuming the environment to be a public good and assumes that pollution (e.g. greenhouse gas emissions) represents a negative externality, i.e. a cost not internalised by polluters. Indeed, in the absence of public interventions firms do not pay for polluting and thus produce a cost for society by reducing environmental quality. In such cases government intervention is required to set the optimal level of output by balancing the private cost of production (paid by firms) against the social cost of pollution (paid by the community). A typical intervention for internalising the cost of pollution takes the form of taxation, but the role of innovation is also important in inducing firms to introduce higher efficiency, cleaner inputs into their production processes. This second case is also known as environmental-induced innovation.

There is increasing interest in studying the role of environmental regulation in fostering innovation, and conflicting results are often reported which leave the debate still open at present. One major strand of literature assigns a pivotal role to environmental regulation as a driver of innovation processes and business competitiveness, in the well-known framework of the Porter Hypothesis [70, 71]. This provides further justification for green public interventions. According to Jaffe and Palmer [40], the Porter hypothesis can be seen as having three different versions: the first ‘weak’ version states that regulation stimulates eco-innovation; the ‘narrow’ version states that the flexibility of different policy instruments can provide firms with even greater incentives to innovate in green technologies; and finally the ‘strong’ version states that compliant firms can even benefit from cost-savings and technological leadership deriving from eco-innovation. All three versions have been subject to empirical investigation in the past few decades, and non-univocal results have emerged. For instance, Ambec and Barla [1] demonstrate that the Porter hypothesis only operates in the co-existence of different market imperfections. Lanoie et al. [51] finds inverse proportionality between the degree of compliance by firms and the relative effect of the Porter hypothesis, while Costantini and Mazzanti [15], analysing trade competitiveness in the EU, test both the strong and narrow versions of the Porter hypothesis and find that environmental policies generate greater efficiency in the production process through various complementarity mechanisms.

Considering the presence of environmental policies in the full set of countries analysed, we include a country-specific variable—the level of residential CO<sub>2</sub>

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<sup>5</sup> For instance, Wilson et al. [77] underline the non-technical nature of this indicator for measuring energy efficiency, while Jenne and Cattel [43] point out the bias due to divergent country-specific sectoral economy mixes.

emissions—as a control variable representing the environmental system which can capture any possible inducement effect due to the stringency of different national environmental regulations. By doing this, we seek to test the potential effects of environmental regulations operating as a mechanism through which cleaner technological change can be induced, which has positive impacts on the countries in which regulations are in force [14]. More precisely, we rely on the hypothesis that the lower the level of CO<sub>2</sub> per capita, the higher the level of technological capabilities is, measured by the patent count. Since this variable measures the final goal of environmental regulations—lower carbon intensity, that is the impact of the overall level of emissions from all sectors in a country weighted by its population—we capture any environmental induced-effect policies. Moreover, due to the generality of this variable, the analysis is also effective in countries where the framework of green regulation is weak but other implicit mechanisms are at work, as for instance in the case of Italy [23]. We use emissions data from IEA CO<sub>2</sub> Emissions from Fuel Combustion Statistics [38], measured in Mt of CO<sub>2</sub>.

