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Assessing the evolution of energy and CO_2 intensities in the EU

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ABSTRACT

Sustainability has been traditionally focused in the three pillar model - Economy, Ecology and Society - all considered to be interconnected and mutually enforcing pillars. One of today's major challenges is to tune environmental sustainability with economic growth and welfare by decoupling resources use and environmental degradation from the growth of the economy. However, the continuous growing demand for energy and resources - to sustain human needs and economic growth - and corresponding consequences on climate change are challenging this objective.

The main aim of this work is to assess these energy-economy-environment interactions by focusing on the analysis of energy and CO_2 emissions intensities through a comparative examination of their recent progress in the EU countries, using data from the World Input Output Database (WIOD). The analysis of the progresses achieved in these indicators will be performed both by assessing whether resources use and/or environmental degradation are decoupling from the growth of the economies, and by the decomposition of the overall rates of change of energy and CO2 emissions into the different explanatory effects contributing to such progression (using a LMDI-Logarithmic Mean Divisia Index approach).

One of the major contributions expected from this work is to derive policy recommendations from the analysis of energy and CO2 emissions intensity trends, with a greater geographical and temporal focus than prior studies (by exploiting the international dimension of the WIOD database).

1. INTRODUCTION

Sustainability has been traditionally focused in the three pillar model - Economy, Ecology and Society - all considered to be interconnected and mutually enforcing pillars. One of today's major challenges is to tune environmental sustainability with economic growth and welfare by decoupling resources use and environmental degradation from the growth of the economy. However, the continuous growing demand for energy and resources - to sustain human needs and economic growth - and corresponding consequences on climate change are challenging this objective.

Energy efficiency improvements are generally considered as one of the best strategies to reduce CO2 emissions, to limit the energy dependence and to alleviate the effects of oil price increases. Most EU countries have been implementing energy efficiency programs and there is the need to monitor the energy performance achieved in order to evaluate the impact of these policies and to tune them for the near future.

The main aim of this work is to assess these energy-economy-environment interactions by focusing on the analysis of energy and CO2 emissions intensities through a comparative examination of their recent progress (1999-2009) in the EU-27 countries, using data from the World Input-Output Database (WIOD) (Timmer, 2012). The analysis of the progresses achieved in these indicators is performed both by assessing whether resources use and/or environmental degradation are decoupling from the growth of the economies, and by the decomposition of the overall rates of change of energy and CO2 emissions into the different explanatory effects contributing to such progression (using a LMDI-Logarithmic Mean Divisia Index approach).

To fulfill its objectives, this study is structured as follows: In section 2 there is a discussion on the relevance of studying energy use, CO2 emissions released and corresponding intensities, as well as of the analysis of their changes, particularly through the concepts of Decoupling and Decomposition Analysis. Section 3 encloses the crucial information on how the empirical analysis is performed and provides a brief 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 its discussion, firstly by analyzing energy and emission intensity trends and secondly by decomposing the different explanatory effects contributing to such progression, for each of the 27 EU countries. Section 5 concludes with a summary of the most important findings and the derivation of corresponding policy recommendations.

2. SCOPE OF ANALYSIS: ENERGY AND CO_2 EMISSONS INTENSITIES AND TRENDS

2.1. Energy and CO_2 intensities

Economy-wide energy efficiency indicators have been developed and applied for evaluating, monitoring and explaining country comparisons in energy performance. Energy efficiency occurs when the level of service is maintained with reduced amounts of energy used. However, at the level of the aggregate economy, energy efficiency is not a meaningful concept because of the heterogeneous nature of the output. Accordingly, when multiple technologies or multiple products underlie what is being compared it is crucial to distinguish between energy intensity and energy efficiency. Indeed, while it would not be sensible to compare e.g. the energy efficiency of steel production with the energy efficiency of ethanol production, it is possible to compare the energy intensity for all the industry sectors.

