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System Transition and Structural Change Processes in the Energy Efficiency of Residential Sector: Evidence from EU Countries

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System transition and structural change processes in the energy efficiency of residential sector: evidence from EU countries

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Abstract

This paper aims to analyse the evolution of energy efficiency systems for the residential sector of EU countries over the past twenty years and the associated process of structural change occurred in EU economies. To this purpose, we develop a set of indicators to measure some significant characteristics of the energy efficiency systems and map European countries in terms of four dimensions: energy system, innovation system, policy mix design and export competitiveness. Building on these indicators we develop a cluster analysis identifying non-arbitrary homogeneous country groups according to several characteristics in order to investigate the co-evolution of technological trajectories, energy use performance and structural change in this specific domain. Results suggest the distinction of EU countries into four groups, that are individually and comparatively scrutinized shedding light on how the four dimensions here considered dynamically evolved and interacted within and across countries. Empirical findings reveal that the design of the domestic policy mix may play a key role in shaping technological trajectories and structural change processes that in turns allow an increase in external competitiveness performance. Such positive impact appears to be closely related to the quality and quantity of international relationships with main economic partners.

Keywords: eco-innovation; policy mix; international competitiveness; structural change; energy efficiency; residential sector

J.E.L. O31, O38, Q48, Q55, Q58

1. Introduction

Energy efficiency (hereafter EE) is one of the three pillars of the EU 2030 Climate and Energy Strategy (EC, 2014), together with the development of renewable energies and the reduction in carbon emissions. In particular, EE has been identified as a preferential means to improve the performance of the national energy system as it could help fostering a sustainable energy transition. The overall performance of the energy system from one side depends on the structural characteristics of countries. At the same time, at the EU level, an increasing effort to spur EE is also pursued through the implementation of national and sector-specific policies to foster eco-innovation. This, in turn, can generate positive effects not only in terms of environmental benefits, but also in terms of economic competitiveness. From the one side, gains in EE might affect the techno-economic structure by providing the economic system new and more resource-efficient production technologies that would allow the system to profit from cost savings. From the other side, the exploration of new technological trajectories might help gaining privileged positions in international markets thanks to first movers' advantages. In this regard, there is growing interest in understanding the role played by different policy instruments in stimulating and directing technical change in eco-innovation domains and more specifically in the EE branch.

Given the central role of EE in the European long term energy transition strategy, here we propose a descriptive analysis based on a large sample of EU countries that aims to measure some significant characteristics of the EE system and map EU countries' behaviour over the past twenty years. The empirical analysis we propose focuses on the case of EE technologies in the residential sector, which appears to be appropriate for three main reasons. First, since a large number of different policies in several countries aims to enhance EE, especially by fostering the generation and diffusion of new technologies (IEA, 2015; Sovacool, 2009), this is a technological domain that is experiencing an increasing range of different instruments for public policy support with a large heterogeneity at the country level. Second, the efforts pursued for creating new technologies can be directly translated in efficiency gains from the consumption side, thus giving the opportunity to measure how innovation influences energy performances via market mechanisms. Third, the high market integration at the EU level allows including in the analysis the role played by trading partners in eventually shaping different patterns of structural change occurring in highly integrated but still substantially different production systems as the EU countries.

The analysis is organized in two steps. The first step consists in applying a descriptive statistical tool as the cluster analysis, in order to map country groups according to several characteristics related to countries' EE systems and their dynamics. This clustering procedure is implemented considering four dimensions that well describe the evolution of the EE techno-economic structure at the country level over time: i) the energy system; ii) the innovation system; iii) the policy mix design; iv) the export performances in the international markets.

In the second step the analysis moves from the characterization of each single cluster to the more complex investigation of potential co-evolutionary patterns of different countries and/or clusters. Given the growing interest in literature on the potential influence of foreign (innovation and environmental) policies on domestic policy design, and consequently on eco-innovation trajectories (Costantini et al., 2017a; Dechezleprêtre and Glachant, 2014; Peters et al., 2012), we investigate if clusters and countries have been influenced by foreign decisions and if they have undertaken a convergence path within each cluster and between clusters. By exploring such convergence patterns under the lens of the aforementioned four dimensions it is also possible to visualize which countries faced structural changes in terms of industrial specialization and comparative advantages in those sectors strictly related to the EE technological domain. This last part of the analysis allows describing in detail the mechanisms behind the virtuous cycle early hypothesized by Porter and van der Linde (1995), where the (environmental) regulatory framework induces positive effects on innovation dynamics and consequently on the whole economic competitiveness performance of the scrutinized sector, by also including the role played by bilateral and multilateral relationships. Such complexity in the analytical framework guarantees that several aspects related to structural change can be jointly considered if the definition by Malerba and Cantner (2006, p. 1) is adopted: "the main analytical concern is that over time industries evolve and change their structure, and that in this dynamic process knowledge and technologies, the capabilities and incentives of actors, new products and processes (as well as variants of existing ones) and institutions affect and constraint change, sometimes more smoothly and sometimes in a rather radical way. Thus, what is meant here with the term […] structural change is […] all those elements and relations among actors, knowledge and technologies which drive innovative activities and greatly affect economic performance in an industry."

At the same time the simultaneous influence played by multiple channels reveals that, although some co-evolutionary patterns might be detected across countries, each country displays peculiarities in the innovation and competitiveness trajectory in this domain that cannot be synthesized in a common framework and deserves *ad hoc* case study complementing statistical analysis.

The remainder of the paper is organized as follows. Section 2 provides a description of the background framework. Section 3 defines the dataset and the methodology. Section 4 presents the results and, finally, Section 5 summarizes the main insights emerging from this analysis and suggests further research lines.

2. Background framework

Although global final energy consumption more than doubled between 1971 and 2015 (from 4,244 Mtoe to 9,384 Mtoe, respectively), especially because of non-OECD countries, which account for a continuously growing share of world energy use, OECD countries have been assisting to a general decoupling of economic growth from final energy consumption since the first big oil crisis (1973) (IEA, 2016a). This was mainly because developed nations have become significantly more energy efficient after the shock thanks to the introduction of many different regulatory instruments and the invention and adoption of new technologies (Geller et al., 2006).

In this regard, EE constitutes one of the most cost-effective strategies for reducing energy consumption and it allowed OECD countries to decrease their energy intensity over time, even though changes in final energy intensities are different across countries, depending on their economic structures and sectors where EE efforts mostly occurred. In line with the OECD trend, the EU has registered a substantial decrease in energy intensity over the same period. Both primary and final energy consumption decreased over time, and in the past two decades this phenomenon was particularly evident for Eastern EU countries. The New Member States have faced a radical change in their economic structures in general, and more specifically they were forced to adapt their policy and legal framework in order to harmonize with that of the EU, including the energy policy (Saheb and Ossenbrink, 2015). Accordingly, in 2015 the EU final energy consumption was equal to 1,083 Mtoe, returning to 1990 levels (Eurostat, 2017a) but with a substantial difference in the energy mix composition and in the relative contribution of different sectors to national energy consumption.

Despite these huge changes in the whole energy system, the EU economy still heavily depends on energy imports. In 2015 the EU average dependency rate on energy imports was equal to 54%, which means that more than half of the EU's energy needs were met by net imports, mainly from Middle East, Norway and Russia.[1] In addition, there is still a large heterogeneity in energy systems at the country level, with strong divergences both in dependency rates and in energy mix composition (Eurostat, 2017b). As an example, there are countries where petroleum products account for a significant share of total energy available (e.g., Cyprus with 93%, Luxembourg with 63%, and Malta with 85%), while other countries mainly use natural gas (e.g., Italy, the Netherlands, and the UK) or nuclear power (as in the case of France and Sweden, with 45% and 32% respectively). Finally, Eastern countries, especially Estonia and Poland, still rely on solid fuels (mainly coal, 62% and 51% respectively). Similar heterogeneity can be found in energy intensity, where the least intensive economies in the EU in 2015 were Denmark, Ireland, Luxembourg, Malta and the UK, while the most energy-intensive EU Member States were Bulgaria and Estonia.[2] Indeed, although energy intensity decreases all over the EU, deep differences still occur among countries, depending on their economic structures and energy systems.

In this specific regard, while in the past three decades huge investments in EE have characterized most of the EU countries in manufacturing sectors (mainly energy-intensive industries), energy consumption in the residential sector is still far from being on a robustly declining path. On the contrary, despite the strong emphasis put by the EU legislation on achieving EE targets in all sectors, only few countries have implemented effective regulatory mechanisms for improving EE in the residential sector.

In what follows we refer to the residential sector according to the definition used for the energy balance computation (Eurostat, 2017a), meaning that we consider the energy consumption occurred in building for private use, excluding commercial and public services buildings. In 2015 the residential sector represented 25% of EU final energy consumption, absorbing alone about 29% of total electricity consumption (Eurostat, 2017b). Quite intriguingly, the introduction of modern technologies in daily life as devices, systems and equipment fuelled by electricity has more than compensated the reduction in energy consumption due to more efficient technologies. Accordingly, the residential sector deserves particular attention by policy makers in order to implement effective regulatory mechanisms that will allow cutting energy consumption in the next decades in order to reach the challenging target of an increase in energy efficiency by 2030 of around 27% with respect to a business as usual scenario as expected by the EU2030 Strategy (EC, 2014).

In order to build our interpretative framework of system transition and structural change processes in the energy efficiency of residential sector, we move from the assumption that the efficiency of the energy system is driven by its structural characteristics, and we consider that its evolution is intimately linked to the rate of generation and adoption of new energy-efficient

[1] The dependency rate describes the extent to which an economy relies upon imports to meet its energy needs. It is measured by the share of net imports (imports minus exports) in gross inland energy consumption (i.e., the sum of energy produced and net imports).

[2] See Figure A1 in Appendix.

technologies. Innovative activities in this field can be included in the wider category of eco-innovation, which according to Kemp and Pearson (2007, p. 7), is “the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives”. From this definition, it is evident that a deep knowledge of all mechanisms behind the introduction, diffusion and adoption of eco-innovative actions deserves a complex framework of analysis. Several studies have investigated determinants and characteristics of eco-innovation (Arundel and Kemp, 2009; Cainelli and Mazzanti, 2013; OECD, 2011; Wagner, 2007).

A variety of factors drives eco-innovation, such as environmental regulations (Veugelers, 2012), investments for the improvement of technological capabilities (Horbach, 2008), as well as knowledge diffusion, good institutions and cooperation (Ghisetti et al., 2015). Accordingly, it is not surprising that deep differences exist among countries, in terms of both eco-innovation performances and drivers. This is also true for the EU, despite the increasing financial and institutional efforts in this field. In this respect, Horbach (2016) finds that, on average, the Eastern EU countries are less eco-innovative compared to the other EU countries, both on the demand and supply side. Given the low environmental awareness of population and the high dependency on subsidies of the industrial system, the role of the public support to foster eco-innovation seems to be much more important for these countries lagging behind in the sustainable energy transition process.

More generally, Hojnik and Ruzzier (2016) find that among the several potential determinants, regulation is the most relevant in fostering eco-innovation and constitutes the most commonly reported driver. Certainly, the role of regulation is strictly related to the nature of eco-innovation. In fact, among its characteristics, one peculiarity of eco-innovation is the so-called double-externality problem, namely the fact that it produces positive spillovers in both the innovation and diffusion phases (Rennings, 2000). This reduces incentives for firms to invest in eco-innovation due to free-riding risks, generating as a market failure a lack of investments that could be solved only by the adoption of public policy measures (Beise and Rennings, 2005).

Indeed, eco-innovation achievements are strictly connected to the instruments identified to implement domestic public policies in order to foster the introduction and diffusion of new environmental technologies (del Río, 2009; Horbach et al., 2012; Mowery et al., 2010; Newell, 2010).

A first distinction among the role of environmental regulatory instruments in fostering environmental innovation is between demand-pull and technology-push policies. The formers aim at expanding the markets and increasing the profitability of innovation by means of changes in market size and demand (e.g. changes in the prices of fossil energy sources, subsidies for consumer purchases, tax credits, direct government procurement or product standards). On the other hand, technology-push instruments are characterized by the idea that innovation is driven by invention, new discoveries and advances in scientific knowledge, thus policies such as public research and development (R&D), government funding for private R&D and adoption incentives are designed to support and promote the development and deployment of new technologies. As a general result for eco-innovation domains, while demand-pull policy seems more appropriate for supporting mature technologies, technology-push instruments are needed for stimulating early-stages innovation (Costantini et al., 2015; Hoppmann et al., 2013; Nemet, 2009).

Beside the conventional classification between these two policy types, further measures that have been introduced are voluntary instruments (e.g., information-based instruments, rating and labelling programme or voluntarily negotiated agreements between governments and industrial sectors) that in several cases have positively affected eco-innovation (Rennings et al., 2006; Wagner, 2008).

More recently, the role of policy has been analysed in a more complex setting, jointly considering all the instruments in place and their combination in terms of policy mix (Borràs and Edquist, 2013; Flanagan et al., 2011). In this case, besides the specific instrument used for environmental and innovation purposes, the overall impact is the result of the interactions and interdependencies between different policy instruments, as several studies investigating the effect of policy mix on innovation and eco-innovation show (Guerzoni and Raiteri, 2015; Uyarra et al., 2016). With respect to the instruments combination, two relevant aspects of the policy mix have been identified: consistency, which refers to the positive effect emerging from instruments interaction, and comprehensiveness, if all the policy purposes have been covered (Rogge and Reichardt, 2016). Moreover, Costantini et al. (2017a) suggest that a balanced policy mix between demand-pull and technology-push instruments has a positive effect on eco-innovation, whether favouring demand-pull policy could result in the risk of lock-in in inferior technologies, while an unbalanced mix towards technology-push could induce a reduction in private investment for new technologies.

