WHY DO THE PRIMARY ENERGY INTENSITIES OF THE EU14 DIFFER?

Zeus Guevara[a], Sergio Muñoz[a], Sofia Henriques[b], Tania Sousa[c]

[a] *Institute of Economic Research, National Autonomous University of Mexico, Circuito Mario de la Cueva s/n, Ciudad Universitaria, 04510, Mexico City.*

[b] *Lund University, Department of Economic History, Box 7083, SE-22007 Lund, Sweden*

[c] *MARETEC, Department of Mechanical Engineering, Instituto Superior Técnico, Universidade de Lisboa, Avenida Rovisco Pais, 1, 1049-001 Lisbon, Portugal.*

** Corresponding author: zshrzmgv@gmail.com*

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Abstract

The European Union is committed to increase renewable energy production and reduce greenhouse gas emissions up to 2050. The EU14* are all developed countries though with significantly different economic structures and energy consumption characteristics. Therefore, the path to follow towards EU energy and emissions targets should be specific to each country's current energy performance. As the primary energy intensity is the most widely used indicator of a country's energy performance, the present study has the objective to understand the differences in primary energy intensity between the EU14 in 1995-2005. To do so, an energy input-output (EIO) model with a better description of energy flows is used for the analysis, i.e. the primary-to-final EIO model, which allows accounting separately for several energy and economic variables. Primary energy intensities of EU14 are then compared to the primary energy intensity of a benchmark country (Denmark). The results show that the determinant factors of primary energy intensity differences are the primary-to-final energy conversion efficiency of the energy sector and the direct energy intensity of non-energy industries of the rest of the economy. Moreover, the results also give insights into the energy efficiency trends of these countries and on other factors that determine the energy performance of an economy.

Keywords: energy input-output analysis; EU15; primary energy intensity

* Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, The Netherlands, Portugal, Spain, Sweden and United Kingdom (Luxemburg is not included due to the low quality of its input-output data).

1 Introduction

Increasing energy efficiency is a key goal of European energy security and climate policies. For the short term, The European Union has established a comprehensive set of measures that will help the European Union reach 20% of energy savings relative to 1990 by 2020. These objectives are expected to be further strengthened for 2050, with the European Union committed to achieve an 80% reduction in greenhouse gas emissions below 1990 levels. Both these objectives are expected to be reached without compromising European competitiveness and prosperity. Therefore, a strong decoupling of energy and economic growth is needed.

The ratio of primary energy to GDP (primary energy intensity) is one of the most widely used indicators for measuring the sustainability or energy efficiency performance of the economy. On aggregate terms, historical trends of primary energy intensity look promising. From 1995 to 2009 the EU-27 decreased its primary energy intensity by 27% and seems well on track to meet its efficiency targets by 2020. Despite this reduction, primary energy intensity levels and evolution patterns differ widely across European countries. For example, Greek primary energy intensity is almost five times larger than the Danish one. One reason for this variance is that primary energy intensity is determined by multiple factors, such as energy prices, climate, income, energy mix and levels and direction of technological and structural developments (Percebois, 1979, Percebois, 1989) Thus, in order to be able to better assess a country potential for primary energy intensity reduction or to be able to identify an example of a successful transition, an understanding of the drivers of primary energy intensity across time and countries is needed.

A popular line of research has been to separate energy intensity into structural or technology effects through the use of decomposition techniques. The main techniques to analyze these changes are Index Decomposition analysis (IDA) and Structural Decomposition analysis (SDA), with the former using aggregated data at the sector level, and the later employing input-output tables (for a review of the two techniques see Ang (2004), Hoekstra and van den Bergh (2003) and Su and Ang (2012)) . Studies that employ IDA or SDA can be divided in time-series studies or cross-country studies. Time-series studies analyze the drivers of change within a specific country between two points in time. European comparative studies that apply time-series decomposition methods have mostly focused on the analysis of final energy intensities (i.e. excluding the primary to final transformation from the energy sector). Technological changes in the manufacturing sector have driven final energy intensities down, while economic structural changes and technological improvement in the service sector have been modest (Henriques and Kander, 2010, Mulder and de Groot, 2012, Mulder et al., 2014, Voigt et al., 2014). In turn, cross-country studies quantify the factors that contribute to differences in the levels of energy intensities across two countries or regions in a given year. Only a few examples of cross-sectional studies including European countries can be found in the literature (see review of SDA studies in Su and Ang (2012)). Alcántara and Duarte (2004) have investigated the causes of primary energy intensity differences among member states in 1996 applying SDA. They conclude that differences in Primary Energy Intensity occur due to differences in direct energy intensity and final demand, with structural changes playing no role.

