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COLLANA DEL
DIPARTIMENTO DI ECONOMIA

THE EMPLOYMENT IMPACT OF PRIVATE AND PUBLIC ACTIONS FOR ENERGY EFFICIENCY: EVIDENCE FROM EUROPEAN INDUSTRIES

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ISSN 2279-6916 Working papers

(Dipartimento di Economia Università degli studi Roma Tre) (online)

Working Paper n° 227, 2017

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Per ciascuna pubblicazione vengono soddisfatti gli obblighi previsti dall'art. l del D.L.L. 31.8.1945, n. 660 e successive modifiche.

Copie della presente pubblicazione possono essere richieste alla Redazione.

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The employment impact of private and public actions for energy efficiency: evidence from European industries

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Abstract

This paper investigates the effects of private and public actions for energy efficiency on EU employment dynamics, relying on an econometric analysis on a sector-based panel dataset for 15 EU countries (1995-2009). Results show that after accounting for the sectoral output growth, investment and innovation activities, sectoral energy efficiency gains display a negative effect on employment growth, especially in energy intensive industries. Conversely, public actions towards energy efficiency may produce positive effects on employment dynamics. Indeed, the higher incidence of taxation on energy costs, the energy efficiency gains realized in the public sector industries and the implementation of a comprehensive policy mix at the country level, are factors positively influencing employment growth. This evidence highlights the complexity of the nexus between energy efficiency and employment dynamics, suggesting that superior employment performances can be achieved when complementarity effects between productivity enhancing activities and energy efficiency actions are realized.

Keywords: Energy Efficiency, Public Policies, Employment, Manufacturing Sectors, Eco-Innovation, European Union
J.E.L. Codes: C230; L600; O330; Q520.

1. Introduction

Energy efficiency (EE) represents one of the most effective means for achieving several goals, as increasing energy security, fostering international cost competitiveness and reducing polluting emissions. In particular, achieving a more secure, sustainable and affordable energy system is recognized as a key challenge for the future world development (EC, 2011; IEA, 2012a).

Decreasing energy and carbon intensity trends may be detected in almost all economic sectors of industrialized countries, with particular regard to the manufacturing industries. Although this trend generally occurred in all advanced economies, the different policy strategies adopted at the country level during the last two decades have had a relevant role in explaining divergences in EE patterns among countries (del Rìo and Hernandez, 2007). Almost all OECD countries are implementing a wide range of policy measures to foster EE, and the EU has developed the most complete policy framework over the last decade. According to the new EU climate and energy strategy 2030, the mandatory 40% emissions reduction target is complemented by a target of 27% increase in EE by 2030 with respect to a business as usual scenario (EC, 2014). The Energy Efficiency Directive 2012/27/EU already introduced legal obligation, binding measures for energy saving schemes, specific advice for public sector and promoted both accurate individual metering to empower households and incentives for best practices and energy audits for the industry sector (IEA, 2015).[1] The EU is also promoting a modernization of the entire energy system through the planned introduction of smart meters for electricity and gas by 2020, the diffusion of easy and free access to data on real-time and historical energy consumption for consumers as well as cogeneration activities. By looking at the past, EU countries seem to have preferred to implement regulatory instruments (e.g. codes and standards, obligation schemes) first and then economic instruments (e.g. direct investment, fiscal/financial incentives,[2] white and green certificates[3]), while policy support

[1] Earlier measures are: Directive 2010/30/EU on energy labelling requirements; Directive 2010/31/EU on energy performance certificates and energy performance requirements for buildings; Directive 2009/125/EC on eco-design requirements for energy-related products.

[2] Financial incentives include subsidies for energy audits or investments and soft loans. Fiscal incentives include tax reduction, tax credit or accelerated depreciation, tax on inefficient equipment (appliances and cars). Economic

tools, research, development and deployment (RD&D) instruments and voluntary approaches were implemented only after the year 2000 (Costantini et al., 2014).

The achievement of an EE target in an advanced economy can be ensured by two channels: first, a pure reduction in energy consumption through changes in consumption and production (energy saving) behaviours; second, adopting new EE technologies that help reducing energy intensity while maintaining high standards in energy services.

With respect to the latter, public support to EE innovation and technology diffusion is crucial to improve the productivity of energy inputs and reduce energy costs, fostering the diffusion of new more efficient environmental-friendly technologies. According to the hypothesis formulated by Porter and van der Linde (1995), the increased demand for EE technologies induced by compliance requirements to policy targets may deliver a strong stimulus for the whole national system of innovation to provide the requested new technologies, allowing the system to be more competitive, with better performances also in terms of economic growth and job creation (Ghisetti and Quatraro, 2017; Mowery et al., 2010). This approach is fully considered in the EU medium term plan, since creating new market opportunities and new jobs is one of the explicit objectives of the EU green growth policy.[4]

In this perspective, understanding how the greening process of economic systems affects economic performance and employment dynamics, and how policies and innovations for the transition to a low-carbon economy can smooth the "jobs versus environment" nexus becomes a key point (Consoli et al., 2016; OECD, 2012; Rennings et al., 2004).

According to previous literature, an interesting perspective to analyse this issue is to look at the evolution of both environmental and labour productivity (Mazzanti and Zoboli, 2009). While

incentives can be defined as a fixed amount, as a percentage of the investment (with a ceiling), or as a sum proportional to the amount of energy saved.

[3] White certificates often imply a legal obligation for energy companies (suppliers, retailers or distributors, usually electricity and gas utilities) to undertake EE activities with their customers.

[4] Today this appears even more relevant given the impacts of the recent economic and financial crisis, which have affected both the environmental and economic dimensions resulting, among other, in decreasing energy demand and increasing unemployment rate. According to EUROSTAT data, after the crisis the EU employment rate started declining from the 2008 peak of 65.8%, recovering that level only in 2015.

stagnating economic dynamics can deliver a reduction of energy consumption and polluting emissions, a flat dynamics of labour productivity may represent a signal of low production efficiency associated with low investment levels towards generation and adoption of environmental technologies. However, these investments have been shown to be at the basis of positive complementarities between labour and environmental performances (Cecere and Mazzanti, 2017). Hence, differentiated patterns among countries and sectors in the co-evolution of environmental and productivity dynamics might explain different employment dynamics, reflecting the prevalence of complementarity or trade-off effects between labour and environmental performances (Marin and Mazzanti, 2013).

For instance, over the last twenty years large differences in labour productivity and EE dynamics have been registered between EU countries. If we look at three major EU manufacturing countries (i.e. France, Germany and Italy), while the first two countries experienced significant progresses in both dimensions, Italy showed a weak dynamic in EE while registered the worst performance in terms of employment rates (IEA, 2016).

Given this analytical framework, the objective of this paper is to provide an evaluation of the impact of EE actions implemented by both the private and the public sectors on employment dynamics. At the best of our knowledge, there are no systematic empirical investigations of the relationship between EE actions and employment dynamics, although as previously mentioned this issue might be of particular relevance for policy design, as the speeding up of a sustainable transition process might be one solution to social challenges such as reducing inequalities and promoting inclusive growth, if positive complementarities between labour use and EE take place.

The rest of the paper is structured as it follows. Section 2 describes the main relevant issues arisen in the existing contributions and provides the context of the analysis. Section 3 describes data and methodology, while Section 4 discusses the empirical model and summarizes the main results. Section 5 concludes and provides the policy implications.

2. Background literature and research hypotheses

The ongoing economic and financial crisis has engendered increasing attention to a transition to the green economy as a powerful mechanism to escape from the current downturn, especially in the EU (EC, 2012). This implies that not only environmental objectives should be achieved without harming economic competitiveness, productivity and economic growth, but also that the framework of policies designed to promote environmental sustainability should be able to sustain economic recovery and employment growth (Crespi, 2016).

Accordingly, two opposite views emerge from the literature. From the one side, environmental protection policies are expected to have a negative or at least neutral impact on employment. From the other side, there is a flourishing literature strand that stresses potential win-win effects associated to stringent environmental policies.

