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Energy and CO_2 intensity changes in the EU-27: Decomposition into explanatory effects

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A B S T R A C T

Sustainability has traditionally focused on three interconnected and mutually enforcing pillars: economy, ecology and society. One of today's major challenges is to tune environmental sustainability with economic growth and welfare by decoupling resources use and environmental degradation from economic growth.

This work aims to assess energy-economy-environment interactions, analyzing energy and CO_2 emission intensity. This is done through a comparative examination of their recent trends in the EU-27 countries, from 1999 to 2009, both by assessing resource and impact decoupling, and through the decomposition of the overall rates of change into their main explanatory effects.

One of this work's major contributions is the derivation of policy implications from the assessment of the main driving forces behind energy and CO_2 intensity, with a greater geographical and temporal focus than prior studies. The results show that, overall, the EU-27 economies reduced total energy use by moving into less energy-intensive structures and improving sectoral energy efficiency, in spite of the adverse results of the activity effect. Regarding CO_2 emissions, the EU-27 decreased these by moving to less carbon-intensive structures and by improving the sectoral energy efficiency, the energy-mix and the emission-factor.

1. Introduction

Fighting climate change is one of today's top priorities of EU environmental policy. This makes the environmental and energy policies even more interconnected than before. As the EU 2020 climate and energy package denotes, improving energy efficiency has received increasing EU attention as a key component of sustainable development that could tackle energy security while addressing climate change concerns. Indeed, energy efficiency improvements are generally considered one of the best strategies to reduce CO_2 emissions, to limit the energy dependence and to alleviate the effects of oil price increases. Most EU countries have been implementing energy efficiency policies and there is a need to monitor the energy performance achieved in order to evaluate their impact and to correct them for the near future. For this it is essential to integrate economic, environmental and social dimensions in the energy planning process (Neves et al., 2015).

This work aims to improve awareness of the complex interactions between energy, economic and environmental issues. For this, energy and (related) CO_2 emission intensity are compared and assessed for the EU-27 countries in the 1999-2009 period, using data from the World Input-Output Database (WIOD) (Timmer, 2012).

This study is structured as follows. In section 2 we discuss the relevance of studying energy use, the CO_2 emissions released and corresponding intensity and examine how they have changed, particularly through the concepts of decoupling and decomposition analysis. Section 3 describes the crucial information on how the empirical analysis is performed and provides a review of the theory and methods, as well as a description of the calculation procedures and data treatment requirements. Section 4 presents the main results and their discussion, firstly by assessing whether resources' use and/or environmental degradation are decoupling from the growth of the economies, and then by decomposing the overall rates of change of energy use and related CO_2 emissions into the different explanatory effects that contribute to such progression, for each of the EU-27 countries. Section 5 concludes with a summary of the most important findings and the derivation of corresponding policy implications.

2. Scope of analysis: energy and CO_2 emission intensity and trends

2.1. Energy and CO_2 intensity

Energy intensity has been a particularly relevant issue in many energy studies and the focus of many programs to lower anthropogenic CO_2 emissions and thus combat climate change (Liddle, 2012). Assumptions about energy intensity and how it changes often form the backbone of energy use and CO_2 emission projections. Policies to decrease energy intensity are generally recognized as an important way to reduce energy-related CO_2 emissions and save exhaustible fossil fuel resources - coal, oil and natural gas (Farla and Blok, 2001), while simultaneously promoting economic growth (Wang, 2013).

In general, energy intensity is measured as the quantity of energy required per unit of output or activity, so using less energy to produce a product reduces its intensity. We use here the most common measure of energy intensity, which is drawn from the International Energy Agency (IEA), namely, the total primary energy supply (TPES)[1] divided by GDP. On the whole, both the principles of analysis and the procedures to estimate energy intensity can be applied fairly straightforwardly to (energy-related) CO_2 emission intensity.

2.2. Resource and Impact Decoupling: absolute or relative

The analysis of energy and CO_2 intensity evolution is closely interconnected with the concept of decoupling. As proposed by UNEP (2011), we first consider the distinction between resource and impact decoupling, and then between relative and absolute decoupling.

On the one hand, resource decoupling means reducing the rate of use of resources (e.g. energy use) per unit of economic activity (GDP) and thus could be referred to as increasing resource

[1] TPES = Indigenous production + imports - exports - international marine and aviation bunkers +/- stock changes. Thus, TPES is said to measure the total amount of energy used by a country in its economic activity.

productivity. On the other hand, impact decoupling requires increasing economic output while reducing negative environmental impacts (e.g. CO_2 emissions), and thus could be referred to as increasing eco-efficiency.

Furthermore, when an economy is growing it is particularly relevant to distinguish between relative and absolute decoupling. Relative (resource or impact) decoupling means that the growth rate of the environmentally relevant parameter (resources used or some measure of environmental impact) is lower than the growth rate of a relevant economic indicator (e.g. GDP). Absolute decoupling, in contrast, means that resource use (or environmental impact) declines, despite of the growth rate of the economic driver.

2.3. Energy and CO_2 emission changes: Decomposition analysis

The analysis of energy use and CO_2 emission changes is also meaningful as it has potential to highlight signs of human development and progress, particularly through the connection with changes in the economic structure, fuel mix, and/or the technological level of a country (Sun, 2002). Decomposition analysis provides important insights regarding trends in both energy use and energy intensity changes.

Changes in aggregate energy intensity (D_{tot}) are usually decomposed into an activity effect (D_{act} - the impact associated with the overall activity level of an economy), a structural effect (D_{str} - the impact associated with the output structure of an economy) and an intensity effect (D_{int} - the impact associated with changes in sectoral energy intensity) (Wang, 2013). Moreover, this type of analysis can be extended to the trends in CO_2 emissions and CO_2 emission intensity. When analyzing the changes in aggregate emission intensity two additional effects are measured: the energy-mix (or fuel-mix) effect (D_{mix} - the impact associated with changes in the sectoral energy mix) and the emission-factor (or emission coefficient) effect (D_{emf} - the impact associated with changes in the carbon emission factors).

Such decomposition analysis is particularly relevant when comparing countries, as they typically have and use different energy (re)sources, diverse degrees of economic specialization, and are of different sizes (in terms of both population and the overall scale of the economy), and thus it is important to distinguish how much of the overall evolution of an aggregate is due to the progress of specific components.

3. Methodology and data

In this section the methods and data used are described. First, the main contents and characteristics of the database are set out. Second, the data treatments required are described. Finally the different methods used to perform the analysis are explained.