Therefore, it is not surprising that energy intensity has been a particularly relevant issue in many energy studies and the focus of many policy programs to lower anthropogenic CO2 emissions and thus combat climate change (Liddle, 2012). Assumptions about energy intensity and how it changes often form the backbone of energy use and CO2 emissions projections. Policies to decrease energy intensity are generally recognized as an important means to reduce energy-related CO2 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 terms, energy intensity is measured as the quantity of energy required per unit of output or activity, so that using less energy to produce a product reduces its intensity. Energy intensity is a ratio and thus there are several variants of the indicator, taking into consideration different elements in the numerator and/or in the denominator of the ratio. Nevertheless the most common measure of energy intensity is drawn from the International Energy Agency's (IEA), namely total primary energy supply (TPES)[1] divided by GDP.

Largely, both the principles of analysis and the procedures to estimate energy intensities can be applied almost straightforward to (energy-related) CO2 emissions intensities.

[1] TPES accounts for all the energy consumed within a country (including energy imports and excluding energy exports); in addition, it adjusts for the energy consumed in producing electricity and, as such, is different from delivered energy (also called net energy or total final consumption (TFC)). Thus, TPES measures the total amount of energy used by a country in that country's economic activity. Because of the energy losses incurred in generating electricity and the increased use of electricity as a final energy supply, TFC is less than TPES, although the ratio of TFC to TPES has been declining in OECD countries to an average of 0,72 (Liddle, 2012).

2.2. Resource and Impact Decoupling: absolute or relative

The analysis of energy and CO2 intensities through time is closely interconnected with the concept of decoupling. In this work, as proposed by UNEP (2011), it is first considered 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 productivity. On the other hand, impact decoupling requires increasing economic output while reducing negative environmental impacts (e.g. CO2 emissions), and thus could be referred to as increasing eco-efficiency.

Further, when an economy is growing it is particularly relevant to distinguish between relative and absolute decoupling. Relative decoupling (of resources or impacts) 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 emissions changes: Decomposition analysis

The analysis of energy use and CO2 emissions changes are also meaningful as it has potential to highlight signals of human development and progress, namely through its 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 are usually decomposed into a structural effect (the impact associated with the output structure of an economy) and an intensity effect (the impact associated with changes in sectoral energy intensity) (Wang, 2013). Further, this type of analysis allows for an extension to the trends in CO2 emissions and CO2 emissions intensity. When analyzing the changes in aggregate emission intensity two additional effects are measured: energy-mix effect (the impact associated with changes in the sectoral energy mix) and emission-factor effect (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 present different sizes (both in terms of the overall population and of 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 with the presentation of the main contents and characteristics of the database. Secondly with the explanation of the data treatment's required. Finally the different methods used to perform the analysis are explained.

3.1. The World Input Output Database

The main data source to be 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, throughout the data collection effort, harmonization procedures were applied to ensure international comparability of the data. 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 allows one to 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 WIOD allow that comparisons. The results provide international tables at current (and previous) 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 such as to cover the broadest range of environmental themes as reasonably achievable while maintaining a data quality that is well grounded in the empirical availability of primary data. In general terms, the variables cover: use of energy; emission of main greenhouse gases; emissions of other main air pollutants; use of mineral and fossil resources; land use; and water use.

Most if not all environmental variables that are needed to fill the data framework derive from sources (e.g. energy statistics, water statistics, etc.) that use a different framework, 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 27 EU countries[2].

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

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 • CO2 Emissions modeled by sector and energy commodity

Source: Timmer (2012)

Table 2 presents a list of the energy commodities aggregation used for this study and the WIOD codes provided in the database.

Table 2 - Energy commodities

	WIOD Code	Flow
Coal	HCOAL	Hard coal and derivatives
	BCOAL	Lignite and derivatives
	COKE	Coke
Oil	CRUDE	Crude oil, NGL and feedstock's
	DIESEL	Diesel oil for road transport
	GASOLINE	Motor gasoline
	JETFUEL	Jet fuel (kerosene and gasoline)
	LFO	Light Fuel oil
	HFO	Heavy fuel oil
	NAPHTA	Naphtha
	OTHPETRO	Other petroleum products
Gas	NATGAS	Natural gas
	OTHGAS	Derived gas
Nuclear	NUCLEAR	Nuclear
Electricity	ELECTR	Electricity
Renewables	BIOGASOL	Biogasoline
	BIODIESEL	Biodiesel
	BIOGAS	Biogas
	OTHRENEW	Other combustible renewables
	HEATPROD	Heat
	HYDRO	Hydroelectric
	GEOTHERM	Geothermal
	SOLAR	Solar
	WIND	Wind power

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. In this study it is also analyzed the progress of another indicator, the CO2 emissions/GDP (or CO2 emissions intensity) ratio.