With respect to the first view, the negative impact of stringent policies on the labour market can generate: a reduction of aggregate employment; no significant variation in employment rates; a change in the distribution of employment in favour of industries with relatively better environmental performance (CEDEFOP-OECD, 2015).

In the debate on the trade-off between environmental protection and job creation, the most common argument supporting the possible negative effect of introducing more stringent environmental regulations is related to the higher costs that firms may face, and the related harmful effect on productivity and competitiveness (Dechezleprêtre and Sato, 2014). According to this view, the increasing production costs due to environmental regulation would determine an increase in the output prices and an output contraction that, coupled with lowering demand level, would result in sale losses, lower labour productivity and, eventually, job losses (Hazilla and Koop, 1990). The actual magnitude of this negative effect depends on several issues as: the pass-through mechanism according to which the cost increases result in price increases; the demand elasticity of output; the differences in term of labour intensiveness between conventional and environmental activities, where the latter are usually considered more labour intensive (Morgenstern et al., 2002). In addition, considering the sectoral heterogeneity, the employment effect also depends on the magnitude of the compliance expenditures with respect to the industries' revenue, the energy intensiveness and the industry size, so that larger losses are expected for power and energy producers and energy intensive industries as minerals and metals production processes (EPA, 2011). In this regard, while environmental regulation may generate a reduction in the employment level in certain sectors, the net aggregate effect also entails the creation of new jobs associated with environmental activities, suggesting a reallocation from regulated to less polluting (or polluting-control) industries (Bartik, 2015).

On the other hand, from the seminal works of Porter (1991) and Porter and van der Linde (1995), the alternative view of the so-called Porter Hypothesis (PH) supports the idea that environmental regulation, rather than merely increasing production costs can stimulate innovation and foster economic performances. The core rationale of this paradigm is that the introduction of more stringent environmental regulation, spurring innovation (in general, and eco-innovation in particular), contributes in reducing the inefficiencies associated with material and resource consumption, thus positively affecting environmental performance, lowering production costs, improving human resources' skills and fostering the overall productivity and competitiveness (Ambec et al., 2013; Antonioli et al., 2013). Therefore, the technological improvements and innovation prompted by environmental regulation, partially offsetting firms' compliance costs, can lead to a win-win situation for environmental sustainability, economic profitability and enhanced competitiveness.

The weak version of the PH highlights the positive influence of well-designed environmental regulation on innovation and the inducement effect on green innovations sectors. While there are numerous contributions supporting the effectiveness of this mechanism, results are still quite heterogeneous depending on the specific regulation measure and technology type (Cleff and Rennings, 1999; Jaffe and Palmer, 1997). Accordingly, more stringent regulation can positively stimulate investments in green technologies, but also needs to be properly integrated with innovation exploration and exploitation policies in a comprehensive policy mix (Costantini and Crespi, 2008; Hoppmann et al., 2013). The strong version of the PH, on the other hand, postulates also a positive influence on the economic performance of the whole system, according to which the positive effects of innovation (due to environmental regulation) exceeds the negative ones associated with the regulation itself. While previous studies highlighted a negative impact on productivity (Jaffe et al., 1995), more recent ones find a positive effect on firms' performance, mainly due to a more appropriate treatment of the dynamic aspects, accounting for the longer time horizon in which the economic gains may emerge (Costantini and Mazzanti, 2012; Ghisetti and Rennings 2014).

These results shed new light on the importance of potential complementarities between environmental and labour productivity as early discussed as eco-innovation activities seem to foster the creation of new jobs (Marin and Mazzanti, 2013; Gagliardi et al., 2016; Horbach, 2010; Kunapatarawong and Martínez-Ros, 2016). When the effects of specific eco-innovations have been addressed results show that, while product or service eco-innovation has a significantly positive effect on the probability of an increase in employment, end-of pipe innovations may favour employment decrease (Rennings et al., 2004). Horbach and Rennings (2013) confirm this result and highlight that the relationship between eco-innovation and employment at the firm level strongly depends on the nature of the innovation, especially with respect to the distinction between process and product innovation.

More generally, studies on the employment effects of innovations outside the green economy paradigm show that technological change plays a major role in shaping the quantity and quality of employment (Vivarelli, 2014). However, while product innovation is more clearly associated with positive effects on employment growth, evidence for process innovation is more mixed and the net effect depends on the relationship between the displacement effect due to increased productivity and the increase in the demand level due to price reductions (Harrison et al., 2008). Sectoral analyses also highlight that innovation appears to have a net job-creating effect in those manufacturing and service industries characterized by high demand growth and an orientation towards product innovation, whereas new processes generally result in job losses (Mastrostefano and Pianta, 2009; Pianta 2001, 2005; Vivarelli, et al., 1996).

Within the environmental economics literature, several studies focus on specific environmental innovation domains, analysing the employment effects of the increasing level of renewable energy production (Wei et al., 2010) or the performance of green industries and environmental products manufacturers (Becker and Shadbegian, 2009; Elliott and Lindley, 2014), while others specifically consider how environmental policies should respond to economic downturn (Bowen and Stern, 2010).

From a methodological point of view, a first approach used to analyse the direct employment impact associated with environmental technologies, mostly renewables, is the analytical method, a bottom-up process-based approach relying on detailed information on specific environmental technologies (Çetin and E□rican, 2011; Mirasgedis et al., 2014; Moreno and Lopez, 2008; Ortega et al., 2015; Wei et al., 2010).[5] On the other hand, the top-down I/O methods are more complex and data intensive[6] but can account also for the indirect employment effects: jobs created in sectors providing inputs to the main sector analysed and jobs created due to the increasing demand determined by a general income increase thank to the indirect job creation effect (Blazejczak et al., 2014; Böhringer et al., 2013; Cai et al., 2014; Chateau and Saint Martin, 2013; Fanning et al., 2014; Kuckshinrichs et al., 2010; Lehr et al. 2008, 2012; Scott et al., 2008; Simas and Pacca, 2014). In some cases, a combination of both methods has been applied (Cai et al., 2011; Lambert and Silva, 2012; Tourkolias et al., 2009). Most of these studies focus on the renewable energy sector while the employment effect associated with EE is considerably less investigated. This is particularly surprising given that the EE domain is associated with labour-intensive industries and may also generate relevant fiscal revenues (Pollin et al., 2009; Rosenow et al., 2014). For instance, Kim and

[5] Information required are, e.g., jobs per MW (for the entire life cycle of the equipment, peak or average megawatt) or the number of households or firms interested by the introduced innovation.

[6] Similar approaches focus on econometric or computable general equilibrium models.

Jeong (2016) find that an increase in EE, in term of improvement in the emission efficiency in the electricity sector, generates an (indirect) increase in employment also in most of the efficiency-related industries accounted for (construction, information, manufacturing, utilities).

This last finding provides evidence that there are two distinguished employment effects, direct and indirect, and more importantly that they might influence sectors in different ways. Given the interdependency of inputs contributing in the production process, and the differences in production strategies across sectors, the final effect in terms of employment impact due to EE achievements is not *a priori* predictable. According to the reviewed literature, on the one side the economic costs to be sustained in order to increase the energy efficiency of production processes can be relevant and might negatively affect employment growth; on the other hand, costly investments in EE may spur technological change, production efficiency and competitiveness resulting in increased output and positive employment dynamics. Considering the heterogeneity among sectors, the relative importance of these contrasting effects might vary across sectors of economic activity. In particular, the employment growth could be severely stifled when energy efficiency gains are the result of restructuring processes aimed at reducing production costs or fulfilling regulations, especially if process innovation is dominant, as in the case of Energy Intensive (EI) sectors. On the other hand, different patterns may emerge when EE gains take place in industries (mainly High-Tech, HT, sectors) characterized by strategies of technological competitiveness where product innovations are prevalent (Bogliacino and Pianta, 2010; Crespi and Pianta, 2008).