3.1. The World Input Output Database

The main data source used in this work is the World Input-Output Database (WIOD). This database is built on national accounts data, which was developed within the Seventh Framework Programme (FP7) of the European Commission. It has two main advantages with respect to previously available data sources. First, harmonization procedures were applied to ensure international comparability of the data throughout the collection process. This ensures data quality and minimizes the risk of measurement errors, which are rather unlikely to occur. Moreover, since the data collection is consistent and fully comparable across countries, it can describe and analyze efficiency gains at the sectoral and global level.

The core of the database is a set of harmonized national input-output tables, linked together with bilateral trade data in goods and services. National tables are typically only available for benchmark years and often not comparable over time, but the WIOD allows these comparisons. The results provide international tables at current year prices, 35 industries by 59 products, for 41 regions in the world. Based on this, annual world input-output tables are derived for the period from 1995 to 2009 (Timmer, 2012).

Further, the database provides environmental satellite data, which is defined so as to cover the broadest range of environmental themes as is reasonably achievable while data quality remains based on the empirical availability of primary data. In general, the variables cover: energy use, main greenhouse gas (GHG) emissions, other air pollutant emissions, mineral and fossil resources' use, land use and water use.

Most, if not all, environmental variables needed to fill the data framework derive from sources (e.g. energy statistics, water statistics, etc.) that use a different framework that is not compatible with national accounts. Data transformations were therefore necessary to achieve conceptual consistency.

For this study, the database assessed displays a time series with the information detailed in Table 1, below, for the EU-27 countries[2].

Table 1 - WIOD data assessed

National Input-Output Tables (NIOT)	• National Input-Output Tables (NIOT) at current prices (35 industries by 35 industries)
Socio-economic Accounts (SEA)	• Industry output, value added, at current and constant prices (35 industries)
Environmental Accounts	• Gross energy use by sector and energy commodity • CO_2 emissions modeled by sector and energy commodity

Source: Timmer (2012)

3.2. Data Treatment

As one of the most widely cited macroeconomic indicators for measuring sustainability through estimates of the decoupling effect, the energy/GDP (or energy intensity) ratio has been the focus of a significant number of published studies. This study also analyzes the progress of another indicator, the CO_2 emissions/GDP (or CO_2 emission intensity) ratio.

Data for CO_2 emissions and energy use is available in Gigagrams (Gg) and Terajoules (TJ) respectively, with no manipulation needed. This information is thus taken directly from the WIOD.

[2] It is worth mentioning that since July 2013 the EU was enlarged to 28 member countries with the accession of Croatia, but this country is not considered here for reasons of data (un)availability.

Regarding the economic dimension, for the purposes of our analysis, some preliminary adjustments and calculus are required regarding the way the relevant information is compiled in the WIOD. Indeed, the GDP estimation approach to follow should be stated and, to allow comparative analysis, GDP must be expressed at constant prices, and some currency conversions performed, as follows.

3.2.1. Deriving GDP from the IO Tables

GDP is the final result of the economic activity of residents in a specified area within a given period of time. In order to calculate the GDP using the WIOD data some manipulation is needed. As the main focus of this study is the energy (and CO_2 emission) intensity assessment, which is more adequately done through the analysis of the inputs required to generate a given level of output, the option was to follow the product approach.

For the product approach, GDP is obtained as the sum of the gross value added (*VA*) at basic prices of the different industries, plus taxes (*T*) less subsidies (*S*) on products.

$$GDP = VA + (T - S) \quad [1]$$

Gross value added (*VA*) is the sum of gross output (*GO*) minus intermediate consumption (*IC*).

$$VA = GO - IC \quad [2]$$

Assessing the WIOD Socio-economic Accounts (SEA) makes it possible to obtain the values for *GO*, intermediate inputs (*II*) and *VA* for the different economies in the various local currencies. In this case *VA* is also the result of subtracting *II* from the *GO*.

$$VA_{SEA} = GO_{SEA} - II_{SEA} \quad [3]$$

The GDP calculation is not direct because *II* is different from *IC*, as *II* includes taxes (*T*) less subsidies (*S*) on products and international transport margins (*ITM*).

$$II = IC + (T - S) + ITM \quad [4]$$

Taxes less subsidies on products and international transport margins can be found in the National Input-Output Tables (NIOT) of the WIOD, but unlike the previously mentioned SEA, these tables are expressed in dollars. Thus, these values must be converted into local currencies, which can be done using the exchange rates provided by the WIOD.

Consequently, to calculate IC we need to subtract taxes less subsidies on products and international transport margins.

$$IC = II_{SEA} - [(T-S) + ITM]_{NIOT} \quad [5]$$

Decomposing Value Added, one gets:

$$VA_{SEA} = GO_{SEA} - IC$$

$$\Leftrightarrow VA_{SEA} = GO_{SEA} - \ [II_{SEA} - [(T-S) + ITM]_{NIOT}] \quad [6]$$

Using the product approach, all the components needed to calculate the nominal GDP value of each economy are then defined, as follows.

$$GDP = VA + (T-S)$$

$$\Leftrightarrow GDP_{nominal} = GO_{SEA} - \ [II_{SEA} - [(T-S) + ITM]_{NIOT}] + \ (T-S)_{NIOT}$$

$$\Leftrightarrow \ GDP_{nominal} = GO_{SEA} - II_{SEA} + (2 * (T-S) + ITM)_{NIOT}$$

$$\Leftrightarrow \ GDP_{nominal} = VA_{SEA} + 2 * (T-S)_{NIOT} + ITM_{NIOT} \quad [7]$$

3.2.2. Converting monetary values at current prices into constant prices

To estimate the trends in energy and CO_2 emission intensity it is important to use GDP values at constant prices (instead of current (or nominal) prices, as the data provided by the WIOD). In this way, the effects of price fluctuations (inflation or deflation) are removed and the real growth of the economy is analyzed.

In theory, there are two alternative methods to convert nominal into constant values. On the one hand, using the NIOT at current and previous year prices and on the other hand using the value added price index provided in the SEA. As WIOD does not provide access to the NIOT at previous year prices (due to unsatisfactory results for the deflation process), in practice, only the second method could be performed.

The price index of the VA provided in the SEA uses 1995 as the base year. The base year preferred for this analysis and assessment is 2005, and therefore a change in the base year is needed. Two fundamental steps are required to perform that change: first calculate the price index deflator, and then employ that deflator to determine the new index.

Thus, to transform nominal values into 2005 constant prices we divide the nominal GDP values with the corresponding year index.