This paper aims at understanding the difference in the levels of primary energy intensity across a sample of fourteen European countries, (Austria, Belgium, Denmark, Finland, France, Germany, Greece Ireland, Italy, the Netherlands, Portugal, Spain, Sweden and the UK - the EU14[1]) during the period 1995 to 2005. Comparatively to previous studies, this paper presents two new contributions. First, while most of the SDA cross-section studies focus only on a single year, we have extended our analysis to three benchmark years (1995, 2000 and 2005). This allows not only to compare cross-country differences in a given year but also to understand which factors have gained or lost importance in explaining these differences. Second, we make use of a new decomposition model based on an early contribution by Guevara (2014). Relatively to other decomposition models, this model has the main advantage of separating the role of efficiencies in the energy sector from the role of efficiencies in the rest of economy. Our new model also decomposes primary energy intensity differences across countries into a wider array of factors than previous studies, namely: (1) the effect of the differences in the primary to final energy efficiency of the energy sector; (2) the effect of differences in the composition of energy demand by industries and households; 3) the effect of differences in the composition of non-energy demand (by final consumers); 4) the effect of final energy intensities (by industries); 5) the effect of differences in the structure of the economy and 6) the effect of differences in total final energy demand and non-final demand in relation to the output.

We compare the results of each country with a reference country, Denmark. Denmark is chosen as a best practice example because it has the lowest primary energy intensity in 2005. We find that differences in the Primary Energy intensity are mostly explained by different levels of primary to final energy conversion structure and efficiency in the energy sector and different levels of direct energy intensity across non-energy industries of the rest of the economy. This implies that efficient improvements should be a key objective in countries with high Primary Energy Intensity. While there has been a convergence on the levels of energy intensity across non-energy industries, the differences in the energy sector are still significant. Some of these differences are likely to be due to the different composition of the energy mix for electricity generation. The efficiency of the energy sectors depends greatly on energy endowments (e.g. abundance of hydro-power) so the Primary to Final Energy conversion potential of each country should always be taken into account in the formulation of effective energy policy measures for the energy sector.

The paper is structured as follows. Section 1 comprises the introduction and the revision of the literature. Section 2 presents the methodology and describes the data. In Section 3, we discuss the results of this study. Finally, Section 4 presents the general conclusions of this work.

2 Methodology and data

Energy input-output analysis (EIO analysis) is used for the present study, as it is designed to account for the energy flows in the economy (Miller and Blair, 2009, Casler and Wilbur, 1984,

[1] Our designation. Due to lack of data, Luxemburg (a EU15 country) is excluded from the analysis.

Bullard and Herendeen, 1975). The selected energy input-output model is the simplified primary to final model (PF-EIO model) developed by Guevara et al. (2014). This model offers a detailed description of the energy flows in the economy according to the physical processes of energy conversion. Moreover, the PF-EIO model is capable to account separately for different variables of the economy. Because of this, inter-country comparisons can be carried out in a more adequately basis, i.e. variables with a consistent definition, a low level of aggregation and clear boundaries can be directly compared between countries.

2.1 The primary-to-final energy input-output model

The PF-EIO model consist in four sub-models (Table 2-1) that are then coupled into a complete model of primary energy use (Eq [2.1]).