In addition, input substitution elasticities in the production process strongly vary across these two groups of industries (Antimiani et al., 2015; Frondel, 2011; Koetse et al., 2008; Stern, 2012). In EI sectors, energy efficiency improvements are achieved reducing energy consumption due to the introduction of process innovation and new capital, for example in the form of new machineries, which represents a further cost in the production process with possible detrimental effects on employment. Accordingly, although the elasticity of the labour demand is generally low with respect to changes in the energy and machinery (capital) prices (Arnberg and Bjørner, 2007), the overall impact on employment level depends on the substitution possibilities between the composite energy-capital input with respect to labour, with the substitutability being lower (or even negative) for EI sectors. If we consider that EI industries are also highly capital intensive (Okagawa and Ban, 2008), we might conclude that energy efficiency measures could bring to lower likelihood for employment expansion.

These last arguments bring to formulate the first research hypothesis, applied to decisions and actions that are typical of the private sphere and that directly influence employment change in the specific industry under scrutiny:

HP1. The employment change impact of costs associated with energy efficiency gains is greater in energy-intensive than in high-tech sectors.

Secondly, while the adjustment process of the production activities to be compliant with energy efficiency targets might bring to substantial costs, the energy saving effect might constitute a potential benefit in terms of higher resource efficiency and lower relative input costs. We might also expect that industries located in countries where the cost of energy is higher would benefit more from EE gains. To this purpose, the strong differentiation across EU countries of taxation frameworks is extremely relevant in shaping the effects on the economic system. Two issues deserve attention (EEA, 2016). First, one country may have a general energy taxation structure that could be distinguished across sectors (industries, transport, households, etc.) or may have a differentiated structure where a share of energy tax revenue is strictly defined as an environmental tax (as the example of carbon tax). In this case, the environmental tax has the specific purpose of reducing negative environmental externalities. Consequently, in the policy design there needs to be explicitly mentioned the scope of the fiscal instrument. This brings to the second key issue. Those countries having environmental taxes might use related revenues for specific purposes, including investments for creating green jobs. Even if such environmental tax framework is strongly recommended by the European Commission, EU countries still present energy tax systems where the environmental protection purpose is a small portion. Therefore, we can consider that in EU countries energy prices are differentiated mainly due to a general taxation on energy consumption (OECD, 2015). Accordingly, the only direct implication we can predict is that greater cost savings deriving from the same amount of EE gains are expected in those countries with higher energy tax level. In addition, such cost saving mechanism will be particularly relevant in EI industries that potentially benefit from a decrease in production costs. Following these arguments, we propose this second hypothesis:

HP2. A higher incidence of taxation on energy costs, ceteris paribus, displays a positive effect on employment growth at the sectoral level, especially for EI industries.

Apart from the impact driven by decisions for increasing energy efficiency in the private sector, also the actions toward EE implemented by the public sector may influence the employment dynamics of industries according to two main mechanisms. The first refers to potential benefits arising from a pure cost saving effect due to the reduction in energy consumption, which in turns might increase public budget that could be allocated to pro-active employment policies (Cambridge Econometrics, 2015). The second refers to the indirect effect on private industries played by efforts to increase EE in the public sector. Public investment for EE in this sector might activate additional demand for other industries, thus giving impulse to employment growth according to a broad green public procurement mechanism (Testa et al., 2016). Given that both channels are likely to benefit employment dynamics, we formulate the third research hypothesis:

HP3. The effort towards energy efficiency gains in the public sector has a positive impact on employment growth of industries.

Beside the direct impact driven by private and public decisions in energy efficiency gains, the aforementioned literature on the Porter Hypothesis has emphasized the role played by public policies in influencing private decisions thanks to systemic mechanisms that also indirectly change firms' production choices. With respect to the impact of public policies for the specific energy efficiency domain, a relevant aspect to be investigated is related to the role played by the *comprehensiveness* of the policy mix, which can be defined as the contextual use of different types of instruments aiming at and enhancing the efficient use of energy within an economic system (Rogge and Reichardt, 2016). Given the complexity of linkages and interrelationships in the energy system and its consumption patterns, the policy framework addressing energy efficiency should be equipped with a large range of measures that need to be implemented at the same time, acting both on the demand and the supply side, and including different types of instruments such as market-based, command and control or soft instruments (del Río and Howlett, 2013; Ekins, 2010; Sovacool, 2009).

Previous evidence shows that a more *comprehensive* policy mix is capable to enhance innovation activities for the generation of new EE technologies (Costantini et al., 2017). This result suggests that the joint implementation of a set of different types of instruments oriented towards EE goals might amplify the dynamic competitiveness effects associated with the PH, with potential strong complementarity effects between labour use and energy efficiency. More specifically, given a certain amount of energy efficiency gains realized in different industries, employment growth is expected to be higher in those sectors localized in countries with a more comprehensive EE policy mix. Following this argument, we then propose our fourth hypothesis to be tested:

HP4. The comprehensiveness of the policy framework for energy efficiency at the country level, ceteris paribus, has a positive impact on employment growth.

3. Methodology

3.1. The econometric model

In order to understand the impact of actions related to EE purposes on the employment performance of economic sectors, it is necessary to consider how all inputs interact in the production process. Accordingly, we can consider a general log-linear form of a production function as:

$$lnY_{i,c,t} = \alpha lnK_{i,c,t} + \beta lnL_{i,c,t} + \gamma lnE_{i,c,t} + \delta lnT_{i,c,t} \quad (1)$$

where the output level ($Y_{i,c,t}$) of each sector *i*, located in country *c*, at time *t*, is a function of the amount of capital stock (*K*), the number of employees (*L*), the quantity of energy consumed during the production process (*E*) and the technological knowledge available for the production process (*T*) in the same dimensions *i*, *c*, *t*. The coefficients $\alpha, \beta, \gamma, \delta$ can be broadly considered as output elasticities (given by the combination of input shares in the production process and input substitution elasticities).

By relying on eq. (1) it is possible to derive the general econometric model necessary to estimate our employment performance function as:

$$lnL_{i,c,t} = \beta_0 + \beta_1 lnY_{i,c,t} + \beta_2 lnK_{i,c,t} + \beta_3 lnE_{i,c,t} + \beta_4 lnT_{i,c,t} + \varepsilon_{i,c,t} \quad (2)$$

that represents how the employment level for each sector, in each country at time *t* is influenced by the whole economic dimension of the sector (represented by the output level), the capital stock, the amount of energy consumed and the level of technological capacity, plus a statistical term $\varepsilon_{i,c,t}$, representing the stochastic error. In this case β_0 represents a constant term, β_1 represents the labour output productivity (which is positive), and $\beta_2, \beta_3, \beta_4$ represent the linear combinations of the input substitution elasticity values and the relative share of each input in the input mix. Accordingly, the sign of these last three coefficients strictly depends on several parameters and it cannot be *a priori* predictable.

Given the object of this study, what we are interested in is to investigate if and to what extent the introduction of specific measures at the country and sector level, represented by policy instruments or by private actions towards EE gains, play a role in influencing employment dynamics. This means that we need to understand the effect on the change of the absolute value of employment level. Accordingly, the econometric model must be performed on differenced variables. In addition, we need to include some further amendments in order to directly account for EE and to include specific EE policies.

Hence, the final general functional form to be econometrically estimated results as follows:

$$\Delta lnL_{i,c,t} = \beta_0 + \beta_1 \Delta lnY_{i,c,t} + \beta_2 \Delta lnK_{i,c,t} + \beta_3 \Delta lnT_{i,c,t} + \beta_4 \Delta lnEE_{i,c,t} + \beta_5 P_{i,c,t-p} + \\ + s_i + c_c + y_t + \varepsilon_{i,c,t} \quad (3)$$

where the term ($EE_{i,c,t}$) represents an EE index calculated as the ratio between the total value added of each sector and the total energy consumption for the same sector and ($P_{i,c,t-p}$) represents a set of different EE policy measures, with potential temporal lags equal to p. In addition, we include three types of dummies, namely s_i, c_c, y_t, in order to account for sector, country, and time fixed effects, respectively. This allows reducing all variability related to heterogeneous aspects that are not directly related to the independent variables modelled in the estimation and to minimize potential bias due to omitted variables, in order to better isolate the real effects associated with each driving factor here investigated.