3.2.3. Currency conversion

GDP values expressed in US dollars at the WIOD were converted into each country's currency using the exchange rates provided by the WIOD. To compare intensity values amongst countries (instead of individual country trends), it is necessary to use a single currency - euro. The Eurozone, or Euro Area, is an economic and monetary union (EMU) of 17 EU Member States which have progressively adopted the euro (€) as their common currency since 1999. Thus, the 10 other countries in this study do not use the euro, but their own specific currencies. For these 10 cases the European Central Bank's statistics provided the nominal effective exchange rate (which is a summary measure of the external value of a currency *vis-á-vis* the currencies of the most-traded partners (ECB, 2013)).

Therefore, even though different currencies are used, it is possible to compare the progression of energy and CO_2 emission intensity in the EU-27 Member States.

3.3. Decomposition analysis of energy and CO_2 emission changes

The analysis of energy use and CO_2 emission changes through the analysis of their decomposition into specific explanatory effects is particularly relevant both to analyzing the progress of the indicator in a specific country and to comparing the trends between countries.

There are two broad categories of decomposition techniques (Hoekstra and Bergh, 2003): using input–output techniques — structural decomposition analysis (SDA) and with disaggregation techniques — index decomposition analysis (IDA). Table 2 shows the main characteristics of each technique.

Table 2 – Comparison of IDA and SDA decomposition techniques

	Application	Scope	Time series	Decomposition form	Factors included	Data needed	Effects studied
IDA	Flexible	Specific sector or economy wide	Annual time series	Additive and multiplicative	From two to eleven	Data with high or low aggregation	Only direct effect
SDA	Restricted to availability of IO tables	Economy wide	Benchmark years	Additive	Same number of factors	IO tables	Direct and indirect effects

Source: Adapted from Su and Ang (2012)

The SDA approach is based on input–output coefficients and final demand from input–output tables, while the IDA framework uses aggregate input and output data that are typically at a higher level of aggregation than input–output tables. This basic difference also determines the main advantages and disadvantages of the two methods. As previously mentioned, the time series for the NIOT are not available in the WIOD, and thus it is not possible to use an SDA. Accordingly, the disaggregation technique computed in this work is an index decomposition analysis (IDA).

IDA has been widely used since the 1980s to study energy use changes (a literature review can be found in Ang (1995) and Ang and Zhang (2000)). From the 1990s, with increasing concerns about climate change and GHG emissions, IDA has been extended to study energy-related CO_2 emissions (Xu and Ang (2013) provide a comprehensive literature survey on emission studies from 1991 to 2012).

An IDA begins by defining a primary function relating the aggregate to be decomposed to a number of pre-defined factors of interest. With this function defined, various decomposition methods can be formulated to quantify the impacts of changes of these factors on the aggregate (Ang, 2004; Ma and Stern, 2008). Ang (2004) compares and discusses various IDA methods, considering their theoretical foundation, their adaptability, ease of use and result interpretation, and concludes by recommending the logarithmic mean Divisia index (LMDI). The LMDI is a weighted sum of logarithmic change rates, where the weights are the components' shares in total value, given in the form of a linear integral. The survey by Xu and Ang (2013) reveals that an increasing proportion and a vast majority of the studies on emissions use the LMDI (as in the case of energy decomposition studies (Ang and Zhang, 2000)). Accordingly, this is the method we chose to track economy-wide energy and CO_2 emission efficiency trends. The LMDI method description below very closely follows the one proposed by Ang (2005).

Changes in industrial energy consumption (D_{tot}) can be studied by quantifying the impacts of changes in three different factors[3]:

i. the overall industrial activity (activity effect - D_{act}),

ii. the activity mix (structure effect - D_{str}),

iii. the sectoral energy intensity (intensity effect - D_{int}).

Thus, energy consumption (E) can be presented/decomposed as:

$$E = \sum_i E_i = \sum_i X \frac{X_i}{X} \frac{E_i}{X_i} = \sum_i X S_i I_i \quad [8]$$

In which i represents the sectors, X the overall output level, S_i the activity share and I_i the energy intensity of each sector.

There are two methods to calculate these effects, the additive and the multiplicative. The focus of our study is the analysis of the direction and relative impacts of each effect. Accordingly, the multiplicative method was chosen as it presents the effect of variations in percentages, which enables a better comparison between countries. Thus, with multiplicative decomposition the variation of E (i.e. the energy consumption change) is the ratio between the final energy consumption level and the initial one:

$$D_{tot} = E^T / E^0 \quad [9]$$

This expression can then be decomposed into the three effects mentioned (overall activity level[4], activity structure and sectoral energy intensity):

[3] The number and designation of the factors may vary across studies, but energy intensity appears in almost all of them as it is generally considered as a good proxy for energy efficiency.

[4] It is worth explaining that less relevance is often given to the activity effect (on the analysis of the empirical results). The main reason for this is that in IDA energy use and (related emissions) are positively correlated with the activity level. Accordingly, increases (decreases) in the activity level of a particular sector or of the overall economy invariably lead to increases (decreases) in emissions.

$$D_{tot} = D_{act}\, D_{str}\, D_{int} \quad [10]$$

These energy changes' explanatory effects can be calculated as:

$$D_{act} = exp\left[\sum_i w_i\left(\ln\frac{X^T}{X^0}\right)\right];\ D_{str} = exp\left[\sum_i w_i\left(\ln\frac{S_i^T}{S_i^0}\right)\right];\ \ D_{int} = exp\left[\sum_i w_i\left(\ln\frac{I_i^T}{I_i^0}\right)\right];$$

$$w_i = \left[\frac{(E_i^T - E_i^0)/(\ln E_i^T - \ln E_i^0)}{(E^T - E^0)/(\ln E^T - \ln E^0)}\right] \quad [11]$$

This analysis can be further extended to assess energy-related CO_2 emissions. For this, two more factors are added to the previously mentioned, namely:

iv. sectoral energy mix (energy-mix effect - D_{mix}),

v. CO_2 emission factors (emission-factor effect - D_{emf}).

Therefore, total energy-related CO_2 emissions (*CO*), can be presented/decomposed as:

$$CO = \sum_{if} CO_{if} = \sum_{if} X\frac{X_i}{X}\frac{E_i}{X_i}\frac{E_{if}}{E_i}\frac{CO_{if}}{E_{if}} = \sum_{ij} X\, S_i I_i M_{if} U_{if} \quad [12]$$

In which CO_{if} represents the CO_2 emissions arising from fuel *f* in industrial sector *i*, E_{if} is the consumption of fuel *f* in industrial sector *i*, M_{if} is the fuel-mix variable and U_{if} is the CO_2 emission factor.