Table 2-1 The components of PF-EIO model

Sub-models	Expressions*
The energy sector (Physical units)	$$\boldsymbol{x}^E = \boldsymbol{Z}^E\boldsymbol{i} + (\boldsymbol{C}^E\boldsymbol{e} + \boldsymbol{c}^H h)\boldsymbol{i}$$ or $$\boldsymbol{x}^E = \boldsymbol{L}^E(\boldsymbol{C}^E\boldsymbol{e} + \boldsymbol{c}^H h)\boldsymbol{i}$$ where • Vector $\boldsymbol{x}^E$ is the total output of the energy sector (total energy use) • Matrix $\boldsymbol{Z}^E$ is the interindustry transactions between energy industries • Matrix $\boldsymbol{L}^E$ is the total primary-to-final energy requirements • Matrix $\boldsymbol{C}^E$ is the composition of energy demand by the rest of the economy • Vector $\boldsymbol{e}$ is the total direct energy demand by the rest of the economy • Matrix $\boldsymbol{c}^H$ is the composition of final energy demand • Scalar h is the total final energy demand
The rest of the economy (Monetary units)	$$\boldsymbol{x}^S = \boldsymbol{L}^S\boldsymbol{c}^S s$$ where • Vector $\boldsymbol{x}^S$ is the economic output of the rest of the economy • Matrix $\boldsymbol{L}^S$ is the total non-energy requirements of the rest of the economy. It corresponds to the economy-wide inverse Leontief matrix without energy industries rows and columns. • Vector $\boldsymbol{c}^S$ is the composition of final non-energy demand • Scalar s is the total final non-energy demand
Direct energy intensity (Mixed units)	$$\boldsymbol{T}^{ES} = \hat{\boldsymbol{e}}\widehat{\boldsymbol{x}^S}^{-1}$$ where • Matrix $\boldsymbol{T}^{ES}$ is the direct energy intensity
Primary energy use (Physical units)	$$PE = \boldsymbol{k}\boldsymbol{x}^E$$ where • Scalar PE is the total primary energy use • Vector $\boldsymbol{k}$ is the bridge vector (constant) that selects primary energy uses

* A bold lower case letter ($\boldsymbol{x}$) corresponds to a vector. Bold capital letter ($\boldsymbol{Z}$) describes a matrix or sub-matrices. Non-bold Latin letters (x_i and z_{ij}) represent matrix entries, vector elements, scalars and indexes. A vector with a hat ($\hat{\boldsymbol{x}}$) represents a diagonal matrix, whose diagonal elements are the elements of vector $\boldsymbol{x}$. $\boldsymbol{i}$ is a vector of ones of a consistent length (or summation vector).

Coupling the sub-models in Table 2-1, the final form of the PF-EIO model is

$$PE = \underbrace{\boldsymbol{k}\,\boldsymbol{L}^{E}\boldsymbol{C}^{E}\boldsymbol{T}^{ES}\boldsymbol{L}^{S}\boldsymbol{c}^{S}s}_{\substack{Caused\ by\ final\\ non-energy\ demand}} + \underbrace{\boldsymbol{k}\,\boldsymbol{L}^{E}\boldsymbol{c}^{H}h}_{\substack{Caused\ by\ final\\ energy\ demand}} \qquad [2.1]$$

The aim of present analysis is the comparison of primary energy intensity between EU14, hence the indicator PE is divided by total output in GDP (Q). The final EIO model of primary energy intensity has the following form

$$PEI = \boldsymbol{k}\boldsymbol{L}^{E}\boldsymbol{C}^{E}\boldsymbol{T}^{ES}\boldsymbol{L}^{S}\boldsymbol{c}^{S}(s/Q) + \boldsymbol{k}\boldsymbol{L}^{E}\boldsymbol{c}^{H}(h/Q) \qquad [2.2]$$

Notice that this model of primary energy intensity is composed by two indicators of energy efficiency ($\boldsymbol{L}^{E}$ and $\boldsymbol{T}^{ES}$), two variables that account for the characteristics of energy use ($\boldsymbol{C}^{E}$ and $\boldsymbol{c}^{H}$) and four other economic variables ($\boldsymbol{L}^{S}$, $\boldsymbol{c}^{S}$, s/Q and h/Q). Models are built for each of the EU14 countries in 1995, 2000 and 2005.

The energy sector sub-model in Table 2-1 was built according to the commodity-by-industry approach to input-output analysis (Miller and Blair, 2009, EUROSTAT, 2008) with the industry technology assumption (Guo et al., 2009, Miller and Blair, 2009, UN, 1999, EUROSTAT, 2008). Energy flows data from the International Energy Agency's energy balances and statistics (IEA, 2011a, IEA, 2011b). Energy flows are arranged to fit the supply and use framework. These tables consist of $n_C = 66$ energy products, $n_T = 18$ energy industries and $n_S = 26$ non-energy industries of the rest of the economy of direct energy demand.