From a more general perspective, the design of policy mix might contribute to changing the structure of the socio and techno-economic systems (Antonelli, 1998). In this regard, the policy mix is able to drive changes both in terms of production and consumption structures and, inevitably, in market dynamics, institutions and social norms (Costantini and Crespi, 2013; Nill and Kemp, 2009; Smink et al., 2015). This viewpoint has its roots in the seminal contribution by Porter and van der Linde (1995) also known as the Porter Hypothesis (PH), according to which there are potential complementarities and private beneficial effects of a properly designed environmental regulation framework. In its strong version, the PH assumes a dynamic evolutionary setting, claiming that environmental regulation would enhance economic performance for compliant firms, the sector to which they belong and, eventually, those sectors interlinked with the regulated one. Indeed, agents could consider new market opportunities and innovation offsets – both through process efficiency and product value enhancement – that may derive from the policy-driven early adoption of both technological and organizational innovation (Jaffe and Stavins, 1995).

To this purpose, the technological innovation system (TIS) approach that focuses the analysis on the interactions occurring in a network of institutions and agents that affect the generation, diffusion and utilisation of specific technologies (Negro and Hekkert, 2008) constitutes a proper analytical framework. The dynamics of a TIS and its success can be analysed through the lens of the multiple activities and relationships among all agents defined by Hekkert et al. (2007) as entrepreneurial activities, knowledge development, knowledge diffusion through networks, guidance of the search (to positively influence the visibility of the technology), market formation, resources mobilization (finance and human), creation of legitimacy (to limit resistance to change). This is particularly important for the energy system in the residential sector where the prevailing socio-technical regime - the rules, artifacts and habits that structure economic viability and social life – is strongly resistant to radical changes and path-breaking innovation (Walrave et al., 2017).

In addition, according to Alkemade et al. (2011), while innovation policy tends to stimulate innovative efforts of industries and firms to enhance competitiveness and international performances of a TIS, transition policy is meant to increase the sustainability of the overall socio-economic system, creating a market for more sustainable goods and services. In this context, a systemic approach to policy design covering innovation, environmental, energy and economic goals seems particularly appropriate to analyse the sustainable transition of a TIS. At the same time, the complexity of such a policy framework strongly requires attention to coordination and effectiveness issues related to the multiple instruments and targets involved.

Hence, in our approach the characteristics and performance of the energy system co-evolve with those of the TIS and of the policy mix, thus shaping processes of structural change and competitiveness dynamics in the domain of EE technologies.

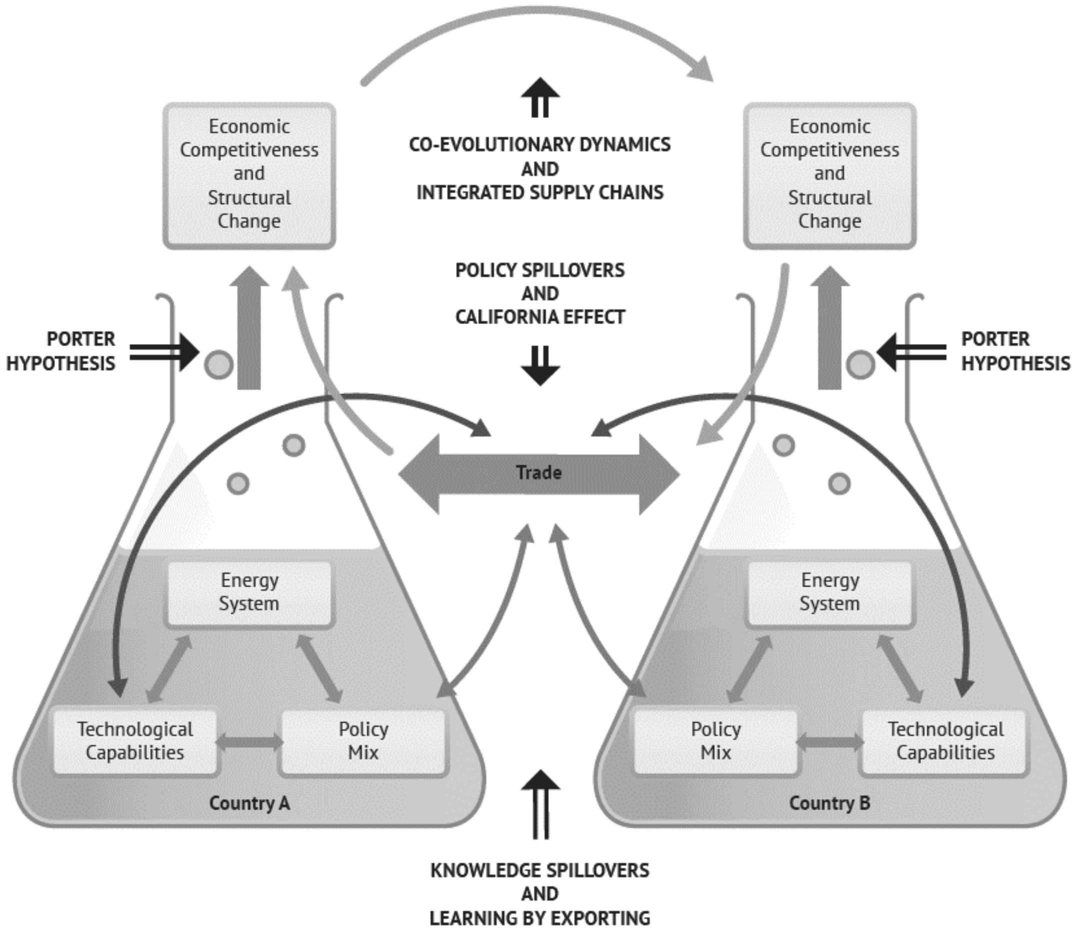
However, beside internal factors, the external context is also expected to matter, as pointed out by recent literature shedding light on the role played by decisions and policy strategies adopted by other countries as driving factors of domestic eco-innovation performances via international knowledge flows and policy spillovers effects associated with trade relationships (Costantini et al., 2017a; Dechezleprêtre and Glachant, 2014; Dekker et al., 2012; Popp, 2006; Popp et al., 2011).

Figure 1 offers a simplified representation of the main ingredients (both internal and external to each country) driving the examined transition process, specifically highlighting - among others - the role of three different international channels.

The first one is a *learning by exporting* effect, occurring both in static terms through comparative advantages and, in dynamic terms, via knowledge flows from trading partners (Grossman and Helpman, 1991; Love and Ganotakis, 2013). In other words, the learning effect depends on the one hand on foreign knowledge spillovers by trading with technologically advanced destination markets, and on the other hand, is associated to the increase of demand induced by the access to foreign markets (Fassio, 2017).

The second one is a *gains from trade* effect mainly regarding environmental regulatory standard convergence as well expressed by Vogel (1995) in the so-called *California effect* that describes the tendency of environmental product standards to ratchet upwards towards levels found in high-regulated countries that are export destination markets. This evidence has been found particularly for product standards because while process standards mainly set domestic producers at a competitive disadvantage, product standards can constitute non-tariff barriers to trade because they also apply to foreign producers (Kono 2006; Perkins and Neumayer, 2012).[3]

Figure 1 – Conceptual analytical framework



The third one relies on the role played by market integration and (sustainable) supply chains (Bi et al., 2016; Costantini et al. 2017b). In highly globalized economies, foreign technological capabilities are increasingly affecting domestic innovation performances, thanks to several channels as a simple international outsourcing activity or a more sophisticated knowledge creation cooperation process (Carlsson, 2006). An example is the success of Chinese photovoltaic industry from learning and technology acquisition through global value chains and vertical integration strategies (Zhang and Gallagher, 2016).

Indeed, the linkages here emphasized are only three examples of the broader category of channels of interactions and exchanges of information with neighbouring components (Antonelli, 2011). The impact of such external effects on structural change patterns might substantially diverge at the country level depending on several factors as the heterogeneity of agents, the functioning of institutions and the social norms, just to mention a few (Cantner, 2016). What here we want to stress

[3] While we acknowledge how limiting is the choice of confining bilateral relationships into trade flows, we consider this analytical framework as adaptable to other relationships, as for instance foreign direct investments, or human capital mobility, or direct cooperative behaviours in knowledge creation.

is that the existence of heterogeneity between Country A and Country B system dynamics relies on the endogenous variability of the fluid inside the ampoule, since we know the components (energy system, technological capabilities and policy mix) but we cannot a priori predict how they react when facing external shocks and inputs (Robert and Yoguel, 2016). Hence, the final outcome of the transition process under scrutiny can be conceived as an emergent system property resulting from the internal co-evolution of individual countries' components (energy system, TIS and policy mix), and the external co-evolution of different economic systems via international exchanges (Crespi, 2016; Antonelli, 2017).

In what follows we try to take advantage of this simplified descriptive framework that while missing to capture all relevant factors influencing the evolution of an economic system, provides a possible guide to transform such a complex network of linkages into measurable dimensions.

3. Methodology

3.1. Indicators for the cluster analysis

The descriptive statistical analysis is based on a sample of 19 EU countries, where two driving criteria are used for the selection: (i) the EU membership and (ii) the availability of information covering the widest range of the selected structural features for the years 1990–2012. As for a computational caveat, the three-year moving average value of variables has been considered. Accordingly, when variables are reported for instance for the year 2012, values refer to the average computed for the years 2010, 2011, 2012. Given the high short term variability of certain indicators, especially related to the energy system and to trade measures, this is recommended to avoid the biasing effect of fluctuations and conjunctural events.[4]

On the basis of the previously described analytical framework, we have selected 19 variables that can describe the four dimensions on which our analysis is focused: the energy system, the technological innovation system in EE, the characteristics of policy mix, and the trade performance on international markets.[5]

The Energy System

The first dimension provides a description of the country energy profile, focusing on the performances of the residential sector. At the country level, we consider: the national energy efficiency index, as the ratio between GDP and total energy consumption, and its change over time (with respect to t-5); energy imports as percentage of energy use and the mean annual temperature. Data for GDP, energy imports and temperature are taken from the World Bank World Development Indicators (WDI) database while the final energy consumption data (expressed in thousand tonnes of

[4] The 19 European countries included in the analysis are: Austria, Belgium, Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Slovakia, Sweden, United Kingdom. Given the amount of missing data in 1990, for the descriptive three-step analysis we take as our base year the period 1995-1997.

[5] The complete list of variables used in the analysis and data sources are provided in Table A1 in the Appendix.

oil equivalent) are retrieved from the EUROSTAT database.[6] In order to describe the specific performance of the residential sector in terms of EE, we also include four additional variables. Data from EUROSTAT and the WDI are used to construct two indicators: the share of residential energy consumption with respect to the total energy consumption and the residential energy consumption per capita. Finally, and coherently with national EE indicators, we include the residential energy efficiency index, as the ratio between the household consumption expenditures and residential energy consumption, and a variable representing the change in residential energy efficiency (with respect to t-5).

Technological Innovation System

The second dimension included in the analysis provides information related to innovation capabilities in EE of the considered EU countries. Following the contribution by Costantini et al. (2014), innovation in the EE domain is measured by the count of patent applications filed at the EPO by EU countries over the period 1990-2012 from OECD PATSTATS. Accordingly, the patents included combine the technologies in the class Y02 of the Cooperative Patent Classification (CPC) with those relative to the residential EE appliances, thus including the following main technological domains: Insulation, High-efficiency boilers, Heat and cold distribution and CHP, Ventilation, Solar energy and other RES, Building materials, Climate control systems and Lighting. The selected EPO patents are classified by application date and assigned to the applicant's country. When multiple assignee countries are present for a single patent, we have assigned a proportion of the considered patent to each country on the basis of the number of assignees for each country.

We build the patent stock indicator starting from patent flows ($Pat\_EE_{i,t}$) and applying a decay rate (μ) of 15 per cent in a continuous discount approach:

$$KPAT\_EE_{i,t} = \sum_{s=0}^{t} \left\{ Pat\_EE_{i,s} \cdot e^{[-\mu(t-s)]} \right\} \tag{1}$$

where i indexes countries and s represents an index of years up to and including year t. The patents stock is then used to build alternative measures of technological performance, in terms of comparative advantages (Archibugi and Pianta, 1996) and specialization (van Zeebroeck et al., 2006) in order to map EU technological trajectories and performances over time. First, we build an EE patent Balassa index as it follows (Balassa, 1965):

$$EE\_Pat\_Balassa_{i,t} = \frac{KPAT\_EE_{\,i,t} / KPAT\_Tot_{\,i,t}}{KPAT\_EE_{EU,t} / KPAT\_Tot_{\,EU,t}} \tag{2}$$

which is given by the ratio between the share of EE patent with respect to the overall patenting activity for country i at time t and the corresponding ratio at the EU level.

Furthermore, in order to provide a more detailed description of the national innovation system,

[6] All indicators in monetary terms originally expressed as constant 2010 USD have been converted in constant 2010 Euro using OECD deflator and exchange rate indicators.

we also include two additional indicators capturing national technological capabilities in the EE sector: the EE patent stock per capita and the EE patent specialisation, calculated as the ratio between the patent stock in EE and the total patent stock at the country level ($KPAT\_EE_{i,t}/KPAT\_Tot_{i,t}$).