Consequently, the variation of *CO* is the multiplication of the 5 different factors mentioned:

$$D_{tot} = D_{act}\, D_{str}\, D_{int}\, D_{mix}\, D_{emf} \quad [13]$$

These CO_2 emission changes' explanatory effects can be calculated from:

$$D_{act} = exp\left[\sum_i w_{if}\left(\ln\frac{X^T}{X^0}\right)\right];\ D_{str} = exp\left[\sum_i w_{if}\left(\ln\frac{S_i^T}{S_i^0}\right)\right];\ D_{int} = exp\left[\sum_i w_{if}\left(\ln\frac{I^T}{I^0}\right)\right];$$

$$D_{mix} = exp\left[\sum_i w_{if}\left(\ln\frac{M_{if}^T}{M_{if}^0}\right)\right];\ D_{emf} = exp\left[\sum_i w_{if}\left(\ln\frac{U_{if}^T}{U_{if}^0}\right)\right];$$

$$w_{if} = \left[\frac{\left(CO_{if}^T - CO_{if}^0\right)/\left(\ln CO_{if}^T - \ln CO_{if}^0\right)}{(CO^T - CO^0)/(\ln CO^T - \ln CO^0)}\right] \quad [14]$$

This decomposition method is used to study the variation in energy and CO_2 emissions for the EU-27 Member States from 1999 (0) to 2009 (T). Using the index method previously explained, the variation of the Output level (X) is considered in real terms (i.e. without the inflation/deflation effect).

4. Results and discussion

This section presents and discusses the main results of the study. First, we look at the estimates of energy use and CO_2 emissions released, and the corresponding intensity. The analysis of energy and GDP trends also supports the assessment of each country's performance regarding (absolute or relative) resource decoupling, while the analysis of CO_2 emissions and GDP trends indicates each country's success in achieving (absolute or relative) impact decoupling. Then, we look at the analysis of the LMDI decomposition of energy use and CO_2 emissions released into their main explanatory effects.

Before such a detailed analysis it is worthwhile establishing subdivisions within the EU-27 countries to help in the comparative analysis and discussion of the results. The South, Center, East and North groups were defined, taking into account their position in the energy intensity 'ranking' (see Figure 1), and simultaneously their geographical proximity, similar weather patterns and 'expected' level of technological progress.

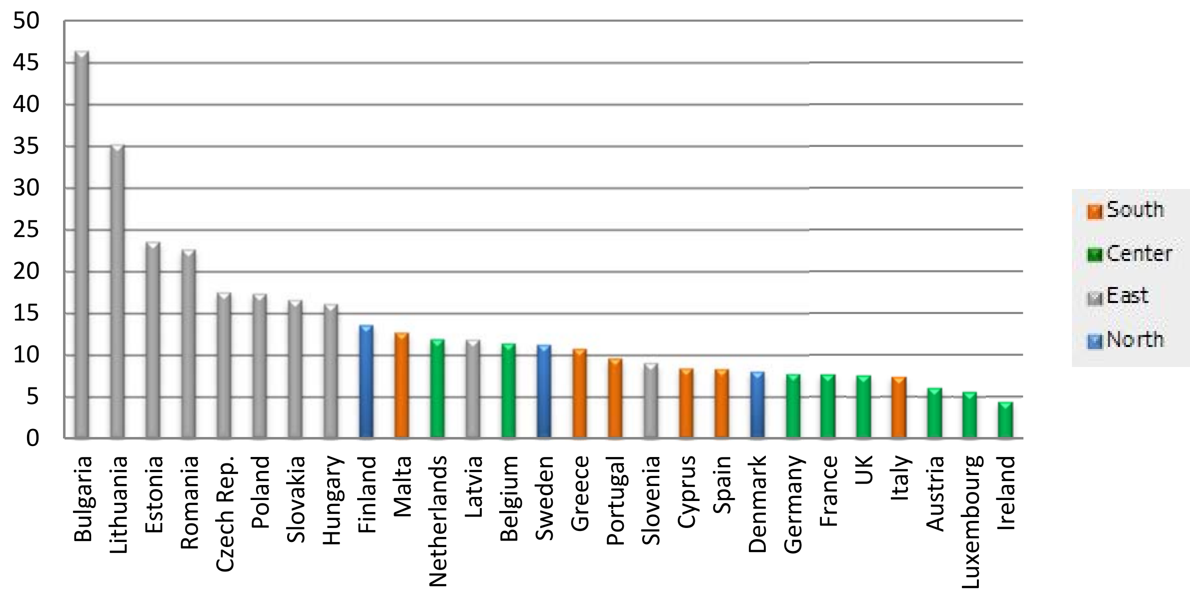

Figure 1 - Energy Intensity in the EU-27, in 2009 (Tj/million euros)

Figure 1 makes clear the wide range of values for the energy intensity (Tj/million euros) in the EU-27 countries, in 2009, varying from 4.4 in Ireland to 46.4 in Bulgaria. Further, the most energy intensive countries tend to be in the East group (which were not expected to have particularly high levels of productivity and most of them usually have harsh climate conditions). Next come the countries considered here as the North group, in which the weather patterns are ruthless (but to some extent compensated by higher productivity). Next is the South group, whose needs in terms of energy gain more (at least during winter) from the (mild) weather conditions. Finally, the least energy intensive countries (with the exception of the northern countries of this group) are those here categorized in the Center group, which are expected to have the best combination of weather patterns and industrial productivity.

4.1. Intensities and Trends

Regarding energy and Resource Decoupling, the majority of the East[5] and North group countries have increased their energy use. Furthermore, although more than half (14) of the countries have increased the energy used from 1999 to 2009, only Denmark and Luxembourg failed to show improvements in terms of the energy intensity and did not achieve either relative or absolute resource decoupling.

Assessing the CO_2 emissions and impact decoupling, we realize that a larger number of countries have been successful in achieving absolute impact decoupling (17 – predominantly East and Center countries) than those reaching resource decoupling (13 – mostly Center and South countries). Three countries have not 'decoupled' at all, namely, Denmark, Slovenia and Malta, although Slovenia managed to reduce its CO_2 emission intensity. Of the 10 countries that have increased CO_2 emissions, there are more South group countries represented, while the East and Center groups are the most representative in terms of CO_2 emission reduction.