The econometric analysis is carried out on a balanced panel dataset, including EU15 countries[7] over the time span 1995-2009, for 30 sectors that represent all industries and services excluding the public sectors. Considering that the time span is longer than 10 years, potential biases due to autocorrelation of the residual terms as well as potential autoregressive forms of the dependent variable or of some regressors are likely to occur. However, the differenced representation of these variables eliminates these potential distortions, thus allowing us to adopt the most effective and efficient estimator for panel data that is given by the panel OLS fixed effects (FE) tool.

The final FE panel estimator has been chosen on the basis of a Hausman test, comparing it with a

[7] Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, UK.

random effect version of the panel estimator.[8] Obviously, given this specific differenced functional form, the values obtained for the model fitting as represented by the R-squared values are rather low. As a robustness check for the econometric modelling choice, we have also performed a panel FE estimator on the model in eq. (3) with variables taken as levels (and not differenced). In this case, all models provide R-squared values higher than 0.75 overall (as an average value of the between and within estimations), thus giving a robust enough model fitting for this econometric specification. Finally, in order to control for potential endogeneity of some regressors with the dependent variable, we have also performed a linear dynamic panel-data estimation in the form of the system estimator based on the work of Arellano and Bover (1995) and Blundell and Bond (1998), that uses moment conditions in which lagged differences are used as instruments for the level equation. Coefficients for covariates remain stable in sign and statistically robust with respect to the panel OLS FE estimates. This suggests that our results are not affected by endogeneity problems and, therefore, we opted to report estimates obtained through FE estimator, as the most efficient ones.[9]

3.2. Database and variables construction

A complex database has been built in order to gather information from different statistical sources on four main dimensions: employment, innovation, energy and other economic variables.[10]

The source of employment data for the dependent variable is the European Union Harmonized Labour Force Survey (EU-HLFS), which is a large sample survey providing quarterly results on labour participation for all EU Member States with data available for the complete country sample until 2009.

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[8] The fixed effects used refer to country-sector dimension and the statistical unit is each single sector in each country. These fixed effects are different from those modelled as dummies and described in the text that refer to country, sector and year that are added to the panel OLS FE to control for heterogeneity and potential omitted variables.

[9] The number of temporal observations does not allow to estimate differentiated effects at the country level. Further research on panel datasets with monthly statistics will allow adopting dynamic estimators and Seemingly Unrelated Regressors (SUR) approaches. Such an approach would allow better investigating differentiated patterns of complementarity between labour use and EE performance across countries.

[10] The final dataset includes 15 EU countries for 1995-2009. The final year (2009) is selected according to the last available information for capital stock in the WIOD database; the countries selection was driven by the EE policy dimension, given that EU New Member States have systematically adopted stringent EE policy only recently.

We then consider economic variables from the World Input-Output Database (WIOD), which consists of a series of databases covering the 27 EU countries and 13 other major countries from 1995 to 2011. We include data on energy use by sector and energy commodity from the Environmental Accounts, and data on nominal Gross Fixed Capital Formation (GFCF) and value added at constant prices at the industry level from the Socio-Economic Accounts.

To derive capital stock from data on investment flows, the Perpetual Inventory Method (PIM) is applied to GFCF (Coe and Helpman, 1995; Ek and Söderholm, 2010). Accordingly, capital stock for the first year is calculated by dividing the annual investment flow *I* (GFCF) for each sector-country pair (*i,c*) by a factor given by the sum of a constant 15% depreciation rate (*d*) and the average annual sector and country specific growth rate (*g*) of GFCF variable from the overall time period:

$$K_{i,c,t0} = I_{i,c,t0}/(g + d) \tag{4}$$

Then, capital stock at each time *t* is the sum of the capital stock at time *t-1* discounted by the depreciation rate of 15% with the investment at time *t*:

$$K_{i,c,t} = K_{i,c,t-1} \cdot (1 - d) + I_{i,c,t-1} \tag{5}$$

As far as technological capacity is considered, we adopt a patent-based measure and use the PATSTAT database on patent applications to the European Patent Office (EPO). Though previous studies have identified several drawbacks in using patent data as an innovation measure, their use is widespread in the literature (Griliches, 1990; Jaffe and Trajtenberg, 2002). With respect to the present analysis it is important here to stress that patent measures are specifically able to capture those innovative activities that are more linked to systematic R&D efforts and closer to product innovation than to process innovation (Archibugi and Pianta, 1996). In order to have a sectoral indicator of innovation capacity, patent data need to be linked to the specific economic sector. Two main concordance systems have been developed recently: the first by Schmoch et al. (2003) and the second one by Lybbert and Zolas (2014). The latter represents the state-of-the-art in matching industrial sectors to patent data and relies on data mining methods and probabilistic matching that creates direct linkages between patent data and a variety of economic classification schemes. Therefore, we adopt this second method for building the final dataset merging the patent data and the sectors detailed in the labour source. A many-to-many matching algorithm is proposed for the matching procedure, as it is necessary to analyse each patent and to assign it to the corresponding industrial sectors with possibility of non-univocal matching (e.g., one patent can belong to many industrial sectors).[11] As a final step, patents assigned for each year to the specific sector-country pair are used for calculating the patent stock as a measure of the technological capability at the sector level. The formulation adopted for such a patent stock is given by a standard discounted accumulation approach:

$$KPAT_{i,c,t} = \sum_{s=0}^{t}\left(PAT_{i,c,s} \cdot e^{[-\mu(t-s)]}\right) \quad (6)$$

where $PAT_{i,c,s}$ represents the number of patents applied in each *i-th* sector and *c-th* country in year *s,* where *s* represents an index of years up to and including year t, whereas μ is the decay rate, here assumed as a standard 15% value (Hall, 1990).[12]

In order to analyse the role played by sector-based EE gains in influencing employment performance (HP1), we firstly build an EE index as the ratio between the total value added of each sector and the total energy consumption for the same sector. The differenced value of this ratio, which is included among the regressors in logarithm form, represents the gains in EE obtained in the past year by each sector in each country at time *t*. This variable might be interpreted as the final output in terms of energy efficiency performance at the sector level determined by all efforts displayed towards EE. It is worth noting that potential multicollinearity bias might occur when including in the model this variable and the output level (*Y*). Nonetheless, since variables are treated

[11] Through the Algorithmic Links with Probabilities (ALP) approach, patents are analysed identifying relevant keywords extracted from industry classification descriptions and tabulated by IPC code. By analysing the identified frequency matches between the industry and IPC classifications, a probabilistic mapping from IPC to the industrial classifications (and vice versa) was generated. Since the ALP concordance is constructed as a probability distribution, the weights represent the probability that the origin classification system was matched into the destination classification system. Thus, we multiplied the values of the origin classification system by these weights to get the new values as measured by the destination classification scheme. As for the case of multiple IPC classes matching, a many-to-many matching algorithm is proposed for the matching procedure, as it is necessary to analyse each patent and to assign this latter to the corresponding industrial sectors with possibility of non-univocal matching (e.g., one patent can belong to many industrial sectors). In this case, we proceed by eliminating double matching.