The sub-model of the rest of the economy was built with the supply and domestic (i.e. use at basic prices) tables from EUROSTAT (EUROSTAT, 2014) with the industry technology assumption. The 1995, 2000 and 2005 tables have the NACE 1 and CPA 2002 industries and product classifications with $l = m = 59$ industries and products (of which, $l_S = 55$ are non-energy industries of the rest of the economy). There are two missing tables in the EUROSTAT databases that cannot be obtained from available national databases, i.e. Ireland 1995 and Greece 1995. The comparison for these countries in this year is therefore avoided. As the inter-country comparisons are evaluated for a given year, i.e. no temporal comparisons are done, the tables are left in current euro prices.

The direct energy intensity is built so that it performs the necessary transformations between the IEA's and EUROSTAT's classifications (n_S vs. l_S) as it is done by Guevara et al. (2014). Finally, the vector $\boldsymbol{k}$ of the sub-model of primary energy use selects and adds the use of primary energy products from the total energy use vector ($\boldsymbol{x}^{E}$). The elements $k_i's$ are equal to 1 for renewable[2] and non-renewable primary energy carriers. Moreover, $\boldsymbol{k}$ accounts for the primary energy equivalent of energy imports, which is calculated with the domestic technology assumption (as if energy imports are domestically produced).

2.2 Comparison through structural decomposition analysis

Decomposition analysis is a procedure that allows identifying the driving factors of differences in economic, environmental or socio-economic variables between economies (Hoekstra and

[2] The fact that $k_i = 1$ for renewable energy sources means that the primary energy equivalent for these sources is estimated according to the *physical content method* (IEA, 2014, UN, 1982)

van den Bergh, 2003, Rose and Casler, 1996, Miller and Blair, 2009). This procedure has been applied to energy-related studies since the 1970's (Ang and Zhang, 2000, Hoekstra and van den Bergh, 2002) and it is now a widely recognized tool for energy policy analysis (Su and Ang, 2012, Xu and Ang, 2013).

Structural decomposition analysis (SDA) is a specific decomposition methodology for the input-output model hence it is able to capture effects that arise from structural differences between economies. According to the SDA, the differences between indicators can be decomposed into static changes (AKA effects or decomposition coefficients) of constitutive factors of an economy-wide indicator. Therefore, from Eq. [2.2], the difference in primary energy intensity between country α and country β is decomposed as:

$$PEI_{\beta} - PEI_{\alpha} = \delta \boldsymbol{L}^{E} + \delta \boldsymbol{C}^{E} + \delta \boldsymbol{T}^{ES} + \delta \boldsymbol{L}^{S} + \delta \boldsymbol{c}^{S} + \delta \boldsymbol{c}^{H} + \delta(s/Q) + \delta(h/Q) \qquad [2.3]$$

where $\delta \boldsymbol{X}$ is a decomposition coefficient, which corresponds to the effect of differences in factor $\boldsymbol{X}$ on the difference in primary energy intensity between two economies. Each coefficient is discussed below:

- $\delta \boldsymbol{L}^{E}$ accounts for the effect on ΔPEI of differences in the structure and efficiency of the primary-to-final energy conversion processes in the economy carried out in the energy sector.
- $\delta \boldsymbol{C}^{E}$ represents the effect on ΔPEI of differences in the composition of direct energy demand by non-energy industries of the rest of the economy for production purposes.
- $\delta \boldsymbol{T}^{ES}$ accounts for the effect on ΔPEI of differences in direct energy intensity of non-energy industries of the rest of the economy.
- $\delta \boldsymbol{L}^{S}$ corresponds to the effect on ΔPEI of differences in the structure of the rest of the economy.
- $\delta \boldsymbol{c}^{S}$ represents the effect on ΔPEI of differences in the composition of non-energy demand by final consumers.
- $\delta \boldsymbol{c}^{H}$ accounts for the effect on ΔPEI of differences in the composition of final energy demand.
- $\delta(s/Q)$ corresponds to the effect on ΔPEI of differences in the total final non-energy demand with respect to output[3].
- $\delta(h/Q)$ represents the effect on ΔPEI of differences in the total final energy demand with respect to output[4].