## 4 Econometric Strategy and Empirical Results

The use of patent data as a proxy of innovation-related activity means that we have to deal with count variables, i.e. variables with non-negative integer values. In our analysis, the variable under scrutiny is the patent count. Patent data on the EE residential sector are divided into three sub-sectors according to policy data: buildings, lighting and four electrical appliances (refrigerators, freezers, washing machines and dishwashers), respectively. As confirmed by Hausman et al. [28] and Baltagi [5], these data usually show a high degree of skewness with upper tails over dispersion (relatively low medians and high means) and a large proportion of zeros. Such features can reflect observed factors such as the size of firms (larger firms usually file more patents than smaller ones) and unobserved heterogeneity (one firm may patent less than another but produce breakthrough technologies). Empirical literature suggests specific modelling strategies for dealing with patents which can be reduced to two main options: the Poisson Regression Model (PRM) and the Negative Binomial Regression Model (NBRM). When the dependent variable is affected by the presence of many zeros the Zero-Inflated Negative Binomial Model (ZINB) may also be a good modelling strategy (for a comprehensive explanation see [11, 78]. In our dataset, the presence of zeros in the dependent variable is negligible and Vuong's test does not justify the use of the ZINB.<sup>6</sup> In the light of this, we decided to use the NBRM, in which the variance is modelled as a quadratic term (NB-2). Equation (4) represents the general expression of the models estimated, taking into account the five groups of variables for the specific drivers of innovation described above:

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<sup>6</sup> Test results are available upon request.

$$\begin{aligned}
&= + \beta_0 + \beta_1(\text{Innov\_Sys}_{i,t-1}) + \beta_2(\text{MarketSys}_{i,t-1}) \\
&\quad + \beta_3(\text{EE\_Policy}_{i,t-1}) + \beta_4(\text{Energy\_Sys}_{i,t-1}) \\
&\quad + \beta_5(\text{EN})(\text{Controls}_{i,t}) + \varepsilon_{i,t}
\end{aligned} \tag{4}$$

We use a log-log fixed effects specification to take into account country-specific unobservable heterogeneity; Hausman's test confirms our choice of using fixed effects.<sup>7</sup> The maximum likelihood method is used to estimate the model parameters. All variables referring to the systems investigated are modelled with a one year lag in order to reduce potential endogeneity bias while preserving the standard inducement effect framework. In this sense, when the resilience of the innovation process is accounted for, it is commonplace to expect policies or market inducement effects to present a time lag from the time when the phenomenon occurs and the reaction in terms of innovations by firms. As a standard method of addressing this issue, a one year lag reduces endogeneity and enables resilience to be accounted for, but a minimal number of observations is lost.

Different model specifications are estimated to test the contributions of the different systems affecting the dynamics of invention of EE technologies. The policy variables are maintained in all the specifications, while different variables for measuring the contribution of other innovation drivers are tested. Moreover, further estimations show the impacts of each policy type by disaggregating the policy dataset according to Table 2.

Table 3 tests a general policy inducement effect together with the contribution of two different proxies of the innovation system. More specifically, estimations (1–4) include the stock of GERD, while in estimations (5–8) innovation capacity is measured by the specific stock of R&D in EE. Broadly speaking, the contribution to invention of the national innovation system is positive and significant both when the effect is tested on the total number of patents and when patents are divided into the three sub-domains. Unfortunately, our dataset suffers from a large number of missing data for specific R&D in EE, which translates into several missing observations. Therefore, in the estimations below we keep only the GERD variable for measuring the contribution of national innovation systems.

The price-inducement effect, represented by the price-tax bundle, also positively and significantly affects our dependent variable, although the statistical robustness is lower than for R&D. Since we measure prices at end-use level, it can be inferred that producers pay more attention to price changes, probably in a demand-driven effect in which consumers are highly sensitive to energy consumption and preferably choose high-efficiency goods to counterbalance increases in energy prices.

In the case of electrical appliances and lighting, two sectors characterised by intensive energy use but prompt responsiveness for energy saving, this effect is particularly strong, for at least two reasons: first, the lifecycle of lamps and appliances is shorter than that of buildings, and the reactivity of consumer's choices

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<sup>7</sup> Test results are available upon request.