[12] The use of alternative decay rates (5%, 10%, 20%) does not change our results.

as difference over time, this collinearity is rather limited.[13] In order to obtain a differenced effect on energy intensive (EI) with respect to high-tech (HT) sectors, we add interaction effects of sector-based EE gains multiplied by two alternative dummy variables assuming value 1 for EI sectors (and zero otherwise), and value 1 for HT sectors (and zero otherwise).[14]

In order to test HP2 we include among the regressors the sector-based EE gains weighted by the energy taxation at the country level in the form:

$$Energy\ tax\ bundle_{c,t} = \frac{\sum_{n=1}^{N} \left(ene\_tax_{c,t}^{n} \cdot ene\_cons_{c,t}^{n}\right)}{\sum_{n=1}^{N} \left(ene\_price_{c,t}^{n} \cdot ene\_cons_{c,t}^{n}\right)} \quad (7)$$

where *n* indexes the energy commodities, generally defined as primary energy sources, electricity and oil products, whereas *c* and *t* refer to countries and time, respectively. Instead of taking only the tax level, we have considered the relative weight of the energy taxation on the production costs, referred to energy consumed as an input in the production function, because it allows better capturing the real impact of taxation on energy production costs.[15] Data on energy sources are from Prices and Taxes Statistics (IEA, 2012c) and data on energy consumption by energy sources from the IEA Energy Balance Statistics (IEA, 2012b). The final index for EU15 countries is represented by the product of the EE gains at the sector level with the energy tax bundle at the country level. The interpretation of this variable is as follows: for those sectors experiencing efficiency gains in terms of energy consumption reduction, *ceteris paribus*, the economic gains obtained, and the consequent employment impact, are greater if the sector is located in a country with a higher energy tax bundle. In fact, considering that a higher energy tax bundle means higher costs for energy

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[13] Conditional numbers and mean VIF tests confirm the absence of multicollinearity biases.

[14] According to ISIC Rev. 3.1 classification, Energy Intensive sectors are those coded from 21 to 28. High-Tech sectors cover code 24, and from 29 to 37. Accordingly, the classified EI sectors include all manufacturing industries covered by the EU ETS. It is worth mentioning that, given the disaggregation available for this dataset, it is impossible to disentangle from the Manufacture of chemicals and chemical products sector (ISIC rev. code 24) that portion that is under the ETS, and that portion that is classified as High-Tech. Accordingly this specific sector enters the definition of both EI and HT sectors.

[15] Given the differences in data availability at the country level, the types of energy commodities included in eq. (8) are not the same for all countries. By taking the weighted average of energy taxation on total energy bill allows reducing biasing effects related to data heterogeneity. For the same reason, we have been forced in using country level energy consumption data since sector based energy consumption is available for sectors more aggregated than those available in the employment statistical source.

consumption, the same EE increase has larger (lower) potential for economic saving in production costs in those countries with a higher (lower) energy taxation. This may allow firms to save more resources that could be used to expand the production, enhance the productivity and the demand for other inputs such as labour. Accordingly, this indicator represents the potential for EE innovation to decouple economic performances from environmental impacts. Investments in green technologies, as EE, can potentially enhance output and employment creation (Cecere and Mazzanti, 2017), and leading to job reallocations across industries (de Serres et al., 2010). According to HP2, in order to verify the differentiated strength of the energy cost saving effect on the two broad sector categories, also in this case we interact EE gains weighted by the energy tax bundle with the two alternative sector-based dummy variables.

To test HP3, we have computed an index representing EE gains for the broadly defined public sector, where postal and telecommunication sectors are accounted for a half of their energy consumption and value added, according to a standard formulation valid for all EU countries, considering the different weight of the public and the private sector in this economic branch (Europe Economics, 2006; Ramboll Report, 2012).

Finally HP4 is tested by taking data on energy policies from the IEA's Energy Efficiency Policy Database available online, which provides comprehensive, up-to-date information on EE policies by demand sectors (buildings, commercial/industrial equipment, energy utilities, industry, lighting, residential appliances and transport) for several countries including EU15, also differentiating by type, e.g., economic instruments, information and education, policy support, regulatory instruments, RD&D, voluntary approaches. Once the country-based EE policies for the EU15 here considered are mapped, following Costantini et al. (2017) we proxy the *comprehensiveness* of the policy framework for EE by building a variable representing the stock of policies at the country level. This is a discrete stock variable calculated as the cumulative number of policy instruments in force at time t in country c, as follows:

$$KPOL_{c,t} = \sum_{s=0}^{t}(POL_{c,s}) \quad (8)$$

Coherently with the energy cost perspective adopted for HP2, also the total stock of policies in force at the national level is weighted by the energy tax bundle, which represents the relative weight of the energy taxation considering fuel-specific prices, tax and energy consumption (as in eq. 7). This allow accounting not only for the simple impulse given by the existence or not of different public policies, but also for a sort of qualification of the intensity of the overall policy stringency in terms of energy costs.

The direct effect played by public policies on employment performance cannot be considered as simultaneous with respect to the moment the policy is adopted. Accordingly, as expressed by eq. (3) alternative p temporal lags are tested. The best model fitting by performing AIC and BIC tests results with one year lag.

Table 1 - Dataset description and statistical source

Name	**Unit**	**Dimension** (Sector/Commodity)	**Description**	**Source**
Employment	No/1000	All private economic sectors	Number of persons engaged in 1000	EU-HLFS
Value added	Const USD	All economic sectors	Total value added	WIOD
Investments	Const USD	All private economic sectors	Total Gross Fixed Capital Formation (GFCF)	WIOD
Energy consumption	Ktoe	All economic sectors	Total primary energy consumption	WIOD
Patent flows	No	All private economic sectors	Number of patents assigned to each sector according to Lybbert-Zolas (2014) method	EPO
EE public policies	No	Country level	In force policies fostering EE in all policy domains and tools	IEA-OECD
Energy price	Const USD	Country level. Energy commodities: petroleum, coal, natural gas, oil products, electricity	End-use energy prices USD (converted in constant USD)	IEA Energy Prices and Taxes
Energy tax	Const USD	Country level. Energy commodities: petroleum, coal, natural gas, oil products, electricity	End-use energy taxes USD (converted in constant values)	IEA Energy Prices and Taxes

In Table 1 we report a summary of the statistical sources used to build the dataset, while in Table 2 we describe the variables representing the different driving factors tested in the econometric estimations with a precise indication of the acronyms used in results Section (see Table A.2 in the Appendix for descriptive statistics).

Table 2 – Summary of variables tested in the econometric estimations

Acronym	Full Description	Availability	Interpretation
◘ value added	Changes over year of total value added	30 sectors	The variable measures changes from one year to the other in the total output produced by each sector
◘ capital stock	Changes over year of capital stock calculated as eqs. (4)-(5)	30 sectors	The variable measures changes from one year to the other in the total capital stock used by each sector in the production process
◘ patent stock	Changes over year of patent stock calculated as eq. (6)	30 sectors	The variable measures changes from one year to the other in the total patent stock developed by each sector
◘ of EE sect-based	Changes over year of EE measured as the ratio between value added and energy consumption at sector level	30 sectors	The variable measures the efforts played by each sector in reducing energy consumption with respect to a given amount of total output (HP1)
◘ of EE sect-based (EI)	Interaction between ◘ of EE sector-based and dummy variable for EI sectors	30 sectors	The variable measures if efficiency gains play a stronger effect on employment change in energy intensive sectors (HP1)
◘ of EE sect-based (HT)	Interaction between ◘ of EE sector-based and dummy variable for HT sectors	30 sectors	The variable measures if efficiency gains play a reduced effect on employment change in high-tech sectors (HP1)
◘ EE sect-based weigh. by en. tax bundle	Interaction between ◘ of EE sect-based and the energy tax bundle as in eq. (7)	30 sectors	The variable measures if cost savings from EE gains positively influence employment dynamics (HP2)
◘ EE sect-based weigh. by en. tax bundle (EI)	Interaction between ◘ EE sect-based weigh. by en. tax bundle and dummy variable for EI sectors	30 sectors	The variable measures if cost savings from EE gains in energy intensive sectors relatively plays a larger effect on employment increase (HP2)
◘ EE sect-based weigh. by en. tax bundle (HT)	Interaction between ◘ EE sect-based weigh. by en. tax bundle and dummy variable for HT sectors	30 sectors	The variable measures if cost savings from EE gains in high-tech sectors relatively plays a reduced effect on employment increase (HP2)
◘ of EE in the pub. sec.	Changes over year of EE measured as the ratio between value added and energy consumption for the Public Sector aggregation	Public Sector	The variable measures the efforts played by the Public Sector of each country in reducing energy consumption with respect to a given amount of total output (HP3)
Pol. compr. in EE	Stock of total EE policy measures in force at time t as eq. (8) weighted by energy tax bundle as eq. (7)	Country level	The variable measure the effect played by the overall policy mix framework at the country level also accounting for the cost component of energy consumption (HP4)

4. Empirical results

We first analyse the empirical results carried out for testing HP1. Accordingly, Table 3 provides the results on the employment effects of sector-based EE measures, dividing results with respect to the sector aggregation considered: all private economic activities, industries and utilities (covering the manufacturing industry plus the energy and water utilities and the construction sector),[16] and finally only manufacturing industries. In particular, with respect to EE gains and coherently with HP1, we distinguish between Energy Intensive (EI) and High-Tech (HT) industries.

