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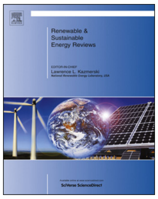

The driving forces of change in energy-related CO_2 emissions in Eastern, Western, Northern and Southern Europe: The LMDI approach to decomposition analysis

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ABSTRACT

The objective of this work is to identify the relevant factors that have influenced the changes in the level of CO_2 emissions among four groups (eastern, western, northern and southern) of European countries. Our results show that CO_2 emissions are correlated with the energy consumption of the economy for the group of countries under analysis, which is determined by the change of population among the various countries. Similarly, renewable energy consumption is also determined by the size and structure of the countries, as reflected by the value added to the economy. When comparing the results of the post-Kyoto period to the previous period for the four groups of European countries, one concludes that there are clear improvements in the reductions of emissions. This resulted primarily from changes to the energy mix, switching to cleaner fuels for end-user energy production (a volte-face in the behaviour of the energy mix effect), while the changes in the factors driving emissions resulted from a reduction in the usage of fossil fuels for producing energy. In general, the relative contributions of these two factors show the importance of the impact of changing the structure of the mix for producing energy, with a view to complying with the targets for reductions in CO_2 emissions, reflecting the value placed on the significant impact assigned to emissions levels.

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1. Introduction

The consumption of fossil fuels, such as coal, oil and natural gas, is one of the major contributors for the major increase of greenhouse gas (GHG) emission which included carbon dioxide (CO_2). Coupled with the rising prices of fossil energy resources, energy efficiency is growing its importance, and as more energy is used inefficiently, the greater the level of emissions. As referred by the International Panel on Climate Change (IPCG) report [1], economic, energy and the environmental policies are mandatory to increase the efficiency of the resources in the production of energy.

The evolution of the population in Europe, assessed the population density, indicates a non-significant evolution across the EU over the past decade. In Ireland, Luxembourg and Spain the population density increased by 21%, 17% and 14%, respectively; however, in most of other member states the population density increased less than 10%, with Sweden, Finland and Germany with very low values population density while the Netherlands and Belgium emerge as the countries with the largest levels of population density [2].

In the current states of the European Union (EU-27) the energy economic reality differs substantially between and within the two major blocs of countries: the countries of the old EU-15 and new member States of the EU-21. In the former group, seven of these new states, Bulgaria, Cyprus, Lithuania, Slovakia, Hungary, Slovenia and Latvia, had an energy balance average deficit greater than 5% of the Gross Domestic Product (GDP), in contrast with the countries of EU-15 average, in which no country exceeds this limit.

The International Energy Agency (IEA) report [3] states that European member States with the highest levels of energy intensity are the Netherlands and Slovakia for the 2nd phase of the 2008–2012 Kyoto period. Conversely, Luxembourg and Slovenia show the lowest levels of energy intensity and, to a lesser extent, Latvia, Austria, Germany and Italy. The report also shows that the highest real energy prices were practiced in France, Slovenia, and Italy, while Estonia, the Czech Republic and Slovakia had the lowest levels of real energy prices.

On the other hand, it is worth mentioning that our results indicate that the effects associated with the improvement of energy intensity of new European member States are also in alignment with what is described in the IEA report [3], which refers that the high growth rates of energy efficiency take place in the Czech Republic, Poland, Slovakia and Slovenia. Moreover, Italy, Spain and Luxembourg present the worst levels of performance in terms of energy intensity. Conversely, France, Sweden and Finland show a growth in energy prices as a result of real energy unit costs with growth rates well above the European average [3].

According to the IEA [4], the progress and trends in the behaviour of CO_2 emissions are intrinsically related to the growth levels of global economies, whose descendent trend in the last 40 years is closely connected to the oil price crisis, in the late 1970s, and to the financial crisis, more recently, that led to the economic recession of the global economies. This variability in CO_2 emissions can be explained by the countries' different effects and levels of energy efficiency. This is seen as a major reason for the analysis of the decomposition of effects of variability of the emissions, given the need to isolate the different levels of economic, energy or environmental efficiency of all the countries that comprise a certain group. As such, as soon as those effects are properly identified they can be controlled allowing a more efficient use of energy according to the levels of economic growth of the group of European countries under analysis.

Since the reality is heterogeneous across Europe some reflection needs to be done, namely regarding the level of intensity in the mix of fossil energy resources, the capacity of existing renewable energy power plants, the energy consumption and production and the economic or population growth that may mitigate or explain the changes in the CO_2 emissions intensities. This is possible to be implemented by group of countries, as is the case of the countries of Northern Europe, Southern Europe, Central Europe and Western Europe.

Clearly, as a change in CO_2 emissions will affect the Kyoto protocol agreement, each group of countries will be differently affected. As such, we aim to answer the following four questions.

First, as power consumption is the result of the aggregated consumption, which includes the various ways of producing energy, from conventional fossil fuels to the newer renewable sources, may the GHG emissions be the result of a complex chain of determinants or may the GHG emissions, particularly CO_2 emissions, be directly correlated with energy consumption, particularly with fossil fuels consumption?