Data for the CO2 emissions and energy use is available in Gigagrams (Gg) and Terajoule (TJ) respectively, with no manipulation needed. Thus, such information is directly taken from the WIOD.

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, there is the need to define the GDP estimation approach to follow, and to allow comparative analysis it is also required to express GDP at constant prices and also to perform some currency conversions, as follows.

3.2.1. Deriving GDP from the IO Tables

The 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 purpose of this study is focused on the energy (and CO2 emissions) intensity assessment, and this is more adequately done through the analysis of the input requirements to generate a given level of output (the columns analysis of the IO tables) the option is to follow the product approach.

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

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

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

$$VA = GO - IC$$

Assessing the WIOD Socio Economic Accounts (SEA) one has in different sheets the values for *GO*, Intermediate Inputs (*II*) and *VA* for the different economies in the different local currencies. In this case *VA* is also the result of the subtraction of *II* to the *GO*.

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

The GDP calculation is not direct because *II* is different from *IC*, as in *II* is included the taxes (*T*) less subsidies (*S*) on products and International Transport Margins (*ITM*).

$$II = IC + (T - S) + ITM$$

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, there is the needed to convert these values into the local currencies, which can be done using the exchange rates (*exc*) provided by the WIOD.

Consequently, in order to get *IC* one needs to subtract taxes less subsidies on products and International Transport Margins.

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

Decomposing Value Added, one gets:

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

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

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

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

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

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

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

3.2.2. Converting monetary values at current prices into constant prices

Further, to estimate the trends in energy and CO2 emissions intensities it is important to use GDP values at constant prices, instead of current (or nominal) as the data provided by the WIOD. In this way, the effects of price fluctuations (inflation or deflation) are removed and one analyzes the real growth of the economy.

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. However, while this study was being done, the WIOD removed the access to the NIOT at previous year prices. Therefore, in practice, only the second method could be performed.

The price index of the VA provided on the SEA uses 1995 as the base year. The base year preferred for this analysis and assessment is 2005, and therefore this requires a change in the base year. In order to perform that change two fundamental steps are required: first to calculate the price index deflator and then to employ that deflator to determine the new index. Thus, in order to transform nominal values into 2005 constant prices one divides the nominal GDP values with the correspondent year Index.

3.2.3. Currencies' conversion

GDP values expressed in US dollars at the WIOD were converted into each country's currencies, using the exchange rates provided by the WIOD. In order to compare intensity values amongst countries (instead of each 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 that from 1999 have adopted the Euro (€) as their common currency. Thus, the 10 other countries considered in this study do not use the Euro, but rather 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 trading partners (ECB, 2013)).

Therefore, even though the different currencies used, it is possible to compare the progression of energy and CO2 emissions intensities among the 27 member states.

3.3. Decomposition analysis of energy and CO_2 emission changes

The analysis of energy use and CO2 emissions changes, namely through the analysis of its decomposition into specific explanatory effects is particularly relevant to analyze both the progress of the indicator in a specific country and 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 3 present the main characteristics of each of these decomposition techniques.

Table 3 – Comparison of IDA with 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	Whole of the economy	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 at the WIOD due to unsatisfactory results on the deflation process. These database problems made impossible the initial intention of computing a SDA. Accordingly, the disaggregation technique computed in this work is an index decomposition analysis (IDA).

An IDA begins with defining a governing function relating the aggregate to be decomposed to a number of pre-defined factors of interest. With the governing function defined, various decomposition methods can be formulated to quantify the impacts of changes of these factors on the aggregate (Ang, 2004). Ang (2004) classifies the IDA methods and recommends the use of a Logarithmic Mean Divisia Index (LMDI), which is a weighted sum of logarithmic change rates, where the weights are the component's shares in total value, given in the form of a linear integral. Accordingly, this is the method chosen in this study to track economy-wide energy and CO2 emissions efficiency trends. The LMDI method description below follows very closely the one proposed by Ang (2005) .