Changes in the employment levels in the EU15 are positively related to changes in the sectoral output, with larger coefficients identified for industry only with respect to the total economy. This result reflects that the output elasticity of labour as an input is positive and suggests that the expansion of sectoral value added is a primary driver of employment growth.

[16] All the sectors classified as Manufacturing, Electricity and Construction in Table A.1 in Appendix.

Table 3 - Impact on employment due to sector-based EE measures – HP1

	Tot. private sector	Tot. private sector	Industries & Utilities	Industries	Industries	Industries
□ value added	0.098***	0.133***	0.138***	0.147***	0.157***	0.152***
	(10.79)	(12.83)	(12.43)	(12.32)	(12.38)	(12.57)
□ capital stock	0.137***	0.134***	0.134***	0.124***	0.115***	0.124***
	(6.03)	(5.93)	(5.71)	(4.95)	(4.57)	(4.97)
□ patent stock	0.026*	0.024*	0.025*	0.026*	0.026*	0.027*
	(2.46)	(2.26)	(2.25)	(2.20)	(2.16)	(2.26)
□ EE sect-based		-0.078***	-0.081***	-0.085***	-0.065***	-0.107***
		(-6.83)	(-6.77)	(-6.70)	(-4.19)	(-6.88)
□ EE sect-based (EI)					-0.056**	
					(-2.78)	
□ EE sect-based (HT)						0.058**
						(2.84)
Constant	0.046***	0.105***	0.109***	0.122***	0.129***	0.124***
	(5.47)	(8.75)	(8.47)	(8.65)	(8.95)	(8.78)
N. Obs.	3,338	3,338	2,964	2,590	2,590	2,590
R-sq	0.089	0.102	0.112	0.122	(-0.12)	0.124
Wald test	4,913	4,939	4,334	3,680	3,683	3,683

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

For what concerns changes in capital stock, two contrasting effects might take place: an increase in capital intensity may displace a complementary input such as labour, leading to employment reductions; on the other hand, positive changes in capital stock reflect investment activities that can be associated with a sectoral economic growth conducing to employment gains. The results reported in Table 3 suggest that the expansionary effect associated with investments in new capital stock strongly prevails with respect to labour substitution effects.

The third control variable in our baseline model reflects sectoral innovation activities and shows that they provide a (slightly significant) positive impulse to employment growth. This result is in line with previous literature, suggesting that innovative activities mainly associated with R&D investment leading to product innovation (as those proxied by patent measures) tend to display a positive effect on employment dynamics (Bogliacino and Pianta, 2010; Vivarelli, 2014).

Moving to the coefficient value of the sector-based EE gains, it turns out to be statistically robust, negative in sign and with a magnitude that increases as we restrict the sample from the total economy to industries only. This coefficient must be interpreted as follows: for those sectors experiencing higher energy efficiency gains, employment growth is lower. This is to say that energy efficiency behaviours are not necessarily responsible for a reduction in the employment rate, but only that they can contribute to smooth increases in the employment rate. This result is not surprising if we consider the insights from previous analyses and the specific model specification here adopted. As highlighted by the literature, on the one hand the economic costs to be sustained to achieve better EE performances might negatively affect employment growth; on the other hand, investment in energy efficiency may activate complementarity effects by spurring technological change, production efficiency and competitiveness resulting in increased output and employment dynamics. However, in our model these potential positive effects are mainly controlled by the three variables previously examined, while here the EE variable mainly captures the cost effects associated with EE gains.

This interpretation seems to be coherent with the results obtained when accounting for the distinction between Energy Intensive and High-Tech industries. In accordance with our research hypothesis HP1, results are different in the two groups of sectors, with a negative and significant coefficient for the interaction effect with EI sectors, and a positive and significant interaction effect for the case of HT industries. This suggests that the cost effect associated with EE gains and captured by the EE variable is larger in EI industries while it is less relevant in HT industries. Given the model specification here adopted, the simultaneous inclusion of both sector-based EE gains and the interaction term with the EI and HT dummies allows computing the total effect played by sector-based EE gains as the sum of the coefficients. Accordingly, for EI industries the net effect on employment change is -0.121 (summing -0.065 and -0.056) while for HT industries the net effect is -0.049 (summing -0.107 and +0.058).

Given the relevance of the cost component in explaining the relationship between energy efficiency efforts and employment impacts, we investigate HP2 by including in the regression analysis the value of EE gains weighted by the energy tax bundle (Table 4).[17]

[17] The variable "¤ EE sect-based weighted by energy tax bundle" is given by multiplying the change in EE sector-based with the energy tax bundle (ETB) at the country level. Although it would have been interesting to control for the specific role played by ETB alone, the country variance of this variable doesn't allow to add much explanation with

Table 4- Impact on employment change due to sector-based EE gains weighted by energy cost – HP2

	Tot. private sector	Industries & Utilities	Industries	Industries	Industries
□ value added	0.135***	0.140***	0.149***	0.154***	0.148***
	(12.92)	(12.57)	(12.48)	(12.54)	(12.39)
□ capital stock	0.132***	0.131***	0.119***	0.116***	0.123***
	(5.81)	(5.55)	(4.75)	(4.63)	(4.94)
□ patent stock	0.023*	0.024*	0.025*	0.025*	0.026*
	(2.21)	(2.18)	(2.14)	(2.11)	(2.23)
□ EE sect-based	-0.051**	-0.043**	-0.044**	-0.070***	-0.094***
	(-2.81)	(-2.83)	(-2.91)	(-4.94)	(-6.49)
□ EE sect-basedD weigh. by en. tax bundle	0.017	0.024*	0.027*		
	(1.85)	(2.50)	(2.51)		
□ EE sect-basedD weigh. by en. tax bundle (EI)				0.023**	
				(2.87)	
□ EE sect-basedD weigh. by en. tax bundle (HT)					-0.015
					(-1.25)
Constant	0.105***	0.109***	0.123***	0.125***	0.123***
	(8.75)	(8.49)	(8.68)	(8.83)	(8.70)
N. Obs.	3,338	2,964	2,590	2,590	2,590
R-sq	0.103	0.114	0.124	0.124	0.122
Wald test	4,941	4,338	3,683	3,683	3,680

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

When considering the whole economic system (excluding the public sector), the cost of energy seems to be not relevant in influencing employment change decisions. However, when the sample is restricted to industries and utilities and to industries only, the coefficient turns to be positive and (although slightly) statistically robust, meaning that industries located in countries with a relatively higher energy cost (due to taxation) face a double effect. From the one side, there is a negative impact on employment change in those industries that face relevant costs to substantially restructure their production processes in order to improve their energy efficiency standards. From the other side, industries located in countries with higher taxation would benefit from the costs saving associated with the use of energy as an input of the production process, thus alleviating the former negative impact. It is worth noting that when accounting for the heterogeneity between EI and HT sectors, it emerges that the positive impact related to the cost saving component of the complex impact of EE measures is rather robust for EI sectors, while it is not statistically significant for HT sectors. Thus according to HP2, given the country-level energy taxation, the EE gains produce

respect to the country fixed effects that are already included in the base model specification. Given that it has a significant effect only if used as a weight of sector-level energy-related variables, this composite variable must be interpreted as the role of sector-based energy cost saving due to energy efficiency gains, rather than an interaction term.

economic benefits mainly in those industries where energy resources constitute a larger share of production costs.[18]

Moving towards the analysis of public policies, in Tables 5 and 6 we analyse the employment change effects due to public EE actions and the overall policy mix framework for energy efficiency at the national level, distinguishing between the whole economic system (excluding the public sector) and the sole manufacturing sectors.