There are different mathematical techniques to determine the value of the decomposition coefficients in Eq. [2.3] (see Su and Ang (2012) and Hoekstra and van den Bergh (2003)). In this work the approximate D&L technique, proposed by De Haan (2001), is used because of simplicity, compared to the complete D&L technique (Dietzenbacher and Los, 1998, Seibel), and other desirable properties such as perfect decomposition capacity (Ang, 2004).

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[3] s/Q is a function of the share of imports in total final expenditures and the ratio of final energy expenditures to total final expenditures.

[4] h/Q is a function of the inverse energy prices to final consumers, the share of imports in total final expenditures and the ratio of final energy expenditures to total final expenditures.

3 Results & discussion

The PF-EIO models of primary energy intensity of the EU14 are compared to the country with the lowest primary energy intensity among them in 2005 (Denmark). The comparisons are made under the assumption that every country of the EU14 should aim to achieve Denmark's primary energy intensity level. The following figures shows the results of the comparison of EU14's primary energy intensity (PEI).

3.1 Year 1995

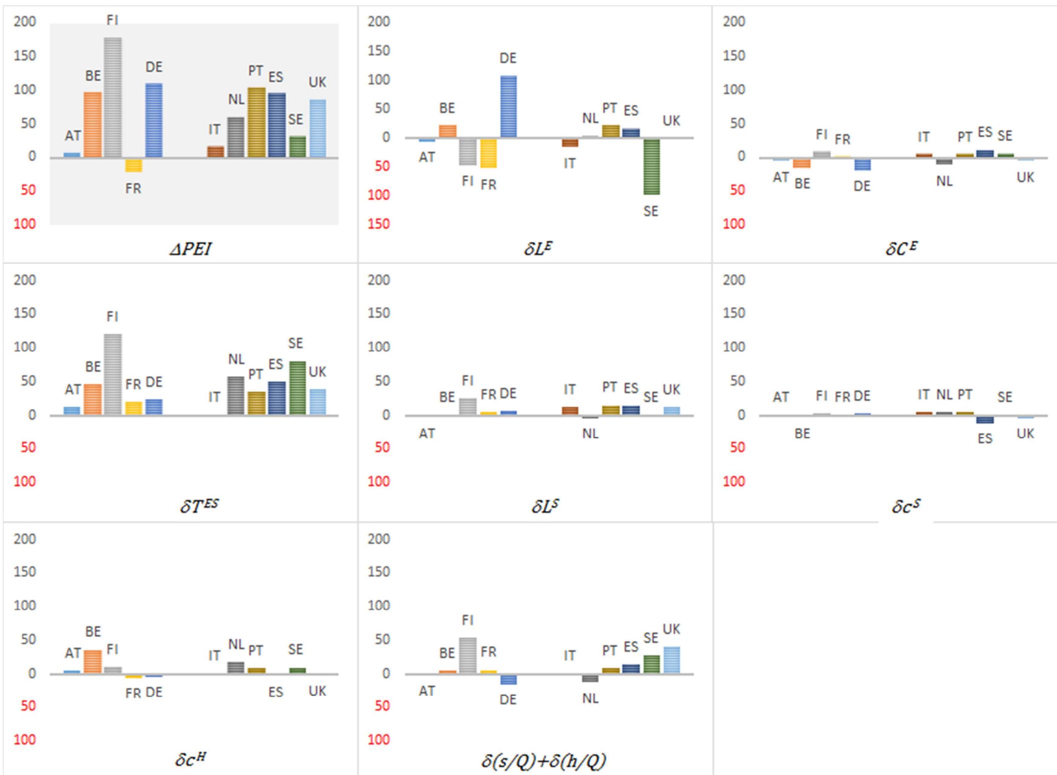

Figure 3-1 Decomposition coefficients of EU14's PEI comparisons: 1995. Note: 1) Vertical axis shows the primary energy intensity in TOE/€. 2) Greece and Ireland data are not available for this year. 3) AT-Austria, BE-Belgium, FI-Finland, FR-France, DE-Germany, GR-Greece, IE-Ireland, IT-Italy, NL-The Netherlands, PT-Portugal, ES-Spain, SE-Sweden and UK-United Kingdom.