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

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:

$$E = \sum_i E_i = \sum_i X \frac{X_i}{X} \frac{E_i}{X_i} = \sum_i X\, S_i I_i$$

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. In this study the chosen one is the multiplicative because it presents the effect variations in percentages, which allows for a better comparison between countries. Accordingly, with the 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:

$$D_{tot} = E^T / E^0$$

And can be broke down in the three effects mentioned (overall activity level, activity structure and sectoral energy intensity):

$$D_{tot} = D_{act}\, D_{str}\, D_{int}$$

These energy change's explanatory effects can be calculated as:

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

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

This analysis can be further extended in order to assess energy-related CO2 emissions. For that, 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 CO2 emissions (CO), can be presented/decomposed as:

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

In which C_{if} represents the CO2 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:

$$D_{tot} = D_{act}\, D_{str}\, D_{int}\, D_{mix}\, D_{emf}$$

These CO2 emissions change's explanatory effects can be calculated from:

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

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

This decomposition method is used to study, for the 27 EU member states, the variation in energy and CO2 emissions 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 chapter presents and discusses the main results of this study (for a more detailed presentation and analysis of the results, for each of the 27 EU countries, see Dias, 2014). Firstly, regarding the estimates of energy use and CO2 emissions released, as well as the corresponding intensities. 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 CO2 emissions and GDP trends indicates each country's successfulness achieving (absolute or relative) impact decoupling. Then, in subsection 2, there is the analysis of the LMDI decomposition of energy use and CO2 emissions released into their main explanatory effects.

Before such detailed analysis it is worth to establish an overview comparing the energy intensities for the 27 EU countries considered for 2009 (the most recent data available, and with the GDP for all the countries expressed in the same currency, namely Euro), as shown in Figure 1.