Table 5- Impact on employment change due to public EE measures and policy framework, total economy – HP3 and HP4

	HP3	HP4	HP3-HP4	HP1-HP3	HP1-HP4	HP1-HP3-HP4	HP1-HP2-HP3
◘ value added	0.099***	0.098***	0.099***	0.133***	0.133***	0.133***	0.134***
	(10.85)	(10.82)	(10.88)	(12.82)	(12.80)	(12.80)	(12.90)
◘ capital stock	0.139***	0.136***	0.138***	0.135***	0.133***	0.134***	0.133***
	(6.09)	(5.99)	(6.05)	(5.99)	(5.89)	(5.95)	(5.88)
◘ patent stock	0.026*	0.026*	0.025*	0.024*	0.024*	0.023*	0.023*
	(2.43)	(2.42)	(2.39)	(2.24)	(2.23)	(2.21)	(2.20)
◘ EE sect-based				-0.077***	-0.077***	-0.076***	-0.055**
				(-6.73)	(-6.73)	(-6.63)	(-2.98)
◘ EE in the pub. sec.	0.077**		0.076**	0.069**		0.069**	0.063*
	(2.75)		(2.74)	(2.79)		(2.79)	(2.26)
Policy comprehen. (t-1)		0.004**	0.004**		0.004**	0.004**	
		(2.92)	(2.92)		(2.68)	(2.69)	
◘ EE sect-based weigh. by en. tax bundle							0.014
							(1.53)
Constant	-0.009	0.057***	0.003	0.055*	0.115***	0.065**	0.059*
	(-0.40)	(6.20)	(0.13)	(2.38)	(9.16)	(2.76)	(2.53)
N. Obs.	3,338	3,338	3,338	3,338	3,338	3,338	3,338
R-sq	0.091	0.091	0.093	0.104	0.104	0.106	0.105
Wald test	4,918	4,918	4,922	4,942	4,943	4,946	4,944

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

With respect to the analysis of HP3, the impact of EE gains realized in the public sector on the employment growth of the whole private economic system is positive and significant as expected. These empirical results show that the efforts towards EE displayed by the public sectors, are able to stimulate additional demand at the country level in several other sectors (e.g. development and

[18] For the sake of clarity, it is worth mentioning that the last two columns of Table 4 consider the differentiated impact on EI and HT sectors specific effect without controlling for additional impacts with respect to the general sector variable ("D EE sect-based weighted by energy tax bundle") as in the case of Table 3. Accordingly, coefficients must not be interpreted as additive but the two dummy variables help only to disentangle the differences between the two sector types.

production of new energy saving materials or devices, installation of new insulation systems or the energy building certification auditing for instance). At the aggregate level, such effects can be further amplified in the medium-long run if EE gains translates into savings in the public budgets, which can be directed to investments for enhancing economic growth and employment dynamics of the economic sectors (for instance via a reduction of labour taxation or by providing incentives for employment creation).

Moreover, the magnitude of the coefficient associated with EE improvements in the public sectors is comparable, in all specifications where HP1 and HP3 are jointly tested, with that of the sector-based EE gains, implying that the positive impulse on the economy provided by EE actions in terms of lower energy consumption for the provision of public services (e.g. education and health system), is able to compensate the negative impact on employment dynamics due to costly private investment for better EE performance at the sectoral level.

With respect to the role played by the policy *comprehensiveness* variable based on the EE policies stock and the energy cost weight (HP4), it has a positive and statistically significant impact on the employment performance. This evidence suggests that, *ceteris paribus*, employment growth is higher in sectors of economic activities localized in countries where a larger set of different types of instruments oriented towards EE is implemented. This appears to be a particularly interesting result within the discussion on the optimal policy mix design, since it shows that the risk of negative employment effects due to stringent EE policies might be turned into positive impulses when a number of different instruments, acting on different elements of the system, allow the enhancement of the expansionary effects that can be activated through EE efforts.[19] This result provides us with a further indication of the importance of designing a policy mix that is coherent and vertically integrated, involving the sector as well as the national levels in order to enhance complementarity effects between labour and environmental productivities.

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[19] When introducing into the model the interaction term between sector-based EE gains and the energy tax bundle (last Column of Table 5) we cannot test the co-occurrence of HP2 and HP4 since the policy comprehensiveness variable is also based on the energy tax bundle indicator, thus bringing to multicollinearity biases.

Table 6 - Impact on employment change due to public EE measures and policy framework, industries – HP3 and HP4

	HP1-HP3	HP1-HP4	HP1-HP3-HP4	HP1-HP3-HP4 (EI)	HP1-HP3-HP4 (HT)	HP1-HP2 HP3	HP1-HP2 HP3 (EI)	HP1-HP2 HP3 (HT)
◘ value added	0.146***	0.146***	0.146***	0.156***	0.151***	0.148***	0.153***	0.148***
	(12.29)	(12.30)	(12.26)	(12.33)	(12.52)	(12.43)	(12.47)	(12.37)
◘ capital stock	0.125***	0.123***	0.124***	0.116***	0.124***	0.121***	0.118***	0.125***
	(5.00)	(4.93)	(4.98)	(4.60)	(5.00)	(4.82)	(4.69)	(5.00)
◘ patent stock	0.026*	0.026*	0.026*	0.025*	0.026*	0.025*	0.025*	0.026*
	(2.18)	(2.19)	(2.17)	(2.14)	(2.23)	(2.13)	(2.10)	(2.21)
◘ EE sect-based	-0.084***	-0.084***	-0.082***	-0.062***	-0.105***	-0.047*	-0.069***	-0.093***
	(-6.56)	(-6.61)	(-6.48)	(-4.01)	(-6.74)	(-2.27)	(-4.89)	(-6.45)
◘ EE in the pub sec	0.081*		0.081*	0.081*	0.082*	0.071*	0.077*	0.084*
	(2.42)		(2.43)	(2.44)	(2.45)	(2.09)	(2.28)	(2.51)
Policy comprehen. (t-1)		0.004**	0.004**	0.004**	0.004**			
		(2.67)	(2.67)	(2.67)	(2.70)			
◘ EE sect-based (EI)				-0.056*				
				(-2.39)				
◘ EE sect-based (HT)					0.059*			
					(2.49)			
◘ EE sect-based weigh. by en. tax bundle						0.023**		
						(2.80)		
◘ EE sect-based weigh. by en. tax bundle (EI)							0.022**	
							(2.83)	
◘ EE sect-based weigh. by en. tax bundle (HT)								-0.017
								(-1.42)
Constant	0.064*	0.134***	0.075**	0.081**	0.077**	0.071*	0.070*	0.062*
	(2.27)	(9.07)	(2.65)	(2.85)	(2.71)	(2.52)	(2.47)	(2.21)
N. Obs.	2,590	2,590	2,590	2,590	2,590	2,590	2,590	2,590
R-sq	0.124	0.124	0.127	0.129	0.129	0.126	0.126	0.125
Wald test	3,683	3,684	3,687	3,690	3,690	3,685	3,686	3,684

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

When limiting our attention to the industry sector (Table 6), it is worth mentioning that all results already commented for the sample of the whole private economic system remain unchanged, as well as the results obtained testing the other research hypotheses, meaning that the robustness of the estimations is not biased by the adoption of different samples or by the introduction of additional variables. In particular, the differentiated effects of EE gains between the two scrutinized groups of industries is confirmed, also when the interaction with the tax bundle is considered.

5. Conclusions and policy implications

In this paper, we investigate the impact on employment performance related to private and public actions towards EE at the EU level. In doing so, we collect, homogenize and integrate several data sources, which enable to systemically describe this complex system. The data coverage includes all economic sectors classified as industry and services and public sectors. The time coverage goes from 1995 to 2009 and data are collected for EU-15 countries.