Policy Mix

The third dimension refers to policy mix design for energy efficiency and includes information divided in three pillars according to Costantini et al. (2017a). The first is the *Demand-pull* policy indicator, a price-based instrument that represents the impact of energy taxation on the market price for energy demand in the residential sector. What we are interested in is capturing the role of this policy in affecting residential energy consumption and consequently favouring EE innovation via a price mechanism (Newell *et al.*, 1999; Noailly, 2012; Popp, 2002; Verdolini and Galeotti, 2011). Accordingly, we calculate the average tax rate applied to energy consumption in the residential sector for each country and year as an ad valorem equivalent on energy market price (here expressed as Euro at constant 2010 prices per tonnes of oil equivalent (toe) of energy consumed). In order to account for different mixes of energy commodities used in the residential sector at the country level, we weight energy tax rates by consumptions related to each specific source as follows:

$$Demand\_pull_{i,t} = Energy\_tax_{i,t} = \frac{\sum_{n=1}^{2}\left(Energy\_tax_{i,t}^{n} \cdot Ener\_cons_{i,t}^{n}\right)}{\sum_{n=1}^{2}\left(Ener\_cons_{i,t}^{n}\right)} \tag{3}$$

where n indexes the energy commodity (electricity and natural gas), whereas i and t refer to countries and time, respectively. Tax rates are taken from the Electricity and natural gas prices and taxes database, whereas data on energy consumption are taken from Electricity and natural gas consumption database for the residential sector, both available in Eurostat online database. In this way, the stringency level of the policy adopted and its relative impact on the specific residential energy input mix used in each country can be considered simultaneously, thus controlling also for the peculiarity of the residential sector within the country-specific national energy system.

The second is the *Technology-push* policy indicator. This policy instrument is quantified by taking the stock of public R&D efforts in EE. Accordingly, R&D expenditure flows taken from IEA Technology Statistics (IEA, online database) have been used in a Perpetual Inventory Method (PIM) formulation to compute stock values as follows:[7]

$$Technology\_push_{i,t} = KRD\_EE_{i,t} = \sum_{s=0}^{t}\left\{RD\_EE_{i,s} \cdot e^{[-\partial(t-s)]}\right\} \tag{4}$$

where $\forall s = 0 \Rightarrow RD_{EE_{i,s}} = RD_{EE_{i,s}}/g$ with g representing the average annual growth rate of R&D expenditures at constant prices throughout the whole period. In so doing, we are supposing that

[7] Data originally expressed as constant 2015 USD have been converted in constant 2010 Euro using OECD deflator.

technological knowledge has a cumulative character and, hence, can be summed over time, but that knowledge capital is also subject to an obsolescence rate represented by the discount procedure (Evenson, 2002).

We have applied an average discount rate of 15 per cent as suggested by OECD (2009), so that similarly to eq. (1) ∂ indicates the discount rate, i indexes countries and t and s indicate time.

Afterward, we build a quantitative measure of the *Policy mix balance* between demand-pull and technology-push instruments in the domestic policy mix, computed as the difference between these two policy domains. Considering that these are expressed in different units, Euro per toe for energy tax and millions of Euro for R&D in EE, we have scaled this second indicator by total residential energy consumption, thus obtaining two homogenous measures expressed in Euro per toe. The empirical formulation of this measure is built as follows:

$$Pol\_balance_{i,t} = Energy\_tax_{i,t} - \frac{KRD\_EE_{i,t}}{\sum_{n=1}^{2}\left(Ener\_cons_{i,t}^{n}\right)} \qquad (5)$$

Given the structure of this indicator, values close to 0 indicate a close similarity in the intensity of the two policy instruments, while negative values indicate a preference towards technology-push with respect to demand-pull and vice versa.

A further characteristic of the policy mix under scrutiny refers to its *Comprehensiveness* and thus includes all types of instruments, where different instruments are homogeneously mapped and quantified in a binary (0-1) system. Here, we collect information from the IEA database on Energy Efficiency Policy Online Database (IEA, 2016b) in three sectors (buildings, lighting, residential appliances) for EU countries in the 1990-2012 period, classified in six types: Economic instruments; Information and education; Policy Support; Regulatory instruments; Research, development and deployment; Voluntary approaches (Table 1).

Considering the qualitative information of the IEA database, we have assigned value 1 if there is a policy for each country and year. The final measure is given by the sum of counts as the cumulative number of policy instruments in force at time t in country i.

Accordingly, we calculate a proxy for policy mix *Comprehensiveness* as an aggregate stock of total policies for EE given by the sum of the stocks of policies belonging to the whole range of policy types described in Table 1:

$$Comprehensiveness_{i,t} = \sum_{q=1}^{6}\left(\sum_{s=0}^{t}\left(Pol_{i,s}^{q}\right)\right) \qquad (6)$$

where $q \in [1,2,\dots,6]$ represents all the six policy types.[8]

The fourth indicator includes information on EE policy *Soft & systemic instruments*. For the construction of this indicator, we only consider policies collected by the IEA database (Table 1) and classified in types $q \in [2,3,6]$, namely Information and Education, Policy Support and Voluntary

[8] If multiple instruments are included in the same policy, when summed up in the comprehensiveness measure, each policy is univocally classified in order to avoid double counting bias.

Approaches. With regard to the first type, it includes all forms of support to the cognitive-informational context as guidelines and recommendations to improve the adoption of energy saving behaviors at the household level or to diffuse the notion of EE at different education degrees in order to prepare executives to be ready to adopt an energy-efficient managerial culture. The second type includes systemic instruments that aim to reinforce the support provided by the institutional context in achieving EE targets such as, for instance, through the creation of ad hoc government agencies (e.g., the creation of the National Agency for Energy Efficiency in Italy in 2008).[9]

Table 1 – Policy types and instruments

Type #	Policy Type	Instrument
1	Economic Instruments	Direct investment
		Fiscal/financial incentives
		Market-based instruments
2	Information & Education	Advice/aid in implementation
		Information provision
		Performance label
		Professional training and qualification
3	Policy Support	Institutional creation
		Strategic planning
4	Regulatory Instruments	Auditing
		Codes and standards
		Monitoring schemes
		Obligation schemes
		Other mandatory requirements
5	Research, Development & Deployment (RD&D)	Demonstration projects
		Research programmes
6	Voluntary Approaches	Negotiated agreements
		Public voluntary schemes
		Unilateral commitments

Source: IEA (2016b).

The third type refers to all voluntary approaches that may help the introduction and adoption of energy-efficient behaviours, as described by Kemp (1997), consisting in agreements between private agents and governments to assist consumers and building industries in achieving better energy performances (e.g., the Voluntary Agreement on the Phase Out of Incandescent Light Bulbs adopted in UK in 2007 and, similarly, the Incandescent Lamp Phase-out implemented in France in 2008). Considering the qualitative information of the IEA database, the final measure of soft and systemic instruments is given by the sum of counts as the cumulative number of these policy instruments in force at time t in country i with respect to comprehensiveness:

$$Soft\_systemic_{i,t} = \frac{\sum_{q=2,3,6}\left(\sum_{s=0}^{t}\left(Pol_{i,s}^{q}\right)\right)}{Comprehensiveness_{i,t}} \quad (7)$$

where $q \in [2,3,6]$ represents the three policy types selected as specified in Table 1.[10]

[9] We acknowledge that policy instruments with systemic purposes can be in principle found in other policy types. However, in the absence of an *ad hoc* classification by IEA in this sense, in order to avoid arbitrary choices in the construction of the indicator, we focus on the policy types for which the systemic nature of instruments is prevalent.

[10] According to Rosenow et al. (2017), the empirical measurement of comprehensiveness of the policy mix for a long term energy transition process can be enriched by several characteristics that might help better qualifying differences in instruments mix at the country level. We acknowledge that our measure of comprehensiveness is less accurate than that discussed by the authors, but it helps combining a wide range of countries in a long time series.

International trade performance

The fourth dimension included in the analytical framework provides a representation of trade performances of EU countries related to EE technologies domain for the residential sector. The indicators built for the cluster analysis are all at the country level, while the ex-post cluster analysis is also based on bilateral export flows. The country-pair and total export flows are taken from the UN-COMTRADE database and cover the class 775 of SITC Rev.3: Household-type electrical and non-electrical equipment, n.e.s. (Household-type laundry equipment, refrigerators and food freezers, Dishwashing machines, Shavers and hair clippers, Electromechanical and Electrothermic domestic appliances). Such data allow building three indicators. First, coherently with the innovation performance dimension, we compute an EE trade Balassa index. In line with the EE patent Balassa index, we computed the EE trade Balassa indicator as follows:

$$EE\_exp\_Balassa_{i,t} = \frac{Export\_EE_{\,i,t}/Export\_man_{\,i,t}}{Export\_EE_{EU,t}/Export\_man_{\,EU,t}} \tag{8}$$

In this case, we consider the ratio between the country and EU in terms of the relationship between the export flows in the EE residential sector identified and the overall export flows in the manufacturing sector.

In addition, we also include an EE trade specialization index as the share of trade in EE with respect to trade in manufacturing ($Export\_EE_{\,i,t}/Export\_man_{\,i,t}$) and the ratio between the share of country export in EE and the GDP share with respect to EU:

$$EE\_export\_GDP_{i,t} = \frac{Export\_EE_{\,i,t}/Export\_EE_{\,EU,t}}{GDP_{i,t}/GDP_{\,EU,t}} \tag{9}$$

3.2. Principal components and cluster analysis

In order to classify EU countries in homogeneous groups on the basis of the previously described dimensions, we perform a cluster analysis. This procedure seeks “to uncover groups in data” (Everitt et al., 2001, p. 5). In other words, it identifies groups of units that are similar to each other within the group, though they differ from units that belong to the remaining groups. A similar analysis has been recently developed by Marin et al. (2015) for eco-innovation patterns at the firm level based on the Eurobarometer dataset. According to the authors, such kind of analysis is particularly helpful in advising policy makers for policy mix design processes applied to complex systems.

In order to have a representative picture of the current EU characteristics, we perform the analysis on the last period of our dataset taking data as three-year average values (2010-2012).[11] We normalized the variables to have values with a mean equal to 0 and variance equal to 1 (Z-scores) and, before applying the cluster analysis, we perform a preliminary Principal Component Analysis (PCA) to avoid potential correlations between variables in the cluster procedure, given that several indicators in the same dimension rely on similar variables. PCA is a technique that replaces the

[11]See Tables A2-A3 in the Appendix.

original variables by a smaller number of derived variables, the principal components (PCs), which are linear combinations of the original variables (Jolliffe, 2002). In so doing, it reduces the dimensionality of a dataset by extracting only the information that is essential for representing the variance of the phenomena. In this regard, to select the number of PCs to be retained, we follow the Kaiser criterion, according to which the components to be selected are those with eigenvalues greater than 1 (Hsieh et al., 2004; Kaiser, 1960). Accordingly, we select six PCs to which we apply the cluster analysis. It is worth noting that this number of components explains 84% of the cumulative variance, thus respecting also the alternative selection criterion that, as illustrated by Jolliffe (2002), consists of selecting the number of components that explains an established variance threshold level in the range 70–90%.[12]

Following Hair et al. (2009), the cluster analysis is conducted in two steps. The first one is a hierarchical cluster analysis to determine the optimal number of clusters. The second step consists of using the number of clusters obtained in the first step to inform a non-hierarchical clustering process.

As for the first step of the cluster analysis, the hierarchical clustering process consists of four phases (Johnson, 1967): (i) to allocate each item in a distinct cluster so that there are N clusters; (ii) to identify the closest (most similar) pair of clusters and unify them into a single one, obtaining N-1 clusters; (iii) to compute distances (similarities) between the new cluster and each of the old clusters; (iv) to run again phases (ii) and (iii) until the delivery of one single cluster for all items (size N). Alternative hierarchical methods exist, depending on the way distances are computed in phase three. The method used in this analysis is the single linkage, according to which the distance between one cluster and another is equal to the smallest distance from any member of one cluster to any member of the other cluster. This is computed in terms of the Euclidean distance, which is the square root of the sum of squares of the differences between the coordinates of the points. Once the entire process is completed and the hierarchical tree is obtained, it is necessary to choose the optimal number of clusters (k). To this purpose, the Duda–Hart test is conducted (Duda and Hart, 1973) and interpreted according to Cao et al. (2008). This test gives as a result a three-columns matrix: the first column indicates the number of clusters, the second column provides the corresponding Duda–Hart Je(2)/Je(1) index stopping-rule, whereas the third one shows the pseudo-T-squared values. From the comparison of these two values, it emerges that in our analysis the best number of clusters is four, as it has a high Duda–Hart Je(2)/ Je(1) value (0.88) associated with a low pseudo-T-squared value (1.63).[13]

Accordingly, four is the number of clusters implemented in the second step of the cluster analysis, namely a non-hierarchical k-means clustering in which the number of groups must be pre-

[12] See Table A4 and Figure A2 in the Appendix.

[13] The Duda–Hart Je(2)/Je(1) index is the ratio between the total within sum of squared distances about the centroids of the clusters for the two-cluster solution (Je(2)) and the within sum of squared distances about the centroid when only one cluster is present (Je(1)), as reported in Table A5 in the Appendix. The optimal number of clusters equal to four is also confirmed following the alternative Calinski selection criterion based on the Harabasz pseudo-F statistics (Table A6 in the Appendix).

determined. This method aims to reduce to minimum the sum of the distances of each item from the centroid of its cluster, thus the intra-cluster variance (MacQueen, 1967). At the end of the process, the final composition of the four clusters is achieved.[14]

3.3. Post-cluster analysis

Since the main objective of this work is to investigate the EE system transition of EU countries, we use the clusters obtained after the three-step analysis as a criterion to map in a systematic way the current characteristics of countries and to analyse their evolution over the last two decades. Both the PCA and cluster analysis are instrumental for dividing the countries in homogeneous and differentiated groups and are preliminary to the co-evolutionary analysis. Accordingly, the different country-groups obtained by the cluster procedure are then analysed by applying the original variables and four additional indicators that allow describing the intra-cluster and inter-clusters characteristics and linkages according to the conceptual framework in Figure 1. First, we consider the export share of energy commodities in the residential sector (UN-COMTRADE digit 775 as described in Section 3.1) of each country *i* with all *c-1* countries belonging to same cluster (intra-cluster):

$$EE\_exp\_share_{i,t} = \frac{\sum_{j=1}^{c-1} Export\_EE_{i,j,t}}{Export\_EE_{i,EU,t}} \quad (10)$$

where *j* indicates countries belonging to the same cluster of country *i* and *c* the number of countries included in the cluster or belonging to each other. Second, we consider the export share of energy commodities in the residential sector of each country *i* with the other clusters (inter-cluster).