[5] It should be noted that some of the Eastern countries were obliged to decommission nuclear facilities in this period, which contributed significantly to the increase in their energy use.

4.2. Index Decomposition Analysis

The LMDI decomposition shown in Figures 2 to 5, one for each group of countries, represents the variation in the amount of energy used (D_{tot}) and how this amount would progress considering the activity (D_{act}), structure (D_{str}) or intensity (D_{int}) explanatory effects alone (i.e. a *ceteris paribus* analysis). Then, in Figures 6 to 9 a similar approach is followed for the CO_2 emissions released.

4.2.1. Energy decomposition

4.2.1.a) The South countries

Figure 2 shows that, in the South group, Cyprus had the best performance (in relative terms) reducing energy use by more than 20%. The achievements in the economic structure (38.8%) and in the energy efficiency (11.3%) enabled this reduction. This move to a less energy intensive-structure can be largely explained with the 'disappearance' of the coke industry.

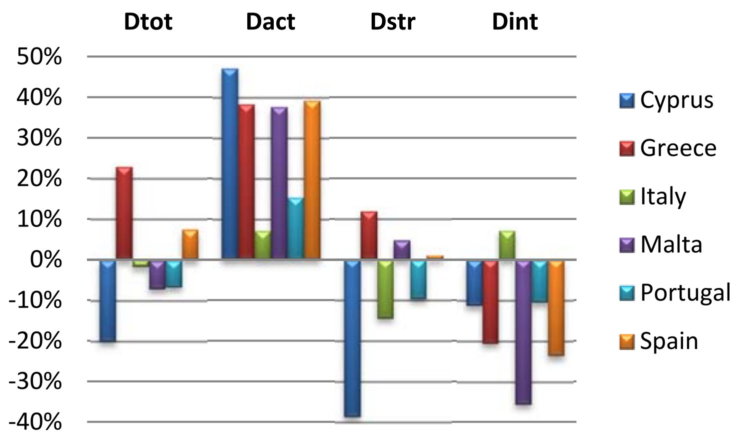

Figure 2. Energy: decomposition into explanatory effects in South countries (1999-2009)

Portuguese energy consumption decreased in the period considered. If only the activity effect were considered (i.e. the growth of economic activity) then Portuguese energy consumption would have grown 15.4% in this period. But the fall (9.7%) in the structure effect (move to an economy with a less energy-intensive sectoral structure) and (10.5%) in the intensity effect (sectoral energy efficiency improvements) exceeded the activity effect. Furthermore, changes in the output of each sector reinforce the results provided by the decomposition concerning the move to less energy intensive industries. Indeed, e.g. there are two dominant cutbacks, in Construction and Textile, and a significant rise in the Financial Intermediation sectors.

On the other hand, only Greece and Spain did not manage to reduce energy use, but even so, there were significant improvements in energy efficiency in both countries.

Italy was the only country which did not improve energy efficiency and Malta was the one that improved the most. Regarding the structure effect, Cyprus, Italy and Portugal moved to a less energy intensive structure while Spain, Malta and Greece did the opposite. In Greece and Malta the growth in energy use in the Water transport sector and in Spain in the Air transport sector could be mainly responsible.

4.2.1.b) The Center countries

Figure 3 shows the UK's contribution to the Center group's overall energy use reduction.

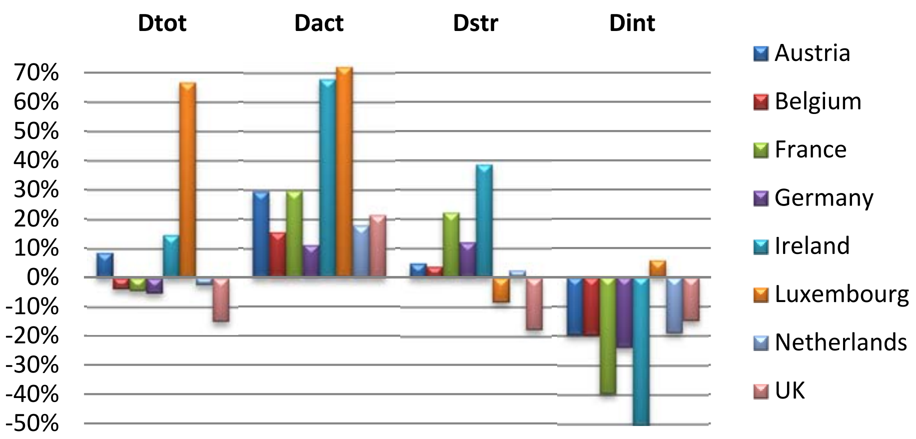

Figure 3. Energy: decomposition into explanatory effects in Center countries (1999-2009)

Among the Center countries it is noticeable that Luxembourg increased its energy use by 66.7%. One of the main reasons for this is the growth in output. From 1999 to 2009 it grew from 16.1% to 53.1% in the top five most energy intensive industries and a total of 72.1% in all industries. Luxembourg has made improvements by moving towards a less energy intensive structure, but it is the only country within this group with a drop in terms of energy efficiency.

Ireland and Austria are the other two countries where energy consumption has increased. Ireland had remarkable improvements in energy efficiency but the high growth in economic activity and the poor performance in terms of the structure effect exceeded the first positive effect. In Austria, one of the main justifications stems from the growth in energy use in the Construction industry and the output growth in the Electricity sector.

France combined a considerable growth in the activity effect (29.7%) and a deterioration in terms of its structure (22.2%), but these were compensated by improvements in energy efficiency (39.7%) to end up with an overall reduction (-4.5%) in energy use.

The Netherlands, Belgium and Germany had similar results in the three explanatory effects, in that they record decreases in energy use, growth in economic activity, more energy-intensive industries and improvements in energy efficiency.

In terms of the structure explanatory effect, it is well known that the UK (together with Luxembourg) moved to less energy-intensive industries. The growth in the output of industries such as Health and Social Work and Renting help to explain this shift.

4.2.1.c) The East countries

Figure 4 shows that all the countries from the East group saw an increase in economic activity and improvements in terms of energy intensity.