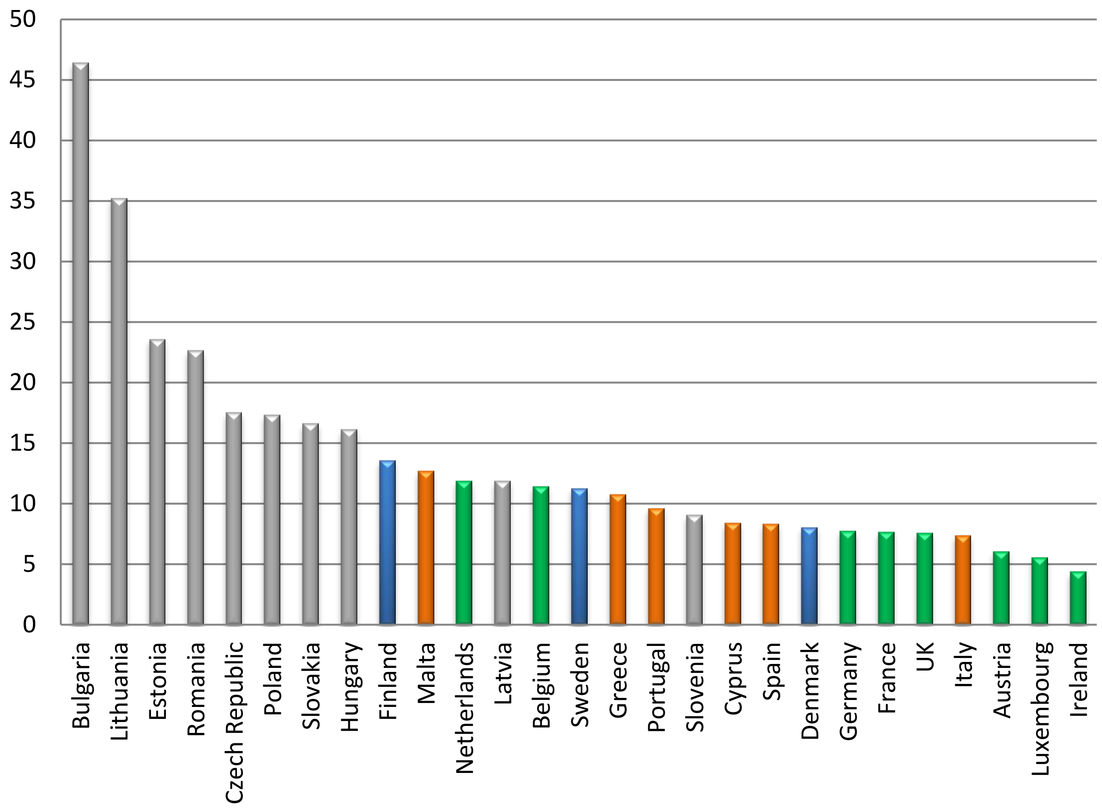

Figure 1 - Energy Intensity in the EU-27 (Tj/millions of Euro)

The observation of Figure 1 makes clear the wide range of values for the Energy Intensity (Tj/Euro) in the 27 EU countries, varying from 4.4 in Ireland to 46.4 in Bulgaria. Further, into some extent, it is possible to identify some groups of countries taking into account on the one hand their position in the energy intensity 'ranking', and on the other hand their geographical proximity, similar weather patterns and 'expected' level of technological progress within Europe. Accordingly, and as the comparative analysis and discussion of the results can be better structured with a subdivision of the 27 EU countries, it is considered as appropriate, for purposes of this analysis, to consider 4 groups of countries, as presented in Table 4.

Table 4 – EU-27 groups

Group	*Countries*
East	Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovak Republic and Slovenia
South	Cyprus, Greece, Italy, Malta, Portugal and Spain
North	Denmark, Finland and Sweden
Center	Austria, Belgium, France, Germany, Ireland, Luxembourg, Netherlands and UK

The generality of the most energy intensive countries are comprised in the East group (which were not expected to have levels of productivity particularly high and most of them usually facing harsh climate conditions). Followed by the countries considered here as the North group, in which the weather patterns are ruthless (but in some part compensated by higher productivity). Next is the South group which in terms of energy needs is the more beneficiated (at least during winter) by the weather (mild) conditions. Finally, as the least energy intensive countries (with the exception of the northern countries of this group) one can find those here categorized in the Center group, which are expected to have the best combination between weather patterns and industries productivity.

4.1. Intensities and Trends

Regarding Energy and Resource Decoupling, the majority of the East and North groups' countries have increased its energy use. Further, although more than half of the countries have increased the energy used from 1999 to 2009, only Denmark and Luxembourg did not achieved either relative or absolute resource decoupling. Thus, also only these two countries did not showed improvements in terms of the energy intensity indicator.

Assessing the CO2 Emissions and Resource Decoupling, one realize that a larger number of countries have been successful in achieving absolute impact decoupling (17) than those reaching resource decoupling (13). Three countries have not 'decoupled' at all, namely Denmark, Slovenia and Malta. Even though, Slovenia managed to reduce its CO2 emissions intensity. From the 10 countries that have increased CO2 emissions, the group more represented is the one of the South countries while the East and Center groups are the most representative in terms of CO2 emissions reductions.

4.2. Index Decomposition Analysis

The LMDI decomposition that follows, in Table 5, presents the variation in the amount of energy used and how this amount would progress considering the activity, structure or intensity explanatory effects alone (i.e. a *ceteris paribus* analysis). Then, in Table 6, follows a similar approach regarding the CO2 emissions released.

The EU has decreased its total energy use through 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 who decreased the most its energy use, both in relative and absolute terms. Center countries (with the exception of the northern countries within 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) present poor performances. Clearly, the East group needs to change its energy use increasing trend.