Third we introduce the concept of intra-cluster policy balance similarity. In line with Costantini et al. (2017a), it is calculated considering the policy balance distance between each *i-th* country and the other *j* countries belonging to the same cluster as:

$$Pol\_bal\_sim_{i,t} = \frac{1}{c-1}\sum_{j=1}^{c-1}\left|Pol\_balance_{i,t} - Pol\_balance_{j,t}\right|^{-1} \quad (11)$$

The higher the value, the closer the similarity of each *i-th* country with respect to the others belonging to the same cluster.[15]

Fourth, we include an indicator that jointly takes into account bilateral export flows and balance similarity that each country has with all the other *n-1* European countries, independently from the

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[14] The k-means algorithm consists of four phases: i) to determine the centroids; ii) to calculate the distance between cluster centroid to each object and assign each object to a cluster based on the minimum distance; iii) to compute the new centroid of each group based on the new memberships; iv) to run again phases two and three until the assignments no longer change. Results remain stable even by applying alternative hierarchical methods (e.g. centroid, average and median linkage methods). We applied the described methodology also to the data normalized according to the min-max method, as well as to the variables in their original levels, and the number of clusters and their composition remain the same. Considering the Z-score normalized data, we perform further analysis to test the robustness of the cluster analysis, by replicating the clustering procedure considering a lower number of PCs as well as rotated components and the same countries' aggregation emerges.

[15] In eq. (11), we apply an average value instead of a sum in order to obtain a measure independent from the number of countries composing each cluster.

cluster they belong. Accordingly, we build a weighted policy balance similarity indicator given by the sum of the policy balance distance between each *ij* European country-pair weighted by the share of the export of country *i* towards country *j* with respect to the export towards all the *n* countries considered.

$$W\_Pol\_bal\_sim_{i,j,t} = \sum_{j=1}^{n-1} \left(\frac{Export\_EE_{i,j,t}}{Export\_EE_{i,EU,t}} * \left| Pol\_balance_{i,t} - Pol\_balance_{j,t} \right|^{-1} \right) \qquad (12)$$

In this case, the indicator must be interpreted as follows: higher values are associated with countries that have higher balance similarity with respect to their main trade partners.

The adoption of these indicators, additional to those used for the cluster analysis, allows better detecting if and to what extent the different channels described in the analytical framework can be highlighted by the empirical evidence. The combination of the information on domestic country features with that of bilateral relationship represents a first step in understanding if co-evolving dynamics occurred in this specific technological domain.

4. Results

4.1 The analysis of internal dimensions

According to the methodology described in Section 3, the 19 EU countries selected in the dataset can be pooled into four groups. Table 2 describes the final composition of each cluster and Table 3 reports the mean and the standard deviation values for the 19 variables in the most recent period (three-year average value 2010-2012) calculated on countries forming each cluster.

Table 2 - Clusters composition

Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**
Finland	France	Czech Republic	Austria
Ireland	Greece	Estonia	Belgium
UK	Italy	Hungary	Denmark
	Portugal	Poland	Germany
	Spain	Slovak Republic	Netherlands
			Sweden

Cluster 1 consists of three countries, Finland, Ireland and the UK; Cluster 2 is formed by Mediterranean countries such as France, Greece, Italy, Portugal and Spain; Cluster 3 assembles Eastern EU countries, while Cluster 4 includes both Central and Northern EU countries, showing a leadership position in many of the dimensions here scrutinized.

In what follows we firstly describe the characteristics and evolution of each cluster with respect to the three key *internal* dimensions highlighted in the proposed conceptual framework, i.e. energy system, TIS and policy mix. Then we discuss for the same clusters, the empirical evidence on trade performance in energy efficient goods for the residential sector and on the potential sources of *external* co-evolutionary mechanisms associated with international relationships between countries.

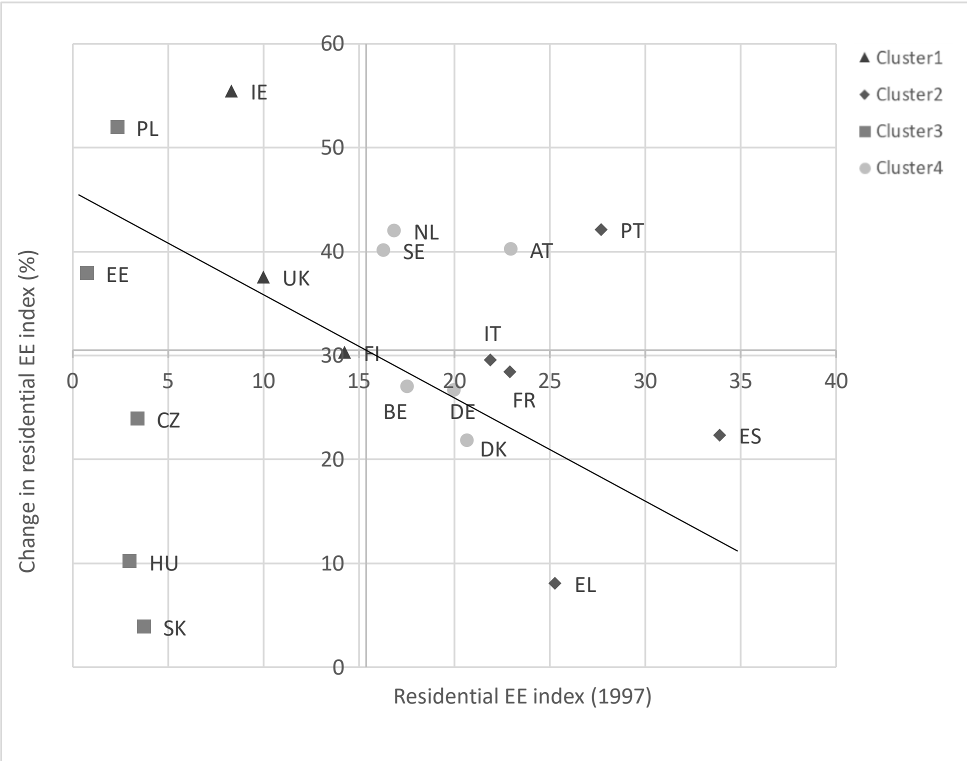
Table 3 – Clusters description (original variables, 2010-2012 average values)

	Cluster1		Cluster2		Cluster3		Cluster4	
Energy	*Mean*	*St.Dev.*	*Mean*	*St.Dev.*	*Mean*	*St.Dev.*	*Mean*	*St.Dev.*
National EE index (Mln Euro per toe)	12.33	4.15	12.06	1.38	6.09	0.37	12.44	2.13
Change in national EE w.r.t. t-5 (%)	-3.30	0.07	4.17	0.02	14.66	0.08	4.16	0.03
Energy imports (% of energy use)	57.12	28.52	68.22	13.48	37.23	22.04	38.69	33.64
Residential ener. cons. (% of tot. ener. cons.)	0.26	0.04	0.23	0.05	0.30	0.06	0.25	0.04
Residential ener. cons. p.c. (Ktoe)	0.77	0.21	0.45	0.15	0.58	0.13	0.75	0.06
Average Annual Temperature (C°)	6.78	4.40	14.21	1.88	8.45	1.83	7.89	3.04
Residential EE index (Mln Euro per toe)	23.75	5.06	33.01	6.39	11.72	3.68	24.17	1.79
Change in residential EE w.r.t. t-5 (%)	-6.28	0.10	3.40	0.08	19.61	0.21	3.82	0.07
Innovation								
EE Patent Stock p.c. (Nr. per 1000 people)	0.75	0.43	0.36	0.37	0.07	0.03	1.88	0.39
EE Patent Stock Balassa Index (Index)	0.70	0.15	1.03	0.18	1.14	0.34	1.15	0.36
EE Patent Stock Specialization (Share)	0.07	0.02	0.11	0.02	0.12	0.04	0.12	0.04
Policy								
Demand-pull (Euro)	0.15	0.10	0.23	0.08	0.20	0.04	0.33	0.11
Technology-push (Mln Euro)	0.38	0.30	0.05	0.04	0.06	0.06	0.12	0.08
Policy balance (Index)	-0.23	0.21	0.17	0.10	0.14	0.03	0.21	0.09
Comprehensiveness (Nr.)	8.10	1.73	10.03	3.97	2.37	1.69	7.60	2.14
Soft & Systemic instruments (Share)	0.35	0.19	0.39	0.14	0.38	0.33	0.47	0.08
Competitiveness								
EE Export Balassa Index (Index)	0.30	0.14	1.18	0.59	1.55	1.38	0.78	0.31
EE Export Specialization (%)	0.27	0.00	1.06	0.01	1.39	0.01	0.70	0.00
EE Export to GDP (Index)	1.62	1.37	4.75	2.55	28.89	23.66	13.61	9.99

Let us start with the evolution of the energy system. In Figure 2 we compare the "Residential EE index" in the initial period (as a three-year average for 1995-1997 on the *x* axis) with the change in residential EE (Change in residential EE index on the *y* axis) occurred between the initial and the final one (as a three-year average for 2010-2012).

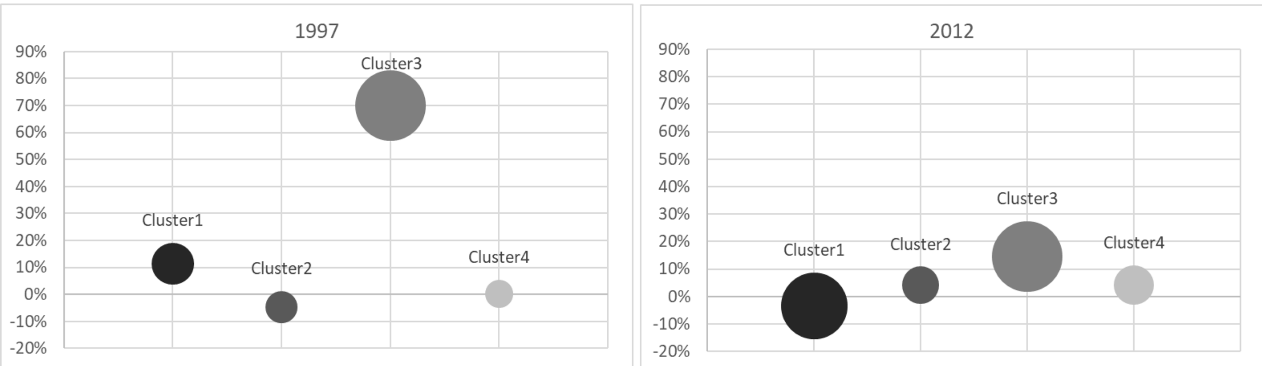
As we can see, the distinction between the four clusters is well defined. Countries belonging to Cluster 2 were the most energy efficient in the initial period (partly explained by the fact that their energy intensity is relatively lower thanks to their higher average annual temperatures), while they registered a change in EE close to the EU average in 2012 (with the exception of Greece that reports lower EE gains). Countries belonging to Cluster 4 continue to register a good performance in terms of EE, while countries for Cluster 1 show a lower initial EE index and, with the exception of Ireland, a modest improvement over time in EE for the residential sector. Finally, Cluster 3 countries are those that had the worst EE performance in the initial period, with marked differences between countries belonging to this cluster, from Poland registering high changes in EE to Slovak Republic, the country with the lowest improvement in energy efficiency. These internal differences, in addition to the initial weak performances, make Cluster 3 a very interesting case study in terms of the evolution over time of the EE system.

Figure 2 – Change in residential EE index in 2012 w.r.t. 1997



In Figure 3 we look at the change in national energy efficiency with respect to the previous five years (t-5) occurred in two temporal points, namely in 1997 (w.r.t. 1992) and in 2012 (w.r.t. 2007).

Figure 3 – Change in national energy efficiency w.r.t. t-5 (1997 and 2012)

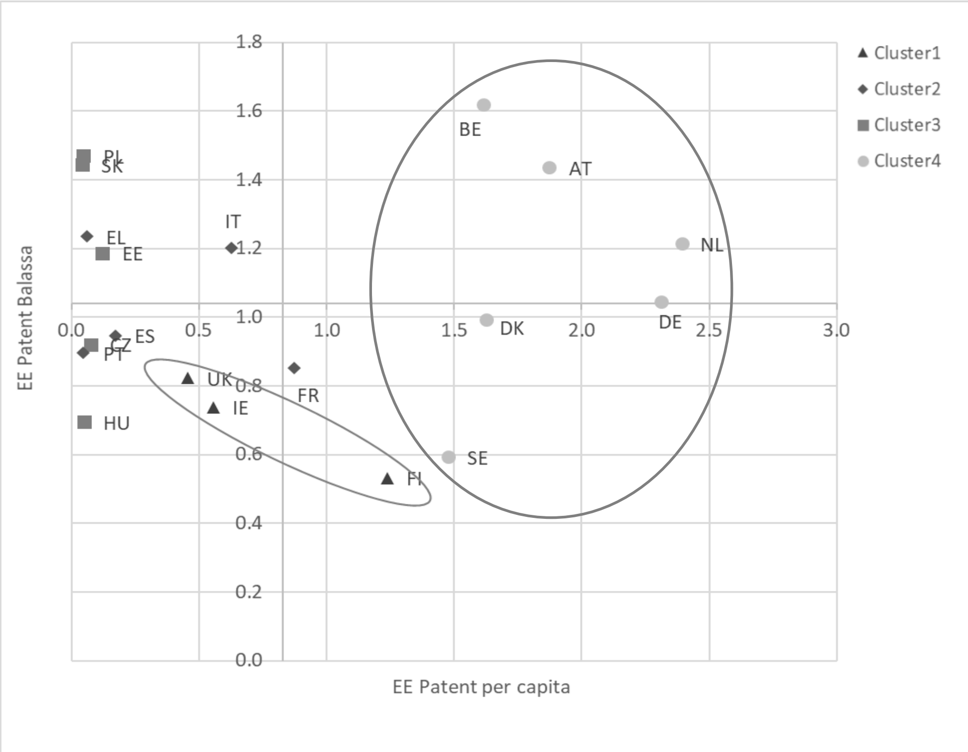


Note: the diameter of each circle is given by the standard deviation within each cluster. The larger the diameter, the greater are intra-cluster differences.