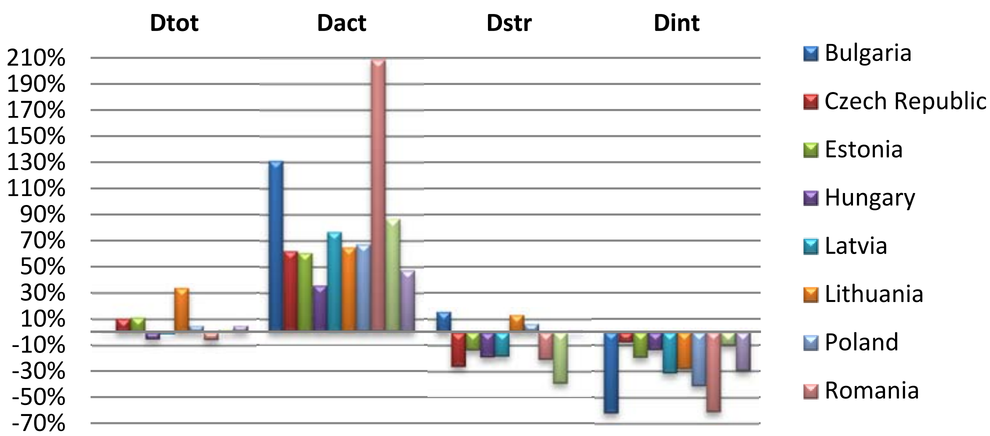

Figure 4. Energy: decomposition into explanatory effects in East countries (1999-2009)

Although only three of the ten East countries managed to reduce energy use, all of them have reported improvements in energy efficiency and most had also improved in terms of the structure. Another particularity of this group is the remarkable expansion in economic activity with eight out of the ten countries growing more than 60%.

Romania and Bulgaria are the two countries that have increased their economic activity the most. They have also had similar results in terms of energy efficiency improvements. Considering the results from the structure effect, Romania reduced its energy use while Bulgaria did not.

Poland, Slovenia and Lithuania had similar results in the three effects considered, with overall energy use and economic activity increasing- more energy intensive industries emerging and improvements being made in energy efficiency.

The Czech Republic and Slovakia were the two countries more successfully moving to less energy-intensive structures. Although they also improved energy efficiency, the final result was an increase in overall energy use. Likewise, Estonia, although showing improvements in the structure and intensity effects, nonetheless increased its energy use (because of the 60% output growth from 1999 to 2009).

4.2.1.d) The North countries

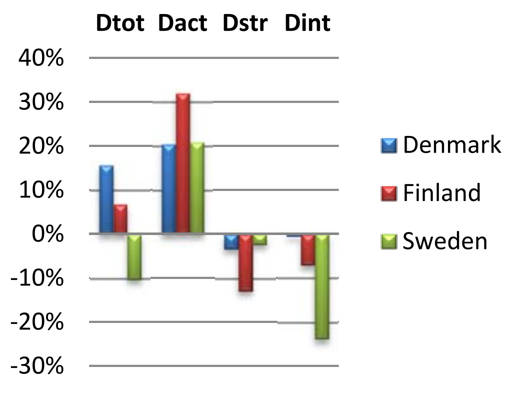

Figure 5. Energy: decomposition into explanatory effects in North countries (1999-2009)

All the three North countries registered growth in economic activity, a less energy-intensive structure and improvements in energy efficiency. Although, only one (Sweden) managed to reduce its overall energy use, mainly because of the greater improvement in energy efficiency.

4.2.1.e) The EU 27

The EU has decreased its total energy use during the period mainly because of the progress in the Center countries (as the other three groups of countries increased their energy use). The UK is the country that cut its energy use the most, both in relative and absolute terms. Center countries (except for the northern countries in the group) have the best performances in terms of energy use reduction. On the other hand, Spain and Greece (unlike the rest of the South group) have poor performances. Clearly, the East group needs to change the increasing trend of its energy use.

Regarding the activity effect, all groups apart from the East registered similar values. Accordingly, this increase in energy use can be in part explained by the large expansion of the activity effect in the East group. The groups that moved to a less energy-intensive structure were the South, East and North, while Center countries deteriorated in this indicator by moving to a more energy intensive structure (7.2%). Most countries (14) improved in terms of this indicator. All the groups have made improvements in sectoral energy efficiency, especially the East (30.6%), followed by the Center (22.8%). Only Italy and Luxembourg deteriorated in this time period.

Overall, the EU-27 have reduced energy use (4.5%) as a counterbalance to the increase prompted by the growth in economic activity (a 50.6% effect), by moving to a less energy-intensive structure (3.9%) and improving sectoral energy efficiency (22.8%).

4.2.2. CO_2 emissions decomposition

4.2.2.a) The South countries

The South group's total emissions have increased, although half of the countries have cut their emissions. As shown in Figure 6, all the South countries had increased emissions because of economic activity and decreased emissions because of improvements in terms of intensity.

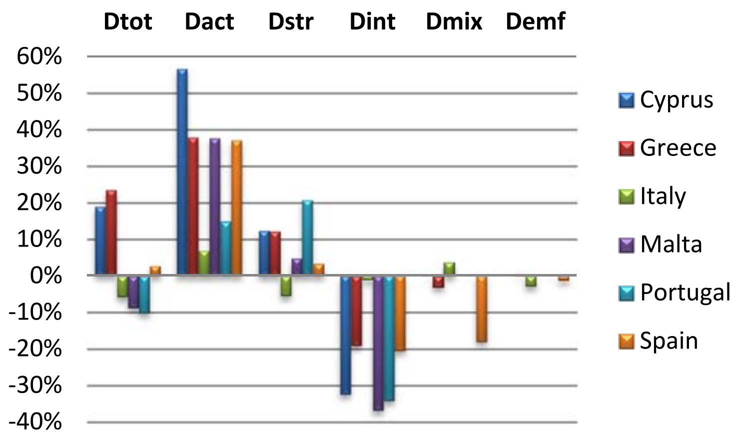

Figure 6. CO_2 emissions: decomposition into explanatory effects in South countries (1999-2009)

Portugal and Malta had similar results in the five explanatory effects and recorded a decrease in the total emissions released. Both had moved to more CO_2 emission intensive structures, present analogous improvements in CO_2 emission efficiency and negligible values for the energy-mix and emission-factor effects. Italy emerged as the only South country that moved to a less CO_2 emission intensive-structure but it is also the one in which the activity effect was the smallest and where the energy-mix deteriorated the most. From 1999 to 2009 Italy only reduced coal consumption by 0.2%, which might help explain why it deteriorated.

Regarding the energy-mix effect, Spain had a remarkable improvement of 18.2%. Indeed, Spain increased renewables use for fuel in 3.2%, reduced oil use by 6.4% and registered the largest rise in gas consumption (10.3%) and shows the largest reduction in coal use (7.1%).