Table 3 General policy inducement effect on specific technological domains

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Patent count in EE-total	Patent count in EE-building	Patent count in EE-lighting	Patent count in EE-elec. appl.	Patent count in EE-total	Patent count in EE-building	Patent count in EE-lighting	Patent count in EE-elec. appl.
Stock of GERD	0.51*** (8.87)	0.52*** (8.74)	0.58*** (6.41)	0.66*** (5.84)				
Stock of R&D in EE					0.20*** (4.65)	0.20*** (4.03)	0.37*** (4.81)	0.32*** (4.89)
Price-tax bundle	0.17** (2.19)	0.13 (1.49)	0.45*** (4.44)	0.70*** (4.90)	0.13 (1.33)	0.04 (0.36)	0.50*** (4.20)	0.47*** (3.38)
Stock of EE policy—total	0.22*** (8.58)				0.28*** (9.66)			
Stock of EE policy—building		0.19*** (5.59)				0.26*** (6.44)		
Stock of EE policy—lighting			0.47*** (6.04)				0.44*** (5.00)	
Stock of EE policy—elec. appl.				0.71*** (10.41)				0.74*** (9.62)
Constant	-5.64*** (-6.47)	-5.94*** (-6.67)	-7.00*** (-4.84)	-7.94*** (-5.18)	1.10*** (4.20)	0.82*** (2.96)	0.81* (1.81)	0.11 (0.26)
N	317.00	317.00	317.00	303.00	298.00	298.00	298.00	284.00
chi2	306.39	184.38	132.86	216.83	198.66	101.10	111.11	170.35

*t* statistics in parentheses; \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

in adopting more efficient goods reflects this quicker pace. Moreover, in the building sector the party that actually benefits from EE performance and pays the energy bill (the owner) is not the same as the part that constructs the building (the contractor). This is known in literature as the principal-agent problem: it describes a framework in which the ‘agent’ (the builder) may not always operate in favour of the ‘the principal’ (the building’s owner or user). In this context, the builder might sub-invest in building dwellings with suboptimal EE performance, dumping the higher costs of energy bills on the future users (see also [41]).

With respect to the policy effect, in the general model specification a modest but positive impact of EE policies can be noted in regard to generating new patents, confirming the important role of public regulation in stimulating new economy-useful technologies [45, 69]. Moreover, the contribution of EE policies seems to follow the same trend as the innovation system, with the impact of policies being amplified in those sectors which are highly-dependent on R&D. For instance, the elasticity related to public regulation in the electrical appliances sector is almost three times the figure for buildings. The same trend can be found using specific EE-R&D expenditures in place of GERD.

The set of estimations shown in Table 4 provides a robustness check, enlarging the framework of analysis so as also to capture the effect of the energy (estimations 1–4) and environmental systems (estimations 5–8) as further innovation drivers. Although the main results remain largely unchanged, part of the variance in EE inventing activity can be seen also to be explained by the energy system and by environmental stringency. In more detail, when the energy system is tested, as represented here by a term showing the interaction between energy intensity and a dummy variable signalling the presence of nuclear power production, a significant, negative impact on new patents is noted, but only in sectors that use mostly electrical power (lighting and appliances). This means that those countries which make intensive use of energy are also less innovative in terms of EE, confirming our hypothesis that energy abundance reduces the stimulus to innovate in EE technologies. The same pattern, although lower, can be found when environmental stringency is examined, as measured by CO<sub>2</sub> emissions in the residential sector.

Finally, Table 5 tests the contribution of each single policy instrument to the total stock of EE patent applications. This last set of estimations provides some interesting insights for analysing the role of different policies. The first important remark that must be made concerns the size effect of different policy types, which is found to be rather similar in all cases. This result is particularly interesting, since economic theory has mainly relied on standard economic instruments (such as direct investments, taxes and subsidies) rather than on regulations aimed at improving the level of information and awareness of consumers.