Cluster 3 is the one with the highest improvements in 1997 with respect to 1992, mainly due to the large economic growth experienced by East European countries in those years. In addition, their initial weak EE performance has contributed to achieve larger improvement, also due to the implementation of new instruments and measures to foster EE. Over the years, this dynamics decreases up to the last period under scrutiny in which we can see an alignment with the other clusters for what concerns the level of national EE, while on the contrary the heterogeneity degree of countries belonging to Cluster 3 remains unchanged over time.

Let us now look at the TIS performance here captured by patent indicators. Figure 4 plots the number of EE patents per capita, a measure of absolute technological capabilities in this specific domain, against the EE patent Balassa index, which measures the relative technological specialization of each country in EE technologies.

Figure 4 – Relation between EE patent per capita and EE patent Balassa index (2012)

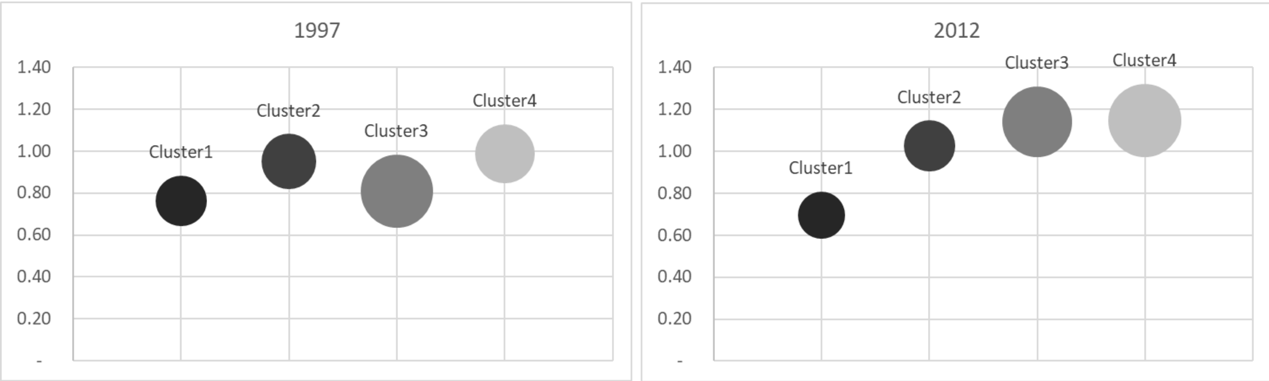


Countries belonging to Cluster 4 have the strongest innovation capacity, with the highest levels of EE patent per capita among the considered EU countries. However, while Austria, Belgium, and (to a lesser extent) Netherlands show a technological specialization in EE technologies, Denmark and Germany report an average specialization, and Sweden an under-specialization. Interestingly enough, countries of Cluster 1 for which we already observed a poor performance in terms of EE, show to be under-specialized in the generation of EE related innovations. As shown by Figure 5, Cluster 1 experienced a process of de-specialization in EE technological innovations in the examined period.

The innovative capacity in EE technologies of Clusters 2 and 3 appears to be modest with the (relative) exception of France and Italy. However, countries like Poland and Slovak Republic show a strong technological specialization in this sector. This result reflects the dynamics occurred in the period of observation, in which a convergence process between levels of technological specialization of Clusters 3 and 4 has taken place (Figure 5).

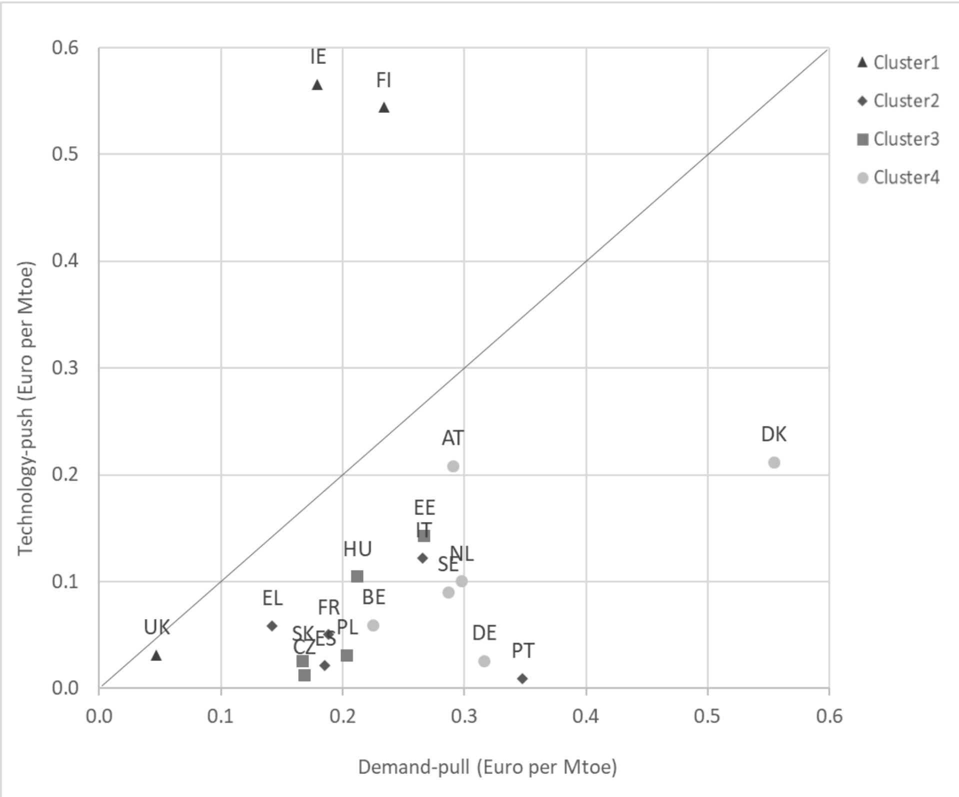
Finally, we discuss the analysis of the third internal dimension related to the public policy framework. Figures 6 and 7 describe the composition of the policy mix by comparing demand-pull and technology-push measures.

Figure 5 – EE patent Balassa index (1997 and 2012)



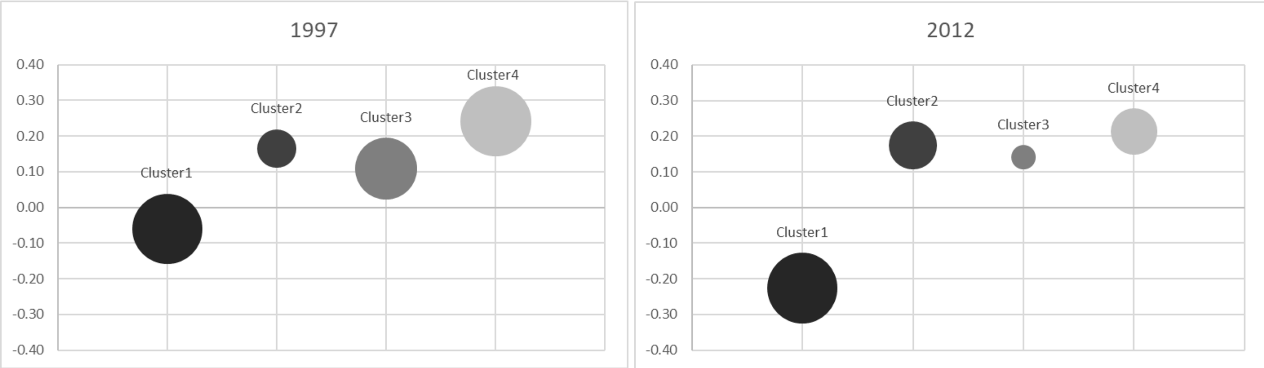
Note: the diameter of each circle is given by the standard deviation within each cluster. The larger the diameter, the greater are intra-cluster differences.

Figure 6 – Demand-pull w.r.t. technology-push policy (2012)



In the most recent period almost all EU countries are located under the bisector, meaning that most of EU countries are more demand pull-oriented. The only exceptions are Finland and Ireland, which have a very high unbalanced policy mix towards technology-push measures, a feature that became more pronounced over time as suggested by Figure 7, which shows the domestic policy balance in the two periods considering the cluster average level. Interestingly, intra-cluster differences decrease over time especially with regard to Cluster 3 and 4, as the intra-cluster standard deviation declines between the two periods (i.e. the size of the bubbles in Figure 7 decreases over time), meaning that countries belonging to the same cluster have become more similar in terms of policy mix structure.

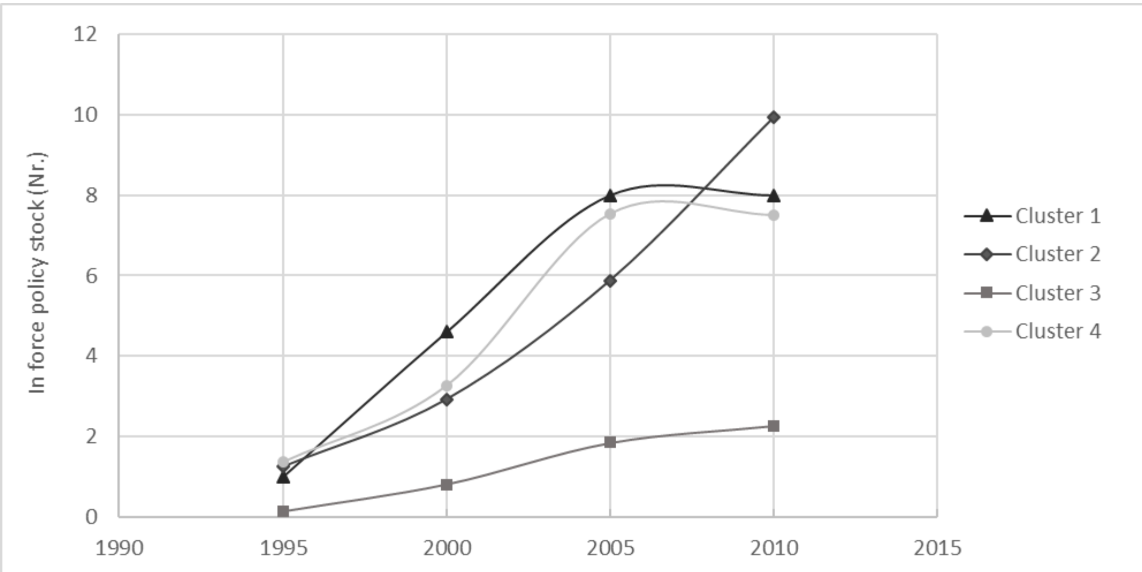
Figure 7 – Domestic balance of policy mix (1997 and 2012)



Notes: domestic balance is the difference between demand-pull and technology-push measures as in eq. (5). Accordingly, negative values indicate technology-push oriented policy mixes. The diameter of each circle is given by the standard deviation within each cluster. The larger the diameter, the greater are intra-cluster differences.

During the considered period, many instruments have been implemented by each country in order to improve the efficiency performance in the residential energy system. In Figure 8 we show the number of policies implemented by each cluster over time.

Figure 8 – Policy mix comprehensiveness



Data show that Cluster 3 is the one that implements the lowest number of policies. Moreover, it is worth noting that while Cluster 2 registers an upward trend, both Cluster 1 and 4 have a reversal trend from 2007, when they reach about eight simultaneous implemented policies. This is in line with results by Costantini et al. (2017a, p. 807), according to which there might be a "threshold level beyond which the number of policy instruments contemporaneously implemented becomes excessive, with an increasing risk of conflicting interactions leading to negative effects in terms of innovation performance".

4.2 The analysis of trade performance and external co-evolutionary mechanisms

Following our analytic framework, the trade performance in energy efficient goods for the residential sector can be shaped by the co-evolution of internal dimensions within countries, and by the external co-evolution of different economic systems via international exchanges. By focusing on the evolution of export performance as shown in Table 4 and Figures 9 and 10, it is worth noting that the four clusters behave quite differently. Table 4 reports individual countries' and clusters' export shares with respect to EU19, while Figures 9 and 10 show the evolution over years of trade specialization in EE goods for the residential sector with respect to the whole country sample.