The Commission of the European Communities (CEC) [5] established a set of goals following 20–20–20 targets: (i) a 20% reduction in EU GHG emissions from 1990 levels in order to change the current system of EU ETS; (ii) legally binding targets to increase 20% the share of UE energy consumption produced from renewable sources, reflecting the needs and potential of each country; (iii) new rules on carbon capture, storage and environmental subsidies in order to reach a 20% improvement in the EU's energy efficiency. As such, the second question is: will common energy and environmental policies among European economies be effective?

Third, can economic growth be associated with the growth of emissions? This is an important question as it is important to find out what factors increase pollution, namely the relationship between energy consumption and the proportion of fossil fuels consumption vis-à-vis the capacity installed of renewable energy and to other conventional power plants.

Finally, can population variation influence the CO_2 emissions? This can be easily addressed taking into account pre- and post-Kyoto protocol target agreements in the four groups of EU countries. It is expected that population growth would have a more severe impact on energy consumption.

In order to answer those questions, a model addressing two different periods, 1999–2004 and 2005–2010, is proposed. The aim is to capture the effects of the Directive 2001/77/EC [6] and Directive 2003/36/EC [7] for a four-group country panel: Northern Europe, Southern Europe, Central Europe and Western Europe.

The work is structured in the following way. In Section 2 we describe the overview of the energy-related CO_2 emission, while in Section 3 we present the data and methodology used for defining the components of the differences in energy intensity. In Section 4 we carry out the application of this technique on the European Union countries and comment on the principal results. The work closes with the main conclusions in Section 5.

2. Overview of the energy-related CO_2 emissions literature

There is extensive literature addressing the relationship between the variations of carbon emissions and the drivers of production and consumption of energy, both at sectoral and at cross-country level. Among others, Chien and Hu [8] concluded that there is a positive relationship between renewable energy and economic efficiency, since the increase in the use of renewable sources in electricity production contributes significantly to improving the technical efficiency of the economy. Moreover, Chien and Hu [9] argue that there is also a positive relationship between renewable energy and GDP due to the increasing capital investment. Menyah and Wolde-Rufael [10] concluded that there is unidirectional causality from CO_2 emissions to renewable energy consumption, but no unidirectional causality from renewable energy consumption to CO_2 emissions in US. Salim and Rafiq [11] concluded from OCDE countries that there is a bidirectional causal relationship between renewable energy consumption and CO_2 emissions in the short run; on the other hand, Shafiei and Salim [12] concluded that in the long run while renewable energy sources affect negatively CO_2 emissions, non-renewable energy sources affect positively CO_2 emissions. They also found that a bidirectional causal relationship between non-renewable energy and CO_2 emissions and unidirectional causality from CO_2 emissions to renewable energy, confirming Menyah and Wolde-Rufael [10] work. In a different vein, Apergis et al. [13] claim that the production of renewable energy does not affect emissions negatively in the short run, which may be explained by the fact that renewable energy still represents a small share of total energy consumption.

Other approaches referenced in the literature include the analysis of the relationship between CO_2 emissions, energy consumption and economic growth. For example, Payne [14] has a different perspective claiming that neither real GDP nor CO_2 emissions cause renewable energy consumption increases, but rather it is unexpected shocks in real GDP and CO_2 emissions that positively affect the consumption of renewable energy over time. In the analysis of the relationship between emissions and economic growth it is generally accepted that as a country develops its environmental pollution levels increase, which then begin to decrease as soon as income rises beyond a critical threshold point, known as the Environmental Kuznets Curve (EKC) [15–29].

A bidirectional causality was found between GDP and renewable energy consumption [30–34]. Their research covered a wide range of countries that include OECD countries, Central America, G7 countries and Brazil. Al-mulali et al. [35] also found bidirectional causality between GDP and renewable energy consumption for 79% of high income, upper middle income and lower middle income countries. In India Tiwari [36] found that as an increase on renewable energy raises GDP and reduces CO_2 emissions, and an increment on GDP has a strong positive impact on CO_2 emissions. Finally, causality from renewable and non-renewable energy to the real GDP was also observed [37].

The presence of the neutrality hypothesis has been extensively referred [35,38–40]. For example, in a study encompassing 27 European countries, the neutrality hypothesis, supports both the short and long-run between real GDP and renewable energy [38]. Yildirim et al. [40] in the US and Tugcu et al. [39] in France, Italy, Canada and the U.S. reached the same conclusions. Finally, Al-mulali et al [35] found the neutrality hypothesis for 19% of the countries.

The presence of the conservation hypothesis has been extensively supported as well [34,35,39,41]. In the study involving G7 countries and 18 developing economies Sadorsky [34] contends that per capita GDP significantly influences the consumption of renewable energy. Al-mulali et al. [35] in their study of bidirectional causality