Indeed, although the effect of economic instruments is positive and significant in terms of invention-related activity, a new point that emerges from our analysis is that other instruments also contribute just as much to the increase in EE patenting. Specifically, the impact of each policy instrument measured as elasticity is—on average—0.23 %, with the exception of voluntary approach instruments, which are found not to be significant. We believe that the most promising result is the

Table 4 The role of the energy and environmental systems

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Patent count in EE-total	Patent count in EE-building	Patent count in EE-lighting	Patent count in EE-elec. appl.	Patent count in EE-total	Patent count in EE-building	Patent count in EE-lighting	Patent count in EE-elec. appl.
Stock of GERD	0.50*** (7.67)	0.49*** (7.20)	0.73*** (6.14)	0.81*** (6.77)	0.53*** (7.39)	0.52*** (6.81)	0.84*** (6.32)	0.87*** (6.96)
Price-tax bundle	0.17** (2.06)	0.11 (1.28)	0.60*** (4.60)	0.81*** (5.12)	0.15* (1.73)	0.09 (1.01)	0.54*** (3.97)	0.74*** (4.54)
Energy intensity inter-acted with nuclear production	0.02 (0.21)	0.06 (0.77)	-0.32* (-1.83)	-0.66*** (-2.81)	0.05 (0.53)	0.09 (1.01)	-0.23 (-1.29)	-0.58** (-2.50)
CO <sub>2</sub> emissions in residential sector					-0.05 (-0.86)	-0.05 (-0.82)	-0.20* (-1.72)	-0.12 (-1.24)
Stock of EE policy—total	0.22*** (8.39)				0.21*** (7.44)			
Stock of EE policy—building		0.20*** (5.62)				0.19*** (4.85)		
Stock of EE policy—lighting			0.39*** (4.40)				0.33*** (3.51)	
Stock of EE policy—elec. app.				0.59*** (7.64)				0.56*** (6.82)
Constant	-5.55*** (-5.76)	-5.59*** (-5.58)	-8.79*** (-5.14)	-9.86*** (-6.24)	-5.86*** (-5.75)	-5.93*** (-5.51)	-9.86*** (-5.40)	-10.53*** (-6.37)
N	317.00	317.00	317.00	303.00	317.00	317.00	317.00	303.00
chi2	306.52	185.50	134.95	222.17	302.52	182.12	134.31	219.20

t statistics in parentheses; \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

**Table 5** Inducement effect of alternative policy instruments on total patents

	(1)	(2)	(3)	(4)	(5)	(6)
Stock of GERD	0.56*** (8.79)	0.54*** (8.05)	0.59*** (9.27)	0.52*** (8.07)	0.63*** (9.97)	0.66*** (9.84)
Price-tax bundle	0.20** (2.43)	0.18** (2.02)	0.18** (2.12)	0.17** (2.05)	0.15* (1.69)	0.12 (1.29)
Energy intensity interacted with nuclear production	-0.02 (-0.20)	-0.02 (-0.23)	-0.07 (-1.01)	-0.04 (-0.51)	-0.09 (-1.19)	-0.12 (-1.62)
Stock of EE policy—economic instruments	0.26*** (6.93)					
Stock of EE policy—information and education		0.25*** (6.15)				
Stock of EE policy—policy support			0.21*** (4.59)			
Stock of EE policy—regulatory instruments				0.25*** (7.12)		
Stock of EE policy—RD&D					0.20*** (3.73)	
Stock of EE policy—voluntary approaches						0.15 (1.50)
Constant	-6.39*** (-6.76)	-6.13*** (-6.18)	-6.90*** (-7.30)	-5.89*** (-6.14)	-7.57*** (-8.10)	-8.07*** (-8.09)
N	317.00	317.00	317.00	317.00	317.00	317.00
chi2	261.32	237.14	220.22	268.11	196.40	161.15

*t* statistics in parentheses; \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

contribution of information and education policies, which include energy labelling and performance codes for all three sectors considered.

Moreover, not only regulatory instruments such as codes, performance standards and other mandatory requirements but also monitoring activities, public research programmes and demonstration projects provide good stimuli for the growth of EE technologies and their impacts probably operate jointly in enriching the heterogeneity of the policy mix and hence the overall policy-inducement effect.