Table 4 – Export share with respect to EU19

		Trade in EE (w.r.t. EU)		**Trade in manufacturing (w.r.t. EU)**	
Reporter	**Cluster**	**1997**	**2012**	**1997**	**2012**
Finland	1	0.55%	0.28%	1.81%	1.10%
Ireland	1	2.13%	0.43%	2.36%	2.36%
United Kingdom	1	7.02%	2.84%	10.49%	6.19%
Cluster 1 Total	*1*	*9.71%*	*3.55%*	*14.66%*	*9.65%*
France	2	12.29%	6.23%	13.08%	10.10%
Greece	2	0.34%	0.35%	0.30%	0.19%
Italy	2	29.61%	15.48%	11.54%	8.59%
Portugal	2	0.97%	0.83%	1.52%	1.30%
Spain	2	6.55%	5.42%	5.09%	5.24%
Cluster 2 Total	*2*	*49.76%*	*28.32%*	*31.52%*	*25.43%*
Czech Republic	3	0.61%	3.11%	1.37%	4.35%
Estonia	3	0.02%	0.04%	0.08%	0.22%
Hungary	3	1.49%	5.54%	0.76%	2.42%
Poland	3	0.76%	14.91%	1.21%	4.15%
Slovak Republic	3	0.73%	2.05%	0.53%	2.06%
Cluster 3 Total	*3*	*3.61%*	*25.64%*	*3.94%*	*13.20%*
Austria	4	2.00%	1.87%	3.35%	3.25%
Belgium	4	1.91%	4.62%	9.12%	9.19%
Denmark	4	2.52%	1.40%	1.75%	1.53%
Germany	4	24.71%	26.93%	24.17%	25.74%
Netherlands	4	2.41%	4.40%	8.11%	9.27%
Sweden	4	3.38%	3.27%	3.38%	2.75%
Cluster 4 Total	*4*	*36.93%*	*42.49%*	*49.88%*	*51.72%*

Cluster 1 has reduced its export quota in EE w.r.t. the rest of the EU, and decreased its already weak trade specialization in this sector. On the contrary, Cluster 4 has consolidated its trade performance while it has experienced an increase in the homogeneity degree among countries. Clusters 2 and 3 have exchanged their role since the leadership in EE comparative advantage hold by Cluster 2 at the beginning of the period has been taken by Cluster 3 in 2012 (Figure 10). This is reflected by the sharp decline in market share for Cluster 2 and the parallel jump in export quotas realized by Cluster 3.

Figure 9 – EE export Balassa index at country level (1997 and 2012)

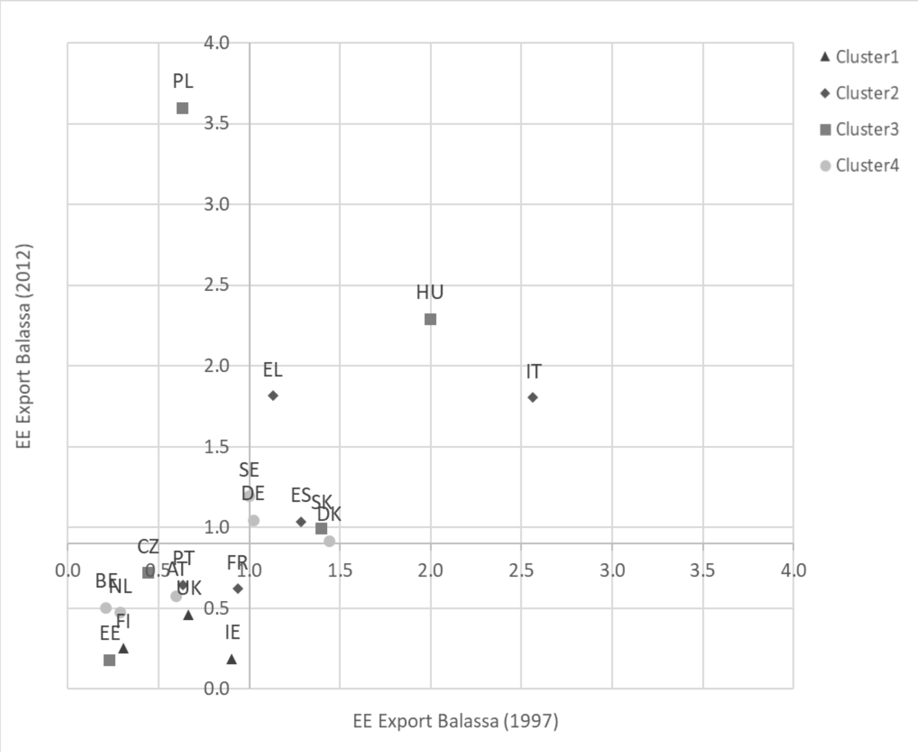
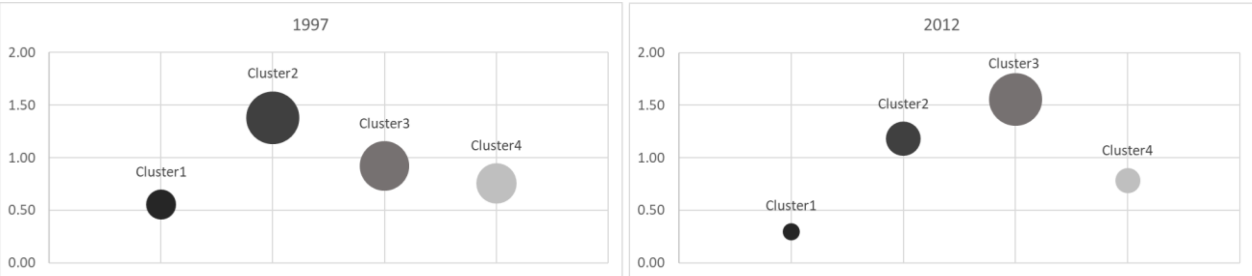


Figure 10 – EE export Balassa index at cluster level (1997 and 2012)



Note: the diameter of each circle is given by the standard deviation within each cluster. The larger the diameter, the greater are intra-cluster differences.

This dynamics mainly involved two countries, Italy for Cluster 2 and Poland for Cluster 3. During the 90s, Italy was the leader in terms of exports in EE commodities. Then, it gradually started to lose its competitive advantages (from 30% w.r.t. EU export in 1997 to 15.5% in 2012) while Poland registered relevant improvements with respect to export performances in EE commodities (from 0.76% in 1997 to 15% in 2012), even without a particular success in terms of absolute innovation performance. It is also worth noting that Poland and, more generally, Cluster 3 registered a general improvement in terms of manufacturing export performances but to a lesser extent than export performances in EE commodities. This suggests a propensity of Eastern countries towards a specialization process in this domain, shifting from the status of countries lagging behind to a rapid catching up.

Together with the Italian case, it is also worth having a closer look at France within Cluster 2. During the considered period, France experienced a reduction in both EE patent stock per capita and in relative comparative advantages in EE goods export flows, reaching a position below the EU average in 2012 for both dimensions. This evidence must be analysed combining information about energy efficiency performance as in Figure 2, and also taking into account the national energy system into the analytical framework. French energy balance is distinct form the EU average since electricity production comes mainly from nuclear power. Considering the production cost structure of these power plants, in the medium term they can ensure a secure energy supply at a very low cost. This specific condition has substantially influenced consumers' behaviour, especially in the residential sector. Given that electricity is the cheapest commodity, the residential system has adopted a consumption pattern mainly based on electrical devices, completely ignoring the use of natural gas. At the same time, the low electricity cost has provided market signal of relatively abundance, thus reducing the impulse to innovate and to adopt new technologies for saving energy. Accordingly, while other countries have needed EE innovation efforts to contain energy costs, France remained on a flat technological trajectory in this field.

These figures associated with those related to innovation performance in EE technologies show that while Cluster 4 countries were able to take advantage of *technological competitiveness* strategies in order to consolidate export performances, countries belonging to Cluster 2 mainly relying on *cost competitiveness* strategies lagged behind in both technological and trade capabilities at the advantage of new emerging exporters (Crespi and Pianta, 2008; Guarascio et al. 2016). In this respect, if we jointly consider the examined internal dimensions for Cluster 2 which suggest an excess in instruments' number and relative unbalance toward demand-pull policies, a weak performance in terms of both innovation activities and EE gains, these might contribute explaining the erosion of comparative advantages based on cost competition in favour of Cluster 3 countries.

Beside the influences played by internal dimensions, the interactions between countries in terms of both bilateral export flows and policy similarity within and between clusters, might have a role. Accordingly, we start analysing the share of EE commodities for the residential sector that each country exports towards each cluster (Table 5) in the two investigated periods (1997 and 2012).

In 1997, countries belonging to Cluster 3 had very strong bilateral trade relationships with Cluster 4. In particular, all countries but the Slovak Republic belonging to Cluster 3 had more than 50% of their exports in EE residential goods (directed to the 19 EU countries here considered) concentrated in Cluster 4 countries, with Poland's exports reaching a 70% share. As already highlighted, Cluster 4 is composed by the best performing countries on the innovation and competitiveness sides. Therefore, we might suggest that the well-established trade relationships have contributed to boosting Cluster 3 countries to improve their trade performances and their technological specialization in EE innovation over the years. While Cluster 3 has experienced an improvement in terms of export performance in EE commodities, Cluster 2, who had a strong competitive position in 1997, not only has drastically reduced its exports, but has also started to import these commodities from Eastern countries (especially from Poland).

Table 5 – Export in EE commodities share of each country towards each cluster

	Cluster 1		Cluster 2		Cluster 3		Cluster 4	
Country name	**1997**	**2012**	**1997**	**2012**	**1997**	**2012**	**1997**	**2012**
Finland	2.34%	4.69%	3.48%	9.91%	21.56%	10.56%	72.63%	74.84%
Ireland	39.16%	68.54%	22.65%	5.83%	0.93%	1.33%	37.27%	27.40%
United Kingdom	17.38%	43.33%	35.46%	22.32%	3.78%	3.31%	43.38%	31.03%
France	14.13%	7.55%	25.64%	27.40%	1.52%	8.51%	58.71%	56.55%
Greece	2.30%	7.08%	22.50%	38.71%	11.06%	4.68%	64.28%	49.62%
Italy	17.78%	14.65%	31.40%	32.97%	9.05%	10.68%	41.76%	41.71%
Portugal	5.48%	3.25%	68.05%	50.46%	0.08%	3.63%	26.39%	42.72%
Spain	10.94%	8.28%	50.48%	45.31%	4.02%	7.29%	34.55%	39.11%
Czech Republic	5.22%	4.14%	11.72%	11.65%	27.81%	21.01%	55.25%	63.21%
Estonia	47.43%	71.12%	1.54%	4.06%	2.72%	3.14%	50.29%	22.86%
Hungary	10.31%	7.25%	23.20%	24.14%	5.51%	22.19%	60.98%	46.42%
Poland	4.03%	14.10%	15.75%	32.54%	8.91%	7.92%	71.35%	45.45%
Slovak Republic	2.34%	3.35%	20.33%	24.82%	60.23%	44.38%	17.10%	27.45%
Austria	9.22%	1.39%	15.44%	18.58%	23.11%	20.16%	52.23%	59.87%
Belgium	7.01%	4.56%	45.28%	62.98%	0.89%	2.34%	46.81%	30.12%
Denmark	24.44%	17.82%	11.71%	8.75%	4.28%	3.60%	59.58%	69.82%
Germany	11.43%	10.72%	34.91%	33.40%	6.03%	12.47%	47.62%	43.41%
Netherlands	6.70%	8.73%	21.99%	13.83%	2.71%	8.27%	68.61%	69.17%
Sweden	22.62%	34.28%	31.56%	7.77%	8.38%	7.24%	37.45%	50.71%

Note: values highlighted in grey represent the intra-cluster trade.

According to these values, it is possible to suggest that the well-established trade relationships of Cluster 3 countries with leading markets have facilitated an upgrade in productive knowledge according to the *learning by exporting* effect discussed in the analytical framework.[16]

However, while this channel appears to have been effective in this case, the same cannot be said with regard to Cluster 2 (especially France and Greece) having comparable bilateral trade relationships with Cluster 4 at the beginning of the period.

The second potential channel highlighted in the analytical framework refers to *gains from trade* driven by environmental regulatory standard convergence (*California effect*) and it is here investigated by looking at the intra-cluster relationships by combining information on bilateral export flows and external policy balance. Accordingly, Table 6 compares the two indicators defined in eqs. (10) and (11), namely the intra-cluster export share and the intra-cluster balance similarity, in 1997 and 2012, respectively.

In both periods we see that, on average, Cluster 4 is the most similar in terms of policy balance even if it has the largest internal variation. Conversely, Cluster 1 is made of countries with the lowest

[16] The potential role of international relationships can be grasped by looking at international patent cooperation. By looking at the most recent available data (year 2012) on the international co-invention performance computed as the % of total patent applications in collaboration with foreign partners (OECD, 2016), countries belonging to Cluster 3 present the highest performance with an average cluster value of 25%, comparing with average values below 15% for the other three clusters.

level of intra-cluster balance similarity, followed by Cluster 3 and Cluster 2, as illustrated in Figure 11.[17]

Table 6 – Intra-cluster policy balance similarity and export share (1997 and 2012)

	1997		2012	
	Balance similarity	**Intra-cluster trade**	**Balance similarity**	**Intra-cluster trade**
Cluster 1	0.09	0.20	0.39	0.39
Intra-cluster st.dev.	*0.02*	*0.19*	*0.33*	*0.32*
Cluster 2	0.85	0.40	0.51	0.39
Intra-cluster st.dev.	*0.11*	*0.19*	*0.33*	*0.09*
Cluster 3	0.62	0.21	0.57	0.20
Intra-cluster st.dev.	*0.31*	*0.24*	*0.12*	*0.16*
Cluster 4	1.12	0.52	1.27	0.54
Intra-cluster st.dev.	*0.74*	*0.11*	*1.34*	*0.16*

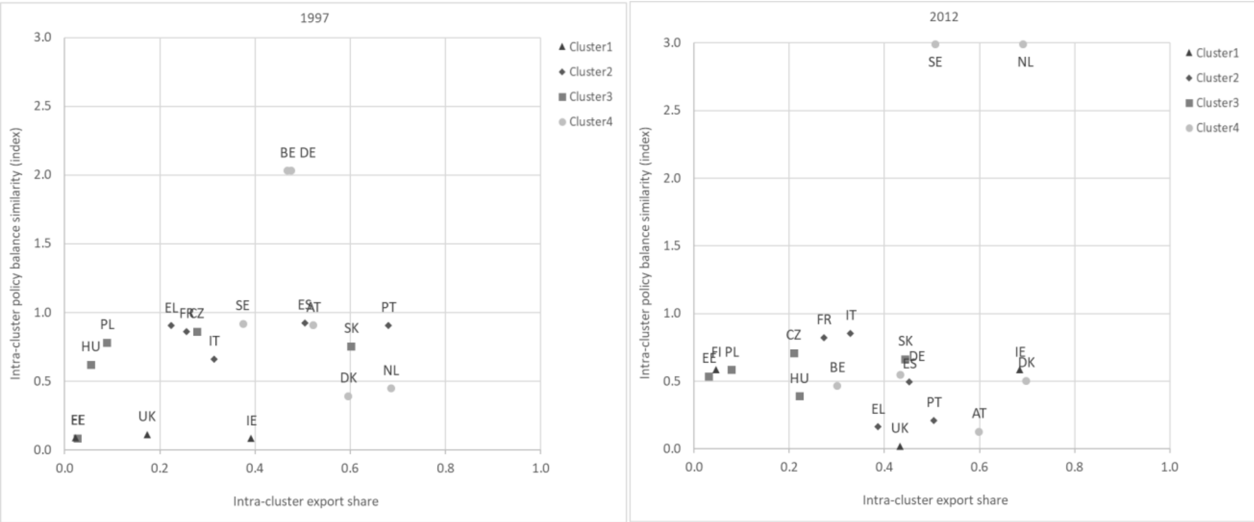
Moreover, in addition to a high level of policy balance similarity, Cluster 4 is characterized by a high intra-cluster export share. This suggests the existence of well-established intra-cluster relationships leading to knowledge and policy spillovers and, consequently, to a high performance in innovating activities and external competitiveness. Furthermore, by comparing the two periods, it is worth noting that Clusters 1 and 4 improve their balance similarity but with an increase in the internal variation. On the contrary, in 2012 Cluster 3 registers a small reduction in the average balance similarity index but a substantial decrease in the internal variation compared to the previous period, being the only cluster reaching a higher homogeneity in policy balance similarity over the analysed period. This information is in line with econometric results provided in Costantini et al. (2017a) with repsect to innovation performance, revealing that countries' competitive position can benefit of well-established bilateral trade relationships and homogenous policy mix designs (Cluster 4), and can take advantage of intense export relationships with leading economies when a process of policy mix design harmonization takes place (Cluster 3).