ΔPEI shows the differences of PEI of each country with respect to Denmark. France is the only country that had a lower intensity, while Finland has the largest PEI of all EU14 countries. Belgium, Germany, The Netherlands, Portugal, Spain and UK has similar PEI's. AU's, IT's and SW's primary energy intensity are closer to the reference country.

Differences in the structure and efficiency of the primary-to-final energy conversion processes of the energy sector, i.e. $\delta \boldsymbol{L}^{E}$, were responsible of a higher PEI of Belgium, Germany, Portugal and Spain. This indicates that energy sector of these countries had a lower efficiency and lower share of renewables that the Danish energy sector. Germany is the country with the lowest primary-to-final efficiency due to broadly use of coal for power generation (IEA, 2011a, IEA, 2011b). The results show that Austria, the Netherlands and the UK have a similar structure of the energy sector compared to Denmark in 1995. On the other hand, Finland, France and

Sweden had the highest efficiency of all EU14 countries, among which Sweden had the largest effect on reducing PEI.

A negative value of $\delta\boldsymbol{C}^E$ indicates that the rest of the economy of a country consumed a lower share of secondary energy products with high primary energy content (e.g. blast furnace gas and coal-fuel electricity) as the case of Belgium, Germany and The Netherlands. However this factor is almost negligible in accounting for differences in PEI in 1995 (i.e. values $\in [-20,15]$ TOE/€).

$\delta\boldsymbol{T}^{ES}$ shows that Denmark has the lowest average direct energy intensity in non-energy industries of the rest of the economy of the EU14. The differences in $\boldsymbol{T}^{ES}$ explain why the rest of the countries have a larger PEI than Denmark, being the other two Scandinavian countries the most influenced by direct energy intensity.

Differences in the economic structure were also responsible for a larger PEI of most countries (with the exception of Austria and Netherlands). This means that the non-energy productive structure of Denmark leaned towards less energy intensives industries than other countries. Moreover, $\delta\boldsymbol{c}^S$ and $\delta\boldsymbol{c}^H$ account for a small amount of the PEI differences, only Belgian PEI was significantly influenced by the share of final energy demand of secondary energy carriers with high related primary energy ($\delta\boldsymbol{c}^H \gg 0$).

Finally, differences in other economic variables such as import structure, energy prices and final energy expenditures share in total final expenditures accounted for by $\delta(s/Q)$ and $\delta(h/Q)$ were responsible for a higher PEI (i.e. $\delta(s/Q) + \delta(h/Q) > 0$) of Finland, Spain, Sweden and UK. On the other hand, these factors had almost no relevance in PEI differences of the rest of the countries.

3.2 Year 2000

The situation of 2000 did not significantly differ from 1995. The two driving factors of differences between countries were the structure and efficiency of the energy sector and the direct energy intensity of non-energy industries of the rest of the economy. Moreover, $\boldsymbol{C}^E$, $\boldsymbol{c}^S$ and $\boldsymbol{c}^H$ are almost irrelevant in PEI differences. It is worth to mention the UK's energy sector became relatively less efficient than the Danish energy sector, or in other words, improvements in conversion efficiencies of the energy sector in the UK were lower than in Denmark.

Greece was the country with the highest PEI of the EU14 ($\Delta PEI = 489$ TOE/€), which was caused mainly by the little efficiency of the energy sector ($\delta\boldsymbol{L}^E = 449$ TOE/€) and by a lower direct energy intensity ($\delta\boldsymbol{T}^{ES} = 113$ TOE/€). Although, these factors were partially offset by $\boldsymbol{C}^E$, $\boldsymbol{L}^S$, $\boldsymbol{c}^S$ and $\boldsymbol{c}^H$. Furthermore, the difference in primary energy intensity of Ireland was mainly due to the composition of final energy demand and other economic variables ($\delta\boldsymbol{c}^H$ and $\delta(h/Q) \gg 0$).