## 5 Conclusions

Our study provides a broad analysis of the drivers of innovation in EE by looking at the residential sector. As evidenced by the descriptive analyses on the trends in EE patterns and public policy interventions, cross-country specific features emerge which appear to be related to different levels of policy stringency adopted in the OECD countries during the last two decades in this field. The econometric analysis, based on an original dataset comprising sectoral patent data and information on specific policy instruments, confirms the importance of public policies as drivers of innovation activities in this poorly explored sector.

More specifically, this study highlights that national and sectoral innovation systems explain a large portion of a country's propensity to innovate in EE technologies within the residential sector. At the same time, environmental and energy systems are shown to shape the rate and direction of technical change in this sector, with energy availability playing an important role, as an abundance of cheap energy sources (such as nuclear power) tends to reduce the propensity to innovate.

Regarding the specific role of general and sectoral public policies, economic instruments such as energy taxation seem to have an inducement effect on the likelihood to innovate in energy saving devices. Moreover, public policies specifically designed to induce efficiency in energy consumption emerge as crucial for boosting the innovations in technology necessary to reach higher resource efficiency standards. In this respect, an analysis of the impact of different policies provides interesting, new insights. In particular, the econometric results point out that not only is the policy inducement effect on innovation relevant when standard instruments such as direct investments, taxes and subsidies are adopted, but its importance also extends to policies aimed at improving the level of consumer information and awareness. Among those policies, information and education policies, which include energy labelling and performance codes for the sectors considered, emerge as strongly capable of affecting innovation dynamics in residential EE technologies. Moreover, the closer the relationship is between agents paying energy bills and agents adopting efficient technologies, the higher the impulse is to innovate in the related technological domains, as clearly emerges from the analysis of the cases of lighting and electrical appliances.

These results appear to have significant policy implications and suggest a way to further develop research in this field. First, the jointly significant influences of innovation, energy and environment systems on innovation-related activities in the sector under examination confirms the importance of adopting a systemic perspective to the analysis of eco-innovation. Second, this implies that different policy dimensions working both on the multiple elements influencing innovation dynamics and at system level should be combined in a properly designed policy mix. Third, an appropriate policy mix should contain not only traditional market-



based instruments as claimed by standard environmental economics theory in the past, but also information/education based instruments or policy instruments designed as voluntary approaches. Moreover, policy instruments should be planned so as to be as closely related as possible to the market of final use of technologies, giving the correct signals to those agents who invest in energy saving technologies. Finally, the emerging complexity of the policy mix in this field calls for specific attention to coordination problems so as to enhance the consistency and persistence of the whole policy strategy. On this issue, further efforts from both the scientific and policy communities are needed in order to increase understanding of policy interactions and consequently enhance the effectiveness of the policy framework adopted.

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## Appendix

**Table 6a** Patent classes by technological domains and keywords

Main domain	Sub-domain	CPC class	Sub-classes	Keywords
<i>Insulation</i>	Heat saving	E06B	3/24, 3/64, 3/66, 3/67	
		E06B	3	High perform+ OR insulate + OR low energy
		C03C	17/00, 17/36	Low e
		E06B	3/67F	Vacuum
		E06B		Aerogel
		E06B	3/20	
		E06B	1/32, 3/26	Thermal break
		E04B	1/74, 1/76	
E04B			Polyurethane OR PUR OR polystyrene OR EPS OR XPS OR heavy gas+ OR pentane OR insulate+	

(continued)