Finally, we consider the bilateral relationship in terms of the weighted balance similarity, which shows the policy balance similarity of each country weighted for the share of the bilateral trade towards all countries independently of their cluster with respect to its overall export to the other 18 EU markets. This can be read as an overall measure of the balance appropriateness of each country considering the characteristics of their trade partners. We build the indicator for the two time periods considered, 1997 and 2012 as shown in Figure 12. Considering a 45° line, all countries above it have experienced an improvement of their balance appropriateness between 1997 and 2012, while for countries in the right lower region of the graph the opposite holds. All countries in Cluster 3 show little variation in their weighted balance similarity between the two periods, while for the other clusters evidence is more mixed. In particular, looking at Cluster 2, France presents no difference

[17] For further details see Table A7 in the Appendix.

between 1997 and 2012, Italy is characterised by a large increase and Portugal by a large decrease in the weighted policy mix balance similarity.

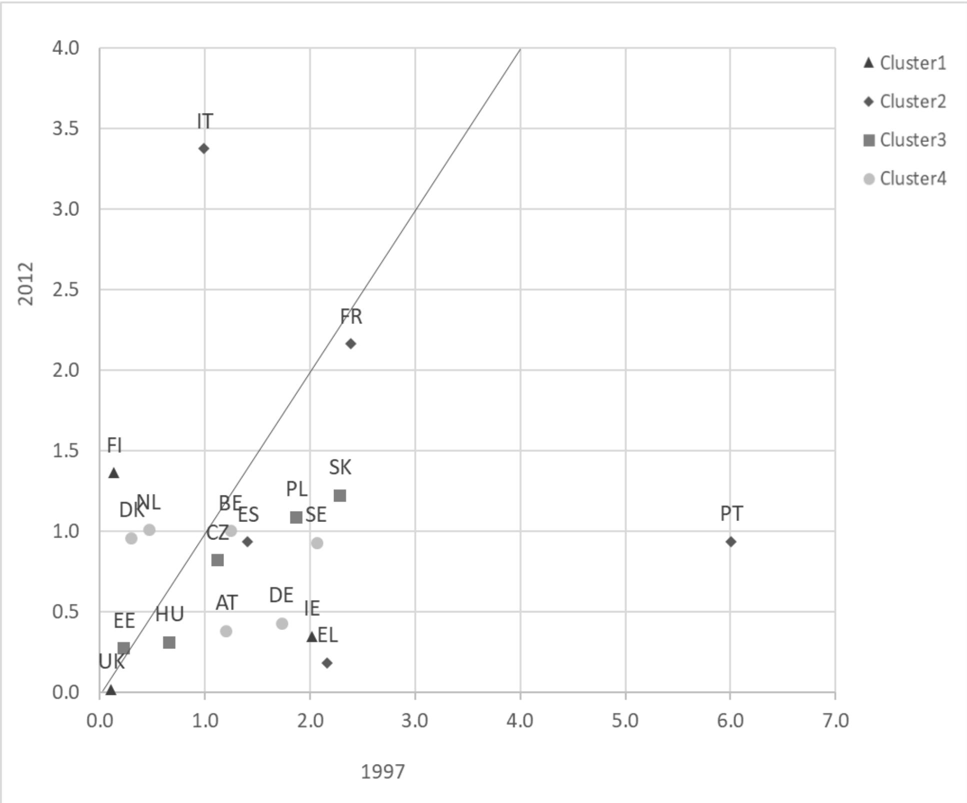
Figure 11 – Intra-cluster export share w.r.t. intra-cluster balance similarity (1997 and 2012)



If we consider that countries as France and Italy present a high level of similarity in the policy mix balance with their trading partners (or a substantial improve in the case of Italy) and at the same time are those countries that faced the worst losses in terms of export competitiveness on the EU market, it is clear that the role played by the regulatory framework is not sufficient to explain what happened in terms of external competitiveness. If we turn back to the theoretical framework discussed in Section 2, the California effect suggests that the (environmental) regulatory framework of more “advanced” export destinations might shape the domestic policy setting accordingly. In the case of France and Italy the convergence process in policy mix balance did not translate into competitiveness gains on target markets as those of Cluster 4. On the contrary, countries belonging to Cluster 3, although they maintained similar level of policy *external* similarity in the whole period, have gained substantial export shares in most advanced markets. This last evidence suggests that the relevance and magnitude of each external mechanisms in shaping country performances is strongly country and time specific.

Finally, the third channel identified in the analytical framework considers the role played by market integration and (sustainable) supply chains. As an example, we can here consider an integrated supply value chain approach applied to the analysis of bilateral trade relationships between Germany and Poland. The largest firms producing electrical appliances for domestic use are based in Germany (AEG, Bosch, Mìele, and Siemens AG just to mention a few), which is an outstanding performer in terms of patents production in EE (Figure 4). Furthermore, German regulatory standards for EE in the residential sector are stringent enough to force companies to incorporate forefront technologies in household-type electrical and non-electrical equipment (SITC Rev. 3 775 code definition).

Figure 12 – Weighted policy mix balance similarity



Accordingly, we can expect that the technological content of these appliances produced in Germany is rather high. If we consider trade flows in the 775 SITC code at the 5 digits detail, it is possible to analyse trade flows in final goods as well as in parts and components (codes 77549-77557-77573-77579-77589 available in EUROSTAT). By looking at data in the period 2002-2016 (considering three-year moving average values), there emerges a clear evolution in the supply chain structure between the two trading partners. During the whole period around 25% of German exports to Poland in the 775 branch are represented by intermediate goods, meaning that a big portion of the technological content of the final goods produced by Polish firms comes from German industries. At the same time during the same period the flows of components exported by Poland to Germany more than doubled (from a 3% in 2002 to an 8% in 2016), revealing that Polish firms start upgrading in the technological ladder in the supply value chain, also thanks to their well-established trade and technological relationships with a leading country.

This represents only one example among the multiple case studies that can be derived by our statistical analysis that is supposed to be only a preliminary investigation on such a multifaceted issue that can be certainly more deeply explored in further qualitative analyses. Moreover, an in-depth analysis of how bilateral trade relationships along the disaggregated supply value chain have evolved will help explaining catching-up processes in the sustainable energy transition, also considering the role played by extra-EU markets in gaining advantages and scaling up the technological ladder.

5. Conclusions

This paper provides a descriptive analysis of some significant characteristics of the energy efficiency in residential sector of EU countries over the past twenty years. By applying a cluster analysis, we pool EU countries into four groups. Then, by analysing and comparing them also in temporal perspective, we observe that there are multiple factors both within each cluster and among clusters that have differently shaped the evolutionary patterns of countries under scrutiny.

More specifically, our analysis suggests that the characteristics and performance of the energy system co-evolve with those of the TIS and of the policy mix, thus shaping processes of structural change and competitiveness dynamics in the domain of EE technologies. In parallel, beside internal factors, the external context via international knowledge flows and policy spillovers effects associated with trade relationships can help explain specific country/cluster trajectories.

By focusing on the policy mix composition, it emerges that almost all EU countries of our sample are demand-pull oriented, with the only exceptions of Finland and Ireland, which have a very high unbalanced policy mix towards technology-push measures. Although this convergence in policy mix design, countries appear to be highly differentiated in their degree of innovative performance and trade specialization in this field. Currently, the most specialized countries in trade in EE commodities are not those with the highest innovation performance (see the case of Poland). This suggests the emergence of a clear division of labour in the value chain, so that a part of Europe (mainly Cluster 4, e.g. Austria, Belgium, Denmark, Germany, Netherlands and Sweden) contributes to knowledge generation and acts as provider of new EE technologies, while another part of EU (mainly Eastern European countries) adopts externally generated technologies to produce and export final commodities.

According to our analysis, the different internal and external mechanisms shaping EE systems do not appear to act in a deterministic way. On the contrary, the European energy efficiency system (in the residential sector) appears to have the characteristics of a complex system that exhibits emergent properties that are specific to individual country systems (Antonelli, 2011, 2017; Robert and Yoguel, 2016). Hence, the energy efficient transformation of economic systems doesn't necessarily involve the convergence to a common development pattern, because the quality of interactions between different elements both within and outside the system can be highly specific (Crespi, 2016). As a consequence, while our empirical study allows detecting the complexity associated with the evolution of the European EE system, it also suggests that a deeper investigation of the specific country-based conditions driving transition processes is needed to better inform policy makers in future policy mix design.

Nevertheless, from our descriptive analysis two main policy insights emerge as potentially relevant. First, the implementation of policies for EE purposes appears to be a key factor to improve energy performances of countries, but there are several additional factors that contribute shaping the evolution of energy efficiency systems. Accordingly, the EU policy framework should encourage the adoption of a systemic approach into policy design able to account for the complexity of a transition system.

Second, there are potential positive spillover effects that might arise between countries characterized by similar policy mix balance and by a high level of bilateral trade relationships. The transformation of such spillovers into benefits is strictly dependent from the combination of concurrent factors that are country-specific. Accordingly, the EU policy framework should encourage countries to coordinate their specific policy mixes and EE strategies, which does not imply the adoption of a one fits for all approach in policy making, but the implementation of an adaptive policy approach able to leverage internal and external interactions to promote the sustainable development of EE systems.

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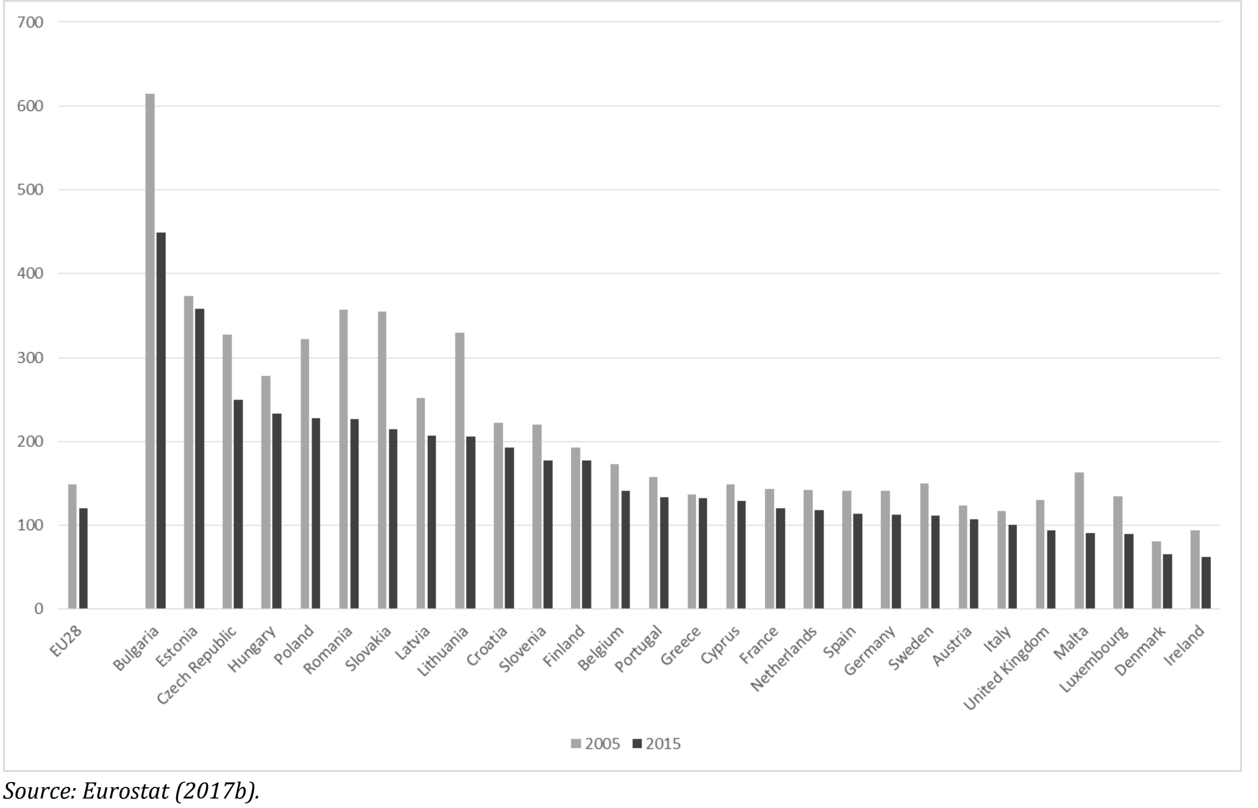
Appendix A

Figure A1 – Energy intensity, 2005 and 2015 (kg of oil equivalent per 1000 EUR of GDP)



Source: Eurostat (2017b).