Cyprus and Greece have both substantially increased emissions due to the activity effect, and have similar results in terms of the structure, energy-mix and emission-factor effects. The Cyprus economy's improvement in terms of CO_2 emission efficiency was higher than that of Greece.

4.2.2.b) The Center countries

The Center group's overall emissions decreased, although an increase in three of the countries (Austria, Ireland and Luxemburg). As illustrated in Figure 7, all the countries have increased their emissions because of the activity effect and decreased them due to the energy-mix effect.

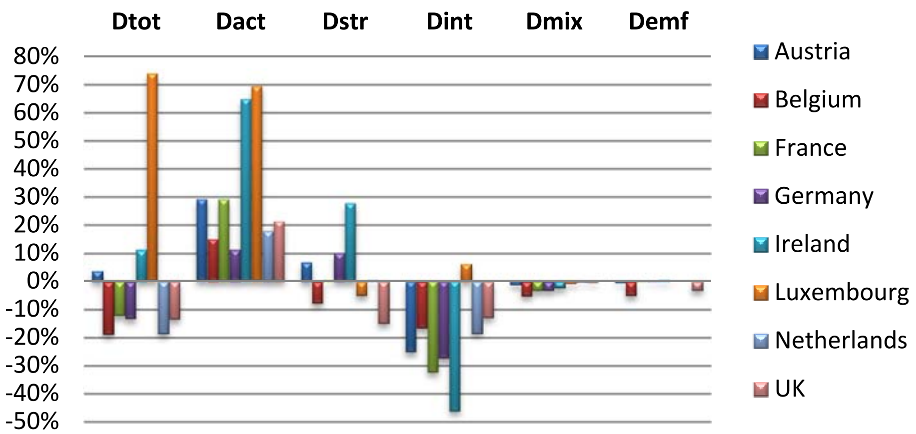

Figure 7. CO_2 emissions: decomposition into explanatory effects in Center countries (1999-2009)

Luxembourg improved the economic structure (to be less CO_2 emission-intensive) but has deteriorated in terms of CO_2 emission efficiency, which combined with the large activity effect, led to a high increase in emissions. Ireland also increased its emissions, but in this case with improvements in efficiency and deterioration in the structure.

France and Austria had similar values in three effects, except for the structure (France poorer)[6] and the energy-mix (France a little better) effects. As a result, France decreased and Austria increased their total emissions. This might indicate that a slightly better energy-mix can avoid more emissions than a better structure does.

UK, Belgium and Luxembourg moved to an economy with a less CO_2 emission-intensive structure. In the UK case, this move results from the greater share of total output being in less energy-intensive sectors, such as Financial Intermediation, Health and Social Work and Renting of Machinery. Additionally, only in the UK and Belgium are the results of the emission-factor effect not negligible, and instead denote considerable improvements. Belgium has also reported the largest improvement in terms of the energy-mix effect. This is explained by the reduction in the use of coal, offset by the increased use of gas and renewables.

[6] In France, the deterioration in the structure can be partially explained by the 3.8% increase in CO_2 emissions on the Air transport sector.

4.2.2.c) The East countries

Most (7) of the (10) East group countries have cut the emissions released. Consequently, the group managed to reduce total CO_2 emissions in the period.

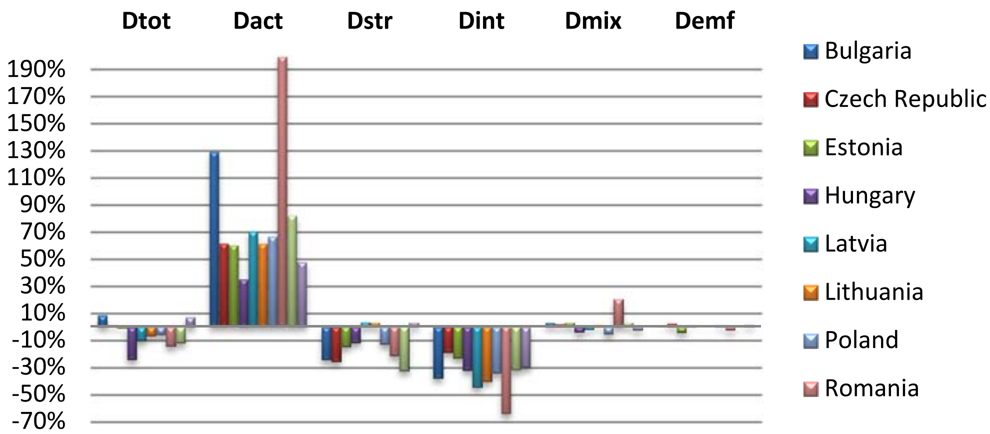

Figure 8. CO_2 emissions: decomposition into explanatory effects in East countries (1999-2009)

As shown in figure 8, the entire group has increased emissions because of the activity effect, but simultaneously decreased them due to the enhanced efficiency of sectoral CO_2 emissions. Only three countries (Latvia, Lithuania and Slovenia) deteriorated in terms of moving into a more CO_2 emission intensive structure. Of these, only Slovenia did not reduce the emissions released, probably because its improvements in terms of CO_2 emission efficiency are more than ten per cent lower than in the two other countries. Lithuania had the worst performance for the energy-mix effect (renewables use increased marginally (0.5%) and oil increased (2.6%)).

Bulgaria, Czech Republic and Slovakia all fell in terms of the energy-mix effect (all have increased oil consumption, while the Czech Republic even reduced the use of renewables). Accordingly, Bulgaria and the Czech Republic have increased the total amount of CO_2 emissions released over the period.

Hungary and Poland significantly decreased emissions, which is explained by the energy-mix (particularly because of increasing renewables and decreasing oil use, while Estonia and Romania deteriorated (both increased their consumption of coal).

4.2.2.d) The North countries

Sweden decreased the emissions released (mainly because of enhanced CO_2 emission efficiency), but this was not enough to decrease the North group's total emissions over the period.

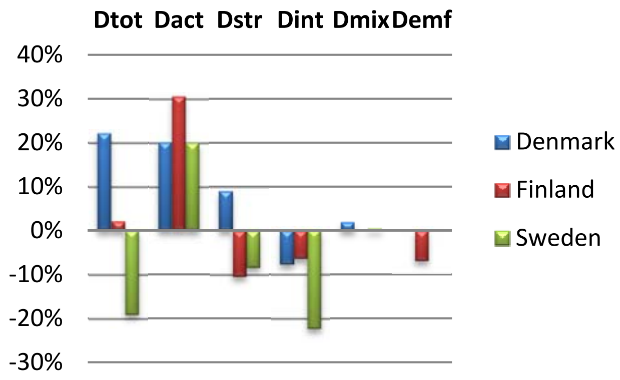

Figure 9. CO_2 emissions: decomposition into explanatory effects in North countries (1999-2009)

Figure 9 shows that all the countries increased their economic activity, enhanced CO_2 emissions because of efficiency and deteriorated due to the energy-mix effects. In Finland, improvements in the economic structure and CO_2 emission efficiency were not enough to reduce total emissions. Mainly thanks to the move to a more CO_2 emission-intensive structure, Denmark had the worst performance. In terms of the energy-mix, all three countries increased the use of renewables and reduced coal use, but only Sweden reduced oil use.