The first important result we find is that, after accounting for the positive role played by sectoral output growth, investment and innovation activities, sectoral EE gains display a negative effect on employment growth, especially in EI industries. This result suggests that in the proposed model the EE variable mainly captures the effects of costs associated with EE efforts, and that these are particularly relevant in EI industries, while being of modest impact in HT sectors.

Secondly, we find that the cost saving effect associated with EE gains plays an important role in shaping employment dynamics in particular in EI industries, as evidenced by the analysis of the interaction between the sector-based energy efficiency gains and the burden of energy taxation at the national level. Considering a given increase in sectoral energy efficiency, those sectors acting in countries characterized by high energy taxation show larger occupation increases than the corresponding sectors from countries where the burden of energy taxation is lower. This can be explained as follows: despite the complementarity between energy and other production inputs, the achieved efficiency gain allows to save financial resources, especially where the cost of energy is particularly high as in EI industries. Other conditions being equal, in this case the overall costs of EE efforts are lower, with a positive effect on employment dynamics.

The empirical analysis also shows that energy efficiency gains achieved in the public sector have a positive effect on the employment dynamics of other economic sectors (industry and services). The reasons behind this positive impact are twofold. The first short-term channel is determined by the new demand for labour needed to realize the energy efficiency intervention in the public sector buildings (e.g., installation of audit system or insulating materials, new lighting systems, etc.). The second medium-term channel through which employment may increase is represented by the reduction in the public expenditure for energy consumption, which in turn allows reducing the ordinary administrative costs, making resources available to finance further investment or employment policies.

Finally, results show that *ceteris paribus*, a more *comprehensive* policy mix targeting EE generates a positive impulse to employment growth. Hence, when the set of policy instruments embraces different elements of the system, it turns out to be capable of enhancing the expansionary forces associated with EE efforts enhancing employment growth.

The main policy implication we can derive is that energy efficiency policies might have different impacts on employment dynamics depending on the specific sector and country involved. As the mechanisms through which EE policies might affect employment dynamics have been shown to be different, the prevalence of job creating or job saving effects strongly depends on sectoral characteristics, but also on the overall policy framework. In this respect, our results suggest that the design of appropriate and comprehensive policy mixes and the coordination between different policies have the potential to increase the positive employment effects associated with energy efficiency efforts.

However, because of the existing cross-country differences not only in terms of policy mix but also with respect to innovation activities, energy and production systems, further analysis is needed to address the employment outcome of idiosyncratic trade-offs or complementary effects between energy and economic productivities across countries.

Further analysis should also account both for the possibility that EE policies can non-linearly affect innovation as suggested Costantini et al. (2017), according to which beyond a threshold level the number of policy instruments implemented may have negative interaction effects, and for unobservable time or individual related factors affecting innovation and performances that can be expected to be heterogeneous across countries (Musolesi and Mazzanti, 2014).

Considering the evidenced relevance of EE actions in shaping employment dynamics, further research is certainly needed also in order to assess their impact not only on the quantity but also on the quality of employment. The present analysis indeed constitutes only a first step in this respect, since it does not consider the impact of such EE efforts on the quality of jobs, the skills and competences required (CEDEFOP, 2013). The inclusion of this dimension in future studies might well provide further insights for policy design aiming at fostering a sustainable and inclusive transition of the economic systems.

Acknowledgements

The authors would like to thank Chiara Martini for her precious suggestions on a first version of this paper and Alessandro Palma for his work on dataset collection. We thank participants at the EURKIND Governance of a Complex World conference on “Innovation, employment and environment” held in Valencia, Spain (GCW 2016) who made helpful comments. The financial support from ENEA within the project “Ricerca di Sistema Elettrico 2014” is also gratefully acknowledged. The usual disclaimers apply.

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Appendix

Table A.1: Sector classification: NACE 1 digit and equivalent ISIC Rev. 3.1. 2 digits

Macro Sector	*List of sub-sectors included*	*ISIC code*
Manufacturing	Manufacture of food, beverages and tobacco products; Textiles, wearing apparel, and leather; Wood, products of wood and cork, except furniture; Paper and paper products; Publishing, printing and reproduction of recorded media; Coke, refined petroleum products and nuclear fuel; Chemicals and chemical products; Rubber and plastics products; Other non-metallic mineral products; Basic metals; Fabricated metal products; Machinery and equipment n.e.c.; Office, accounting and computing machinery; Electrical machinery; Audio, television and communication equipment; Medical, precision and optical instruments, watches and clocks; Motor vehicles, trailers and semi-trailers; Other transport equipment; Furniture; Manufacturing n.e.c.; Recycling.	16 to 37
Trade	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel; Wholesale trade and commission trade, except of motor vehicles and motorcycles; Retail trade (except of motor vehicles, motorcycles); repair of personal and household goods.	50-51-52
Transport	Land transport; transport via pipelines; Water transport; Air transport; Supporting and auxiliary transport activities; activities of travel agencies.	60 to 63
Public Sector	Public administration and defence; compulsory social security; Education; Health and social work; Other community, social and personal service activities; Post and telecommunications.	L-M-N-O-64
Real Estate	Real estate activities; Renting of machinery and equipment without operator and of personal and household goods; Computer and related activities; RD; Other business activities.	70 to 74
Agr-Fish	Agriculture, hunting and forestry; Fishing.	A-B
Electricity	Electricity, gas and water supply.	E
Construction	Construction	F
Other	Mining and quarrying; Hotels and restaurants; Financial intermediation	C-H-J

Table A.2: Descriptive statistics

Tot. private sector					
Variable	Obs	Mean	Std. Dev.	Min	Max
Employment (Number of persons engaged in 1000)	7 650	329.83	591.61	0.00	5 861.89
Value added (Const USD)	7 650	18 363.63	34 329.56	0.00	381 271.00
Capital stock (Const USD)	6 868	66 201.23	333 213.60	0.00	6 074 016.00
Energy consumption (Ktoe)	7650	172 048.30	626 911.30	0.00	6 452 892.00
Patent stock (No)	7 650	415.26	1 365.14	0.00	17 027.05
EE sector-based	7 650	2.02	0.26	1.00	9.27
EE in the public sector country-based	7 650	1.99	0.08	1.58	2.31
EE in the other sector country-based	7 650	2.04	0.05	1.88	2.19
Policy stock in EE country-based (No)	7 650	4.44	5.04	0.00	24.00
Energy tax bundle	7650	0.25	0.14	0.05	0.61
Public RD in EE country-based	7 650	29.08	35.99	0.01	195.30
Policy comprehensiveness	3 148	0.53	0.79	0.00	4.00
Industries & Utilities					
Variable	Obs	Mean	Std. Dev.	Min	Max
Employment (Number of persons engaged in 1000)	3 600	175.67	333.95	0.00	3 236.00
Value added (Const USD)	3 600	10 723.74	17 935.40	0.00	154 346.40
Capital stock (Const USD)	3 232	18 500.71	33 311.73	0.00	337 241.70
Energy consumption (Ktoe)	3600	300 936.60	892 326.90	0.00	6 452 892.00
Patent stock (No)	3 600	762.37	1 827.59	0.17	17 027.05
EE sector-based	3 600	2.03	0.30	1.00	7.55
Industries					
Variable	Obs	Mean	Std. Dev.	Min	Max
Employment (Number of persons engaged in 1000)	3 150	136.76	208.69	0.00	1 248.99
Value added (Const USD)	3 150	8 859.73	14 870.65	0.00	144 893.30
Capital stock (Const USD)	2 828	14 042.63	22 117.67	0.00	155 021.30
Energy consumption (Ktoe)	3150	220 462.30	720 611.60	0.00	6 274 808.00
Patent stock (No)	3 150	791.37	1 907.21	0.17	17 027.05
EE sector-based	3 150	2.03	0.31	1.00	7.55