Table 5 - Energy Decomposition explanatory effects

Group	*Country*	**Energy use change** (1999-2009) (Tj)	**Total Change** (%) D_{tot}	**Activity** (%) D_{act}	**Structure** (%) D_{str}	**Intensity** (%) D_{int}
South	Cyprus	-29885,6	-20,1	47,2	-38,8	-11,3
	Greece	412126,1	22,9	38,3	11,9	-20,6
	Italy	-171854,5	-1,7	7,2	-14,5	7,2
	Malta	-4995,7	-7,1	37,7	4,8	-35,6
	Portugal	-105749,0	-6,7	15,4	-9,7	-10,5
	Spain	541166,5	7,5	39,3	1,1	-23,7
	Total/Average	*640807,9*	*-0,9*	*30,8*	*-7,5*	*-15,7*
Center	Austria	126505,3	8,7	29,5	4,8	-19,9
	Belgium	-145734,0	-3,8	15,7	3,9	-19,9
	France	-630112,6	-4,5	29,7	22,2	-39,7
	Germany	-990301,2	-5,3	11,3	12,1	-24,1
	Ireland	92610,9	14,7	67,9	38,6	-50,7
	Luxembourg	74843,7	66,7	72,1	-8,5	5,9
	Netherlands	-160457,9	-2,4	18,0	2,4	-19,2
	UK	-1909056,8	-15,0	21,5	-17,8	-14,9
	Total/Average	*-3541702,7*	*7,4*	*33,2*	*7,2*	*-22,8*
East	Bulgaria	6978,1	0,6	131,2	15,9	-62,5
	Czech	211856,6	10,4	62,1	-26,2	-7,8
	Estonia	25723,3	11,3	60,7	-13,8	-19,6
	Hungary	-73316,4	-5,4	36,0	-19,2	-13,8
	Latvia	-1896,8	-1,2	76,7	-18,4	-31,5
	Lithuania	186947,6	33,8	64,9	13,4	-28,4
	Poland	245237,6	5,1	67,3	6,5	-41,0
	Romania	-116521,3	-6,0	208,5	-20,8	-61,5
	Slovakia	21699,3	2,2	86,8	-39,1	-10,2
	Slovenia	13682,1	5,1	47,5	1,4	-29,7
	Total/Average	*520389,8*	*5,6*	*84,2*	*-10,0*	*-30,6*
North	Denmark	217043,2	15,6	20,4	-3,4	-0,6
	Finland	137677,1	6,8	32,0	-12,9	-7,1
	Sweden	-354511,5	-10,3	20,9	-2,5	-23,9
	Total/Average	*209*	*4,0*	*24,4*	*-6,3*	*-10,5*
EU 27 Total/Average		*-2380296,0*	*4,5*	*50,6*	*-3,9*	*-22,8*

Regarding the activity effect, with the exception of the East Group, the other groups registered similar values. Accordingly, this increase in energy use can be in part explained by the large improvement in the activity effect occurred in the East group.

The groups that moved to less energy intensive structure were the South, East and North, while Center countries have deteriorated in this indicator (moving to a more energy intensive structure (7.2%)). The majority of the countries (14) improved in terms of this indicator.

Regarding sectoral energy efficiency improvements, all the groups have made improvements. 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 the energy use, as a "counter-balance" of the increase because of the growth in the economic activity (a 50.6% effect), with the moving to a less energy intensive structure (3.9%) and of improving sectoral energy efficiency (22.8%).