Table A1 – List of variables adopted in the cluster analysis

Dimension	Variable	Definition	Source
Policy	Comprehensiveness	Number of policies (as in eq. 6)	IEA
	Demand pull	Ratio between the energy taxation levy on the total cost of energy consumption as in eq. 3	Our elaboration on Eurostat data
	Technology push	Stock of public gross R&D expenditures in energy efficiency (Euro 2010) as in eq. 4	Our elaboration on IEA data
	Domestic balance	Balance between demand-pull and technology-push policies as in eq. 5	Our elaboration on Eurostat and IEA data
	Soft & Systemic	Ratio between qualitative policies classified as EE soft and systemic instruments (as in eq. 7) and comprehensiveness	Our elaboration on IEA data
Competitiveness	EE Balassa Index	Degree of specialization of energy efficiency trade as in eq. 8	Our elaboration on UN Comtrade data
	EE Trade specialization	Share of trade in energy efficiency w.r.t. trade in manufacturing	Our elaboration on UN Comtrade data
	EE Trade w.r.t GDP	Ratio between national trade in energy efficiency share and GDP share w.r.t. EU (as in eq. 9)	Our elaboration on UN Comtrade and World Bank data
Energy	National energy efficiency index	Ratio between GDP and total energy consumption	Our elaboration on World Bank and EUROSTAT data
	Change in national energy efficiency	Change in national energy efficiency w.r.t. t-5	Our elaboration on World Bank and EUROSTAT data
	Energy imports	Energy imports (% of energy use)	World Bank (from IEA data)
	Residential energy consumption	Share of residential energy consumption w.r.t. total energy consumption	Our elaboration on Eurostat data
	Residential Energy consumption, per capita	Ratio between residential energy consumption and population (ktoe)	Our elaboration on Eurostat and World Bank data
	Temperature	Mean Annual temp. (Celsius)	World Bank
	Household energy efficiency index	Ratio between household consumption and residential energy consumption	Our elaboration on EUROSTAT data
	Change in household energy intensity	Change in household energy consumption per unit of output w.r.t. t-5	Our elaboration on EUROSTAT data
Innovation	EE Patents, per capita	Ratio between the stock of patents in energy efficiency and population	Our elaboration on OECD PATSTAT and World Bank data
	EE Patent Balassa Index	Degree of specialization of patents in energy efficiency as in eq. 2	Our elaboration on OECD PATSTAT data
	EE Patent specialization	Share of patents in energy efficiency w.r.t. total patents	Our elaboration on OECD PATSTAT data

Table A2 – Main statistics for variables adopted in the cluster analysis

Variable	Mean	Std. Dev.	Min	Max
Comprehensiveness	6.94	3.82	0.10	14.10
Demand pull	0.24	0.10	0.05	0.55
Technology push	0.13	0.16	0.01	0.57
Domestic balance	0.11	0.18	-0.39	0.34
Soft & Systemic	0.41	0.19	0.00	0.91
EE Balassa Index	1.01	0.85	0.18	3.60
EE Trade specialization	0.01	0.01	0.00	0.03
EE Trade w.r.t GDP	13.41	16.26	0.06	59.84
National energy efficiency index (Mln)	10.7	3.4	5.7	16.5
Change in national energy efficiency	0.06	0.08	-0.11	0.26
Energy imports	48.99	27.21	-14.50	88.25
Residential energy consumption	0.26	0.05	0.16	0.34
Residential Energy consumption, per capita	0.63	0.18	0.27	1.01
Temperature	9.53	3.85	1.70	16.09
Household energy efficiency index	23.16	8.92	8.67	41.02
Change in household energy intensity	-0.07	0.06	-0.21	-0.01
EE Patents, per capita	0.83	0.83	0.04	2.39
EE Patent Balassa Index	1.04	0.31	0.53	1.62
EE Patent specialization	0.11	0.03	0.06	0.17

Table A3 – Correlation

	Compr	Demand pull	Technology push	Domestic balance	Soft & Systemic	EE Balassa Index	EE Trade spec.	EE Trade w.r.t GDP	National EE index	Change in national EE
Compr	1									
Demand pull	0.0249	1								
Technology push	0.0165	0.1112	1							
Domestic balance	-0.0005	0.4699	-0.825	1						
Soft & Systemic	0.1941	0.1834	0.0088	0.0965	1					
EE Balassa Index	-0.4149	-0.0707	-0.3514	0.2719	-0.6095	1				
EE Trade spec	-0.416	-0.0706	-0.3512	0.2718	-0.6105	1	1			
EE Trade w.r.t GDP	-0.3992	-0.0699	-0.2431	0.1761	-0.1788	0.3662	0.3649	1		
National EE index	0.6601	0.2707	0.1754	-0.0019	0.1928	-0.3114	-0.3119	-0.496	1	
Change in national EE	-0.4351	0.0258	-0.2909	0.273	-0.1351	0.2103	0.2111	0.4451	-0.653	1
Energy imports	0.4407	-0.3801	0.1181	-0.3211	-0.0774	0.0164	0.015	-0.0098	0.0555	-0.2072
Residential energy consumption	-0.5266	-0.0569	-0.0301	-0.0056	-0.0212	0.3773	0.3773	0.3647	-0.1347	0.0243
Residential Energy consumption, per capita	-0.1427	0.2592	0.5233	-0.3174	0.0229	-0.3233	-0.322	-0.0113	0.0952	-0.1106
Temperature	0.2733	-0.1261	-0.4505	0.3285	0.0489	0.2035	0.2016	0.0253	0.2214	-0.1794
Household EE index	0.795	0.1194	-0.1002	0.1569	0.1118	-0.2527	-0.2535	-0.5572	0.6735	-0.4998
Change in household energy intensity	-0.4239	0.1573	-0.2896	0.3467	-0.2053	0.4611	0.4616	0.2153	-0.6077	0.5469
EE Patents, per capita	0.2492	0.4988	0.1774	0.1261	0.1752	-0.3305	-0.3308	-0.1501	0.4522	-0.3229
EE Patent Balassa Index	-0.3212	0.0173	-0.3891	0.3555	0.1268	0.2309	0.2307	0.0805	-0.2002	0.2354
EE Patent spec	-0.321	0.0174	-0.3892	0.3556	0.1263	0.2312	0.2309	0.0806	-0.1998	0.2351

Table A3 – Correlation (continued)

	Energy imports	Residential energy consumption	Residential Energy consumption, per capita	Temperature	Household EE index	Change in household energy intensity	EE Patents, per capita	EE Patent Balassa Index	EE Patent specialization
Compr									
Demand pull									
Technology push									
Domestic balance									
Soft & Systemic									
EE Balassa Index									
EE Trade spec									
EE Trade w.r.t GDP									
National EE index									
Change in national EE									
Energy imports	1								
Residential energy consumption	-0.4603	1							
Residential Energy consumption, per capita	-0.4364	0.2639	1						
Temperature	0.4531	-0.1572	-0.814	1					
Household EE index	0.4338	-0.6394	-0.4288	0.5834	1				
Change in household energy intensity	-0.1078	0.0687	-0.2388	0.0845	-0.2732	1			
EE Patents, per capita	-0.1882	-0.2072	0.6106	-0.3496	0.1264	-0.259	1		
EE Patent Balassa Index	0.0687	-0.0218	-0.2138	0.2454	-0.0852	0.3015	0.0773	1	
EE Patent spec	0.0687	-0.0219	-0.2139	0.2458	-0.0848	0.3014	0.0774	1	1

Table A4 – Principal Component Analysis (PCA)

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	5.26	1.56	0.28	0.28
Comp2	3.71	1.12	0.20	0.47
Comp3	2.58	0.77	0.14	0.61
Comp4	1.81	0.40	0.10	0.70
Comp5	1.41	0.14	0.07	0.78
Comp6	1.27	0.38	0.07	0.84
Comp7	0.89	0.16	0.05	0.89
Comp8	0.73	0.32	0.04	0.93
Comp9	0.41	0.08	0.02	0.95
Comp10	0.33	0.05	0.02	0.97
Comp11	0.27	0.14	0.01	0.98
Comp12	0.14	0.05	0.01	0.99
Comp13	0.08	0.03	0.00	0.99
Comp14	0.05	0.01	0.00	1.00
Comp15	0.04	0.03	0.00	1.00
Comp16	0.01	0.01	0.00	1.00
Comp17	0.00	0.00	0.00	1.00
Comp18	0.00	0.00	0.00	1.00
Comp19	0.00	.	0.00	1.00

Figure A2 – Eigenvalues after PCA

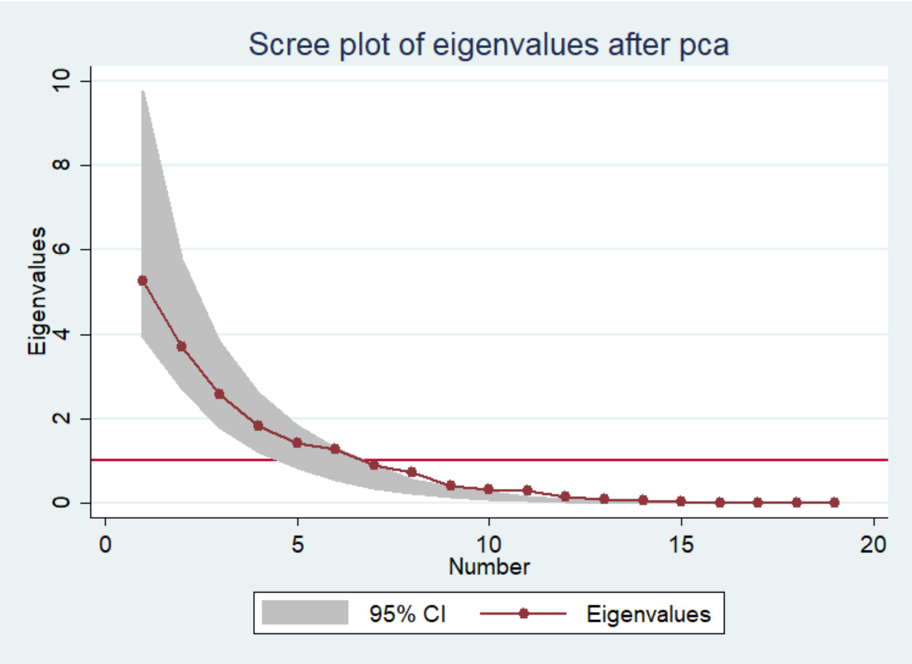


Table A5 – Duda-Hart test

	Duda/Hart	
Number of clusters	**Je(2)/Je(1)**	**Pseudo T-squared**
1	0.89	2.19
2	0.85	2.90
3	0.77	4.39
4	0.88	1.63
5	0.27	2.66
6	0.80	2.70
7	0	.
8	0.82	2.22
9	0.70	3.78
10	0.81	1.68
11	0.71	2.49
12	0.51	4.75
13	0.51	2.83
14	0.48	2.20
15	0.32	2.10

Table A6 – Calinski test

Calinski/Nr. of clusters	Harabasz pseudo-F
2	2.19
3	2.67
4	3.62
5	3.25
6	2.9
7	3.23
8	2.73
9	2.93
10	3.75
11	3.89
12	4.6
13	7.33
14	10.16
15	13.14

Table A7 – Intra-cluster policy balance similarity and export share (1997 and 2012)

		1997		2012	
Reporter	**Cluster**	**Balance similarity**	**intra-cluster trade**	**Balance similarity**	**intra-cluster trade**
Finland	1	0.09	0.02	0.58	0.05
Ireland	1	0.08	0.39	0.58	0.69
United Kingdom	1	0.11	0.17	0.02	0.43
Cluster 1		*0.09*	*0.20*	*0.39*	*0.39*
Intra-cluster st.dev.		*0.02*	*0.19*	*0.33*	*0.32*
France	2	0.86	0.26	0.82	0.27
Greece	2	0.90	0.22	0.16	0.39
Italy	2	0.66	0.31	0.85	0.33
Portugal	2	0.91	0.68	0.21	0.50
Spain	2	0.92	0.50	0.49	0.45
Cluster 2		*0.85*	*0.40*	*0.51*	*0.39*
Intra-cluster st.dev.		*0.11*	*0.19*	*0.33*	*0.09*
Czech Republic	3	0.86	0.28	0.71	0.21
Estonia	3	0.08	0.03	0.53	0.03
Hungary	3	0.62	0.06	0.39	0.22
Poland	3	0.78	0.09	0.58	0.08
Slovak Republic	3	0.75	0.60	0.66	0.44
Cluster 3		*0.62*	*0.21*	*0.57*	*0.20*
Intra-cluster st.dev.		*0.31*	*0.24*	*0.12*	*0.16*
Austria	4	0.91	0.52	0.13	0.60
Belgium	4	2.03	0.47	0.47	0.30
Denmark	4	0.39	0.60	0.50	0.70
Germany	4	2.03	0.48	0.55	0.43
Netherlands	4	0.45	0.69	2.99	0.69
Sweden	4	0.92	0.37	2.99	0.51
Cluster 4		*1.12*	*0.52*	*1.27*	*0.54*
Intra-cluster st.dev.		*0.74*	*0.11*	*1.34*	*0.16*

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