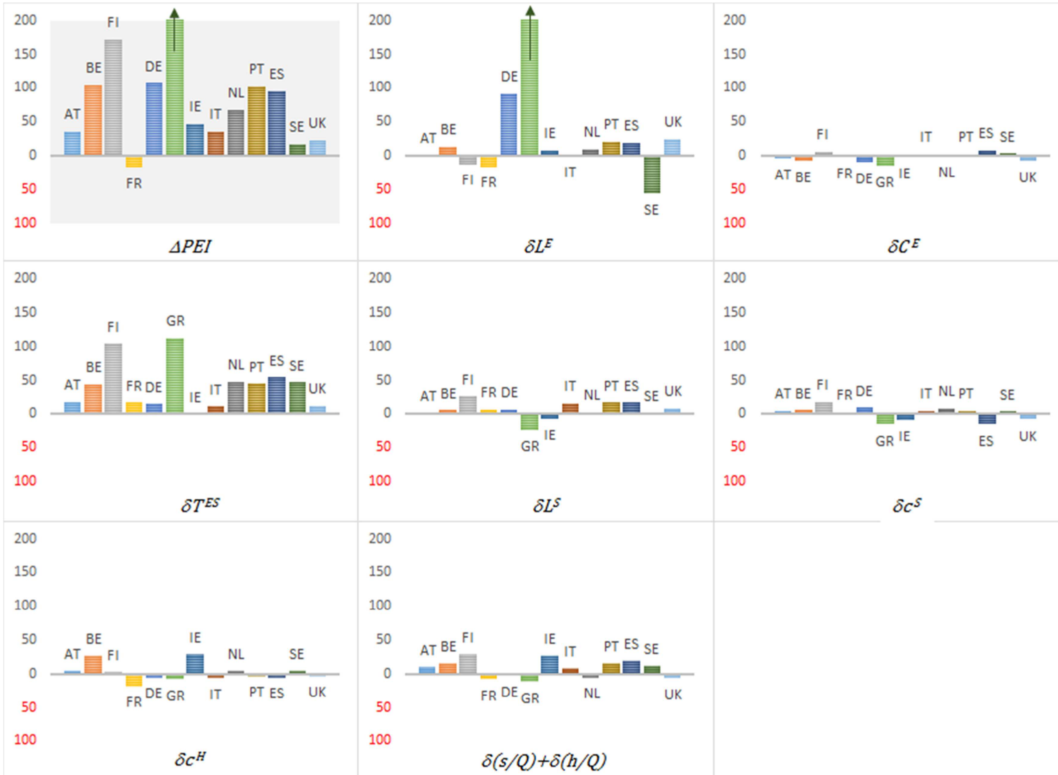

Figure 3-2 Decomposition coefficients of EU14's PEI comparisons: 2000. Note: Vertical axis shows the primary energy intensity in TOE/€.

Other economic variables, $\delta(s/Q) + \delta(h/Q)$, were responsible for a higher primary energy intensity of Austria, Belgium, Finland, Ireland, Italy, Portugal, Spain and Sweden. On the other hand, these variables had a little influenced for a lower PEI of France, Greece and the UK.

3.3 Year 2005

The coefficients of most factors in 2005 had similar trends as in 2000. The main variations are in the direct energy intensity, the economic structure and the composition of final energy demand, which show a lower influence in PEI differences (in absolute terms than in 1995 and 2000). The $\delta\boldsymbol{c}^{H}$'s suggest a convergence in the use of the type products in final energy demand. The values of $\delta\boldsymbol{L}^{S}$ might have been caused by a shift in non-energy production toward less energy intensive industries in the EU14. The $\delta\boldsymbol{T}^{E}$'s suggest that the average direct energy intensity of non-energy industries of the rest of the economy in these countries came closer to the Danish average.