Table 6 - CO_2 emissions decomposition explanatory effects

Group	*Country*	**Emissions released Change** (1999-2009) (Gg)	**Total Change** (%) D_{tot}	**Activity** (%) D_{act}	**Structure** (%) D_{str}	**Intensity** (%) D_{int}	**Energy-mix** (%) D_{mix}	**Emission-factor** (%) D_{emf}
South	Cyprus	1217,1	18,9	56,7	12,4	-32,6	-0,1	0,0
	Greece	19158,6	23,5	37,9	12,2	-19,2	-3,2	0,2
	Italy	-17894,8	-5,8	7,0	-5,5	-1,2	3,7	-2,9
	Malta	-416,9	-8,8	37,7	4,9	-37,0	0,0	0,0
	Portugal	-5302,0	-10,3	14,9	20,7	-34,4	-0,1	0,1
	Spain	6063,4	2,8	37,1	3,3	-20,6	-18,2	-1,3
	Total/Average	*2825,4*	*3,4*	*31,9*	*8,0*	*-24,2*	*-3,0*	*-0,7*
Center	Austria	1370,4	3,7	29,1	6,8	-25,3	-1,3	-0,5
	Belgium	-16468,2	-18,9	15,0	-7,9	-16,7	-5,2	-5,1
	France	-31914,4	-12,3	29,1	0,4	-32,6	-3,4	-0,1
	Germany	-92724,2	-13,4	11,3	10,2	-27,6	-3,3	0,3
	Ireland	3402,9	11,2	64,9	27,7	-46,3	-2,5	0,5
	Luxembourg	4716,3	74,0	69,5	-5,1	6,3	-0,8	0,0
	Netherlands	-35215,0	-18,8	17,7	0,5	-18,7	-0,3	0,0
	UK	-54123,3	-13,5	21,3	-15,1	-13,0	-0,5	-3,3
	Total/Average	*-220955,5*	*1,5*	*32,2*	*2,2*	*-21,7*	*-2,2*	*-1,0*
East	Bulgaria	3278,4	8,5	129,0	-24,5	-38,2	3,1	0,3
	Czech	1161,9	1,3	61,4	-25,9	-18,9	2,0	2,4
	Estonia	-141,0	-1,0	60,1	-14,8	-23,2	3,0	-4,3
	Hungary	-10951,4	-24,3	35,2	-11,8	-32,1	-4,2	0,5
	Latvia	-650,3	-10,3	70,3	3,6	-44,9	-2,0	-0,1
	Lithuania	-729,5	-6,8	61,2	3,2	-40,6	1,3	0,0
	Poland	-15824,5	-5,9	66,6	-13,1	-34,1	-5,5	1,1
	Romania	-10200,6	-14,5	199,1	-21,6	-64,4	20,7	-2,4
	Slovakia	-3336,9	-12,1	82,1	-32,7	-32,1	2,9	0,3
	Slovenia	784,7	7,2	47,9	3,0	-30,1	-2,7	1,6
	Total/Average	*-36609,2*	*-5,8*	*81,3*	*-13,4*	*-35,9*	*1,9*	*-0,1*
North	Denmark	13716,1	22,2	20,1	9,0	-7,7	2,0	0,0
	Finland	1039,0	2,2	30,6	-10,4	-6,4	0,1	-6,9
	Sweden	-8570,0	-19,2	20,0	-8,4	-22,4	0,6	0,0
	Total/Average	*6185*	*1,7*	*23,6*	*-3,3*	*-12,2*	*0,9*	*-2,3*
EU 27 Total/Average		*-248554,2*	*-0,8*	*49,4*	*-2,9*	*-26,4*	*-0,5*	*-0,7*

The EU has reduced the energy-related CO2 emissions released in the period considered almost entirely due to Center group's action (decreased six times more than the East group, while the South and the North countries total emissions even increased).

The majority of the countries (16) has decreased their total emissions, despite all of them have 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 have deteriorated (8% and 2.2% respectively) while the East and North groups have improved, moving to less CO2 emission intensive structures (13.4% and 3.3% respectively). Concerning the sectoral energy efficiency effect, only Luxembourg deteriorated, with improvements in all groups, especially in the East. In relation to the energy-mix effect, the South and the Center groups have improved (3% and 2.2%, respectively), while the East and the North groups have deteriorated (1.9% and 0.9%, respectively). It is also noticeable that many of the East and North countries have increased the use of Oil, while the South and Center countries have reduced its use. Finally, in what concerns to the emission-factor effect, all of them have improved, especially the North group.

To sum up, overall, the EU 27 have decreased total CO2 emissions, moving to less CO2 emissions intensive structures (2.9%) and improving also in terms of the sectoral energy efficiency (26.4%), of the energy-mix (0.5%) and of the emission-factor (0.7%) effects. The activity effect (49.4%) counteracted those effects. Regarding the fuel-mix, it is relevant to note that the use of Renewables and Gas increased over the period (2.5% and 0.6%, respectively) while the use of Coal and Oil decreased (1.8% and 1.3%, respectively).