4.2.2.e) The EU 27

The EU reduced the energy-related CO_2 emissions released in the 1999-2009 period almost entirely because of the Center group's action (fell by six times more than the East, while South and North countries' total emissions even increased).

Most countries (16) reduced their total emissions, despite all of them having faced increasing emissions due to the activity effect (South 31.9%, Center 32.2%, North 23.6% and East 81.3%). Regarding the structure effect, the South and Center groups deteriorated (8% and 2.2% respectively), while the East and North groups improved by moving to less CO_2 emission intensive structures (13.4% and 3.3% respectively). Concerning the sectoral energy efficiency effect, only Luxembourg deteriorated, with all groups improving, especially the East. In relation to the energy-mix effect, the South and Center groups improved (3% and 2.2%, respectively), while the East and North groups deteriorated (1.9% and 0.9%, respectively). It is also clear that many of the East and North countries increased the use of oil, while the South and Center countries reduced it. Finally, regarding the emission-factor effect, all groups showed improvement, especially the North.

To sum up, overall, the EU-27 decreased total CO_2 emissions (0.8%), moving to less CO_2 emission-intensive structures (2.9%) and also improving in terms of the sectoral energy efficiency (26.4%), the energy-mix (0.5%) and the emission-factor (0.7%) effects. The activity effect (49.4%) counteracted those effects. Regarding the fuel-mix, it should be noted that the use of renewables and gas increased over the period (by 2.5% and 0.6%, respectively) while the use of coal and oil decreased (1.8% and 1.3%, respectively).

Generally, the results found here are consistent with the literature. Indeed, Xu and Ang (2013) analyzed the empirical results reported in the studies surveyed (covering a wide spectrum of countries), focusing on the role of the structure in terms of direction and relative impacts, intensity, and emission-factor effects. Among the results, the authors stress that energy intensity change was generally the key driver and, further, that in most countries such energy efficiency improvements contributed to decreases in the intensity of aggregate emissions.

There have been fewer comparative studies of EU member states that have used IDA techniques. Gonzaléz et al. (2014), Bhattacharyya and Matsumura (2010) and Moutinho et al. (2015) (the first for the EU-27, but only for the power sector, and the other two just for the EU-15 countries) are notable exceptions in using LDMI approaches, though all account only for CO_2 emission drivers of change, not energy. In general, our results are in accordance with those of these works. Actually, as in this work, all these studies found that the energy intensity and the energy-mix effects are important ways of reducing CO_2 emissions, and both Bhattacharyya and Matsumura (2010) and Moutinho et al. (2015) also found that the United Kingdom and Germany were the greatest contributors to the overall reduction in EU energy-related GHG emissions.

5. Conclusions

Improving energy efficiency is an area that has received growing attention from the EU as a key component of sustainable development that would tackle energy security while addressing climate change concerns. Understanding the effectiveness of these policies requires an assessment of the main driving forces behind energy and (related) CO_2 intensities and a comparison of country performance. This work contributes by making use of a greater geographical coverage of the EU countries (allowing for the influence of their heterogeneity and development levels) and temporal focus than prior studies have done.

Regarding the energy intensity components (energy use and GDP) trends from 1999 to 2009, most (14) of the EU countries increased energy use and all increased GDP over the period. Half of the countries where energy use increased are East countries, while those where energy use decreased are mainly Center and South countries. As regards CO_2 emissions, 10 countries (mostly South countries, except for Italy and Portugal) failed to reduce them over the period, and the largest reductions were in the Center and East countries. Thus, in the EU it is still critical to move towards more energy (resource) and CO_2 emission (impact) efficient economies.

Regarding the inputs from the different explanatory effects for these changes, the results show that, overall, the EU-27 economies reduced total energy use by moving into less energy-intensive structures and improving sectoral energy efficiency, despite the contrary results of the activity effect. Further, although economic activity grew, the EU-27 cut CO_2 emissions by moving to less carbon-intensive structures and by improving sectoral energy efficiency, the energy-mix and the emission factor.

Finally, and clearly relevant to policy, the results of this research provide evidence to back the importance of using this type of decomposition to support decision makers, particularly in a context of crisis such as the one the EU has been facing. Indeed, recent GDP trends in many EU countries (with very low growth rates, or even negative ones) is likely to be translated into declines in energy use and CO_2 emissions, but this does not necessarily mean they are moving in the right direction regarding energy and CO_2 emission policies. Moreover, in the current context of crisis and the simultaneous recent downward shift in oil price, several countries are retreating from supporting and encouraging renewables, thus threatening the trend to curb CO_2 emissions. On the other hand, the less developed EU regions (East) still have a long way to go before they reach the higher stages of development. Accordingly, if economic activity growth in the East countries particularly aims to bring them closer to the richest EU countries, it reinforces the need of governments and EU institutions to analyze the different explanatory effects in order to improve the intensity indicators in this region of the EU. For this, the already interesting results in terms of the intensity effects must be combined with improvements that should be achieved by moving towards implementing less energy- (and CO_2 emission-) intensive structures in these economies.

Acknowledgments

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Nomenclature

D_{tot} - changes in aggregate (energy or CO_2 emission) intensity
D_{act} - activity effect
D_{str} - structural effect
D_{int} - intensity effect
D_{mix} - energy-mix (or fuel-mix) effect
D_{emf} - emission-factor (or emission coefficient) effect
GO - gross output
IC - intermediate consumption
II - intermediate inputs
ITM - international transport margins
S - subsidies on products
T - taxes on products
VA - Gross value added

Abbreviations and Acronyms

GHG - Greenhouse Gas
IDA - Index Decomposition Analysis
LMDI - Logarithmic Mean Divisia Index
NIOT - National Input-Output Tables
SDA - Structural Decomposition Analysis
SEA - Socio-Economic Accounts
TPES - Total Primary Energy Supply
WIOD - World Input Output Database