**Table 6a** (continued)

Main domain	Sub-domain	CPC class	Sub-classes	Keywords	
		E04B		Flax OR straw OR (sheep + AND wool)	
		E04F	15/18		
		E04F		Sea shell	
		E04D	11	Insulate+	
		E04D	11	Green roof	
		E04D	11, 9	Thatch+	
		F16L	59/14		
	Water saving	F24H		Water AND (sav+ OR recover +)	
		F16 K	1	Water AND (sav+ OR recover +)	
		E03C	1	Water AND (sav+ OR recover +)	
	Cooling reduction	E04F	10		
		C03		Glass AND (reflect+ OR sun-proof OR heat resist+)	
		E06B	3	Glass AND (reflect+ OR sun-proof OR heat resist+)	
		B32B	17	Glass AND (reflect+ OR sun-proof OR heat resist+)	
	<i>High-efficiency boilers</i>	HE-boilers	F23D	14	Low
			F24D	1	
F24D			3, 17		
F24H, excluding F24H7					
<i>Heat and cold distribution and CHP</i>	Heating system	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		

(continued)

**Table 6a** (continued)

Main domain	Sub-domain	CPC class	Sub-classes	Keywords
	Combined heating and refrigeration systems	F25B29		
	Heat pumps	F25B30		
	CHP	X11-C04		
		R24H240/04 (ICO code)		
<i>Ventilation</i>	Ventilation	F24F	7+	
<i>Solar energy and other RES</i>	Solar energy	F24 J	2	
		H01L	31/042, 31/058	
		H02 N	6	
	Biomass	F24B		Wood+
Geothermal	F24 J	3		
<i>Building materials</i>	Construction structures	E04B	1	Building+ or house+
	Materials	C09 K	5	Building+ or house+
<i>Climate control systems</i>	Control of temperature	G05D	23/02	
	Electric heating devices	H05B	1	
<i>Lighting</i>	Lighting	F21S		Not vehicle, not aircraft
		F21 K	2	Not vehicle, not aircraft
		H01 J	61	Not vehicle, not aircraft
		F21 V	7	House or home or building
	LED	H01L	33	Light and LED
		H05B	33	Light and LED

Source adapted from Noailly and Batrakova [57]

**Table 6b** Patent classes by technological domains and keywords

CPC general class related to each appliance		Technologies aimed at improving the efficiency of home appliances	Description
<i>Refrigerators and freezers</i>	F25D see <a href="http://www.cooperativepatentclassification.org/cpc/scheme/F/scheme-F25D.pdf">http://www.cooperativepatentclassification.org/cpc/scheme/F/scheme-F25D.pdf</a>	Y02B 40/32	Motor speed control of compressors or fans
		Y02B 40/32	Thermal insulation
<i>Dish-washers</i>	A47L 15/00 see <a href="http://www.cooperativepatentclassification.org/cpc/scheme/A/scheme-A47L.pdf">http://www.cooperativepatentclassification.org/cpc/scheme/A/scheme-A47L.pdf</a>	Y02B 40/42	Motor speed control of pumps
		Y02B 40/44	Heat recovery e.g. of washing water
<i>Washing machines</i>	D06F (excluding D06F31/00, D06F43/00, D06F47/00, D06F58/12, D06F67/04, D06F71/00, D06F89/00, D06F93/00, D06F95/00 as well as their subgroups). See <a href="http://www.cooperativepatentclassification.org/cpc/definition/D/definition-D06F.pdf">http://www.cooperativepatentclassification.org/cpc/definition/D/definition-D06F.pdf</a>	Y02B 40/52	Motor speed control of drum or pumps
		Y02B 40/54	Heat recovery, e.g. of washing water
		Y02B 40/56	Optimisation of water quantity
		Y02B 40/58	Solar heating

Source adapted from Costantini et al. [16]

**Table 7** Countries

Country	Code	Country	Code
Austria	AT	Ireland	IE
Australia	AU	Italy	IT
Belgium	BE	Japan	JP
Canada	CA	Korea	KR
Switzerland	CH	Luxembourg	LU
Germany	DE	Netherlands	NL
Denmark	DK	Norway	NO
Spain	ES	New Zealand	NZ
Finland	FI	Portugal	PT
France	FR	Sweden	SE
United Kingdom	GB	United States	US
Greece	GR		

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