5. CONCLUSIONS

Fighting climate change is one of today's top priorities of EU environmental policy. This makes the environmental and the energy policies even more interconnected than before and reinforce the guidance of the EU energy policy by the continuous search for a balanced management amid energy security, environmental protection and economic growth, thus much in line with the pursuance of sustainability. Further, as the implementation of the 'Energy Roadmap 2050' and the 'Energy Efficiency Directive' denote, improving energy efficiency has received EU's growing attention as a key component of sustainable development that would tackle energy security while addressing climate change concerns.

Regarding the Energy Intensity components (energy use and GDP) trends from 1999 to 2009, the majority (14) of the EU's countries have increased energy use and all have increased the GDP throughout the period. Half of the countries where energy use increased are East countries while the ones where energy use decreased are mainly Center and South countries. It is also worth to remind that the largest GDP's growth occurred in the East countries.

As regards to CO2 emissions, 10 countries (mostly South countries, with the exception of Italy and Portugal) could not manage to reduce CO2 emissions over the period, and the largest reductions occurred in the Center and East countries. Analyzing the CO2 emissions intensity, only Denmark and Malta were not able to reduce it over the period, and the largest enhancements occurred in the East countries.

Thus, it is critical to move towards more energy (resource) and CO2 emissions (impact) efficient economies. Resource or impact decoupling comes mostly from energy or CO2 emissions intensity reductions. As the results made evident, in terms of the reduction of energy use there are still many improvements to be made (only the Center group have reduced it) as well as in the CO2 emissions intensity (in which 10 countries increased emissions over the period).

Analyzing the energy decomposition explanatory effects, one observed that the EU, as a whole, has decreased its energy use through the period and the driver of this effect was the Center group of countries, with the East group reporting the poorest performance. This can be partly explained with the increasing energy needs as a result of the activity effect, in which this last group has registered significantly larger values than the remaining. 14 countries (mainly East and North countries) have succeeded in terms of moving into a less energy intensive structure, while the remaining 13 (mostly Center countries) register, at the end of the period, more energy intensive structures. In terms of the energy efficiency explanatory effect, it is noticeable that only Italy and Luxembourg deteriorated, with the largest improvements occurring in the East countries. Overall, the EU-27 have reduced total energy use by moving into less energy intensive structures and improving sectoral energy efficiency, although the contrarious results of the activity effect.

Assessing the CO2 emissions decomposition effects, the EU has reduced total CO2 emissions released and, once more, almost entirely due to the Center group's action. Nevertheless, all the countries have increased emissions as a result of the economic activity growth. In terms of moving to less energy intensive structures the results are similar to the ones for the energy decomposition and regarding the energy efficiency explanatory effect, only Luxembourg has deteriorated. In relation to the energy-mix effect, the South and Center groups have improved, while the East and North groups worsened. Concerning the emission-factor effect the worst performance is found in the East countries. Overall, although the growth in the economic activity, the EU-27 have decreased CO2 emissions by moving to less carbon intensive structures and by improving the sectoral energy efficiency, the energy-mix and the emission-factor.

Although the less developed EU regions (East) are registering interesting structural improvements they still have a long way to go until reaching the higher stages of development. Accordingly, if the economic activity growth in the East countries is particularly desirable to get closer to the richest EU countries, it reinforces the governments and the EU institutions' need to analyze the other explanatory effects in order to improve the intensity indicators in this region of the EU. To this, there is the need to combine the already interesting results in terms of the intensity effects with improvements to be achieved by moving to less energy (and CO2 emissions) intensive structures of these economies.

Regarding the progress in terms of energy-related CO2 emissions, the two extra explanatory effects considered are related to the fuel mix of an economy (energy-mix) and to the carbon content of those fuels (emission-factor). In this regard, the East and North groups (by increasing Oil use and decreasing the use of Gas) deteriorated in terms of the fuel mix, while in terms of the emissions' carbon content all the groups have improved. Consequently, a better fuel mix (decreasing Oil use while investing in Renewables) would be particularly helpful to the East region. However, this is now a huge challenge for national and EU's policy makers as the current period of austerity has imposed tight constraints on national budgets, with some countries reverting energy policy measures like the ones directed for promoting clean energy technologies.

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