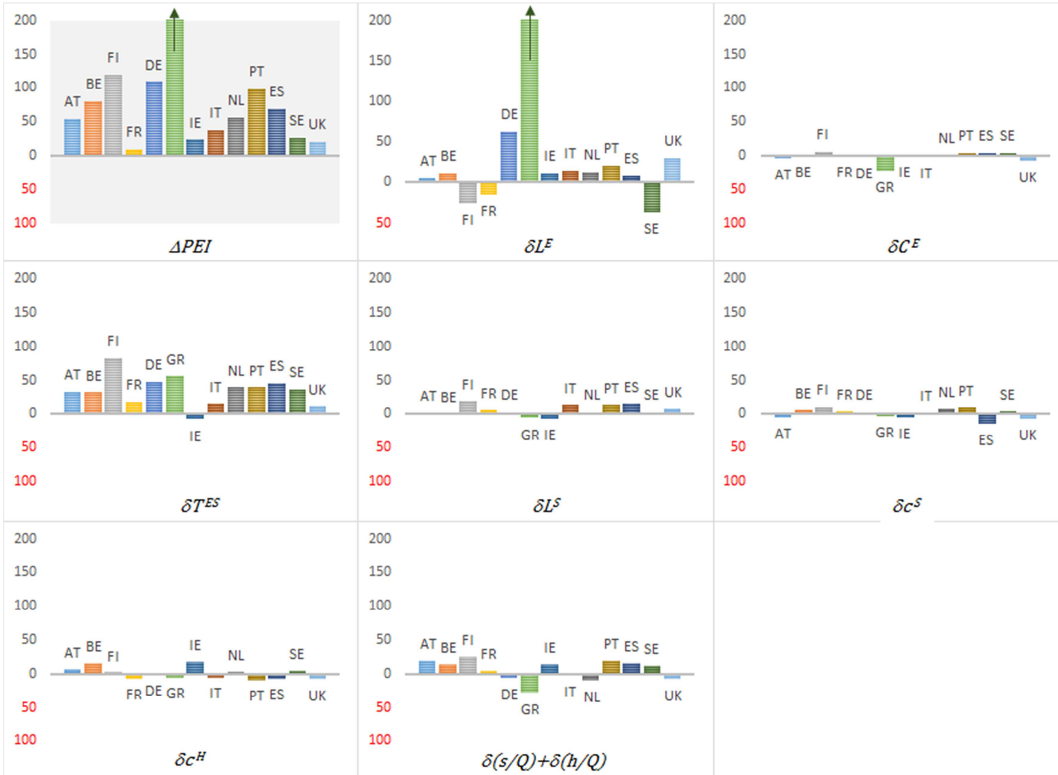

Figure 3-3 Decomposition coefficients of EU14's PEI comparisons: 2005. Note: Vertical axis shows the primary energy intensity in TOE/€.

4 Conclusion

In this paper, we performed a comparison of the primary energy intensity (PEI) of the EU14 for the years 1995, 2000 and 2005. To do so, we used the primary-to-final energy input-output approach, which allows accounting for different factors that determine the energy performance of an economy.

The results show that there were two main driving factors of differences in PEI: the primary-to-final energy conversion structure and efficiency and the direct energy intensity.

The first factor, the primary-to-final energy conversion structure, corresponds to the characteristics of the production processes within the energy sector. It was found that Finland, France and Sweden had that most efficient while Germany and Greece had the least efficient energy sectors among the EU14. This factor was responsible for a higher than average PEI of the two latter countries. The trend of the effects on PEI of this factor did not significantly change along the studied period, which might have been caused by a slow transition in the energy sectors of the EU14.

On the other hand, the second factor, the direct energy intensity, accounts for the efficiency in the energy use for the production of non-energy products. Regarding this, Denmark was the country with the lowest direct energy intensity. This factor largely accounted for a higher PEI of Finland and Greece relative to Denmark in every year. However, there is a decreasing tendency of the effect of this factor for every country, which suggests that the average direct energy intensity in most countries came closer to the Danish average.

Other factors had less influence in PEI differences. The structure of the rest of the economy shows a convergence in the EU14 towards less energy intensive rest of the economy . The composition of energy demand by the rest of the economy and by final consumers explained a negligible part of the differences in PEI. In addition, other variables such as energy prices to final consumers and the import structure led most countries to have a higher PEI. Nevertheless, the effect of these other variables should be separately estimated in future research.

The present analysis can provide information for the design of country-specific energy policy measures so to reduce their primary energy intensity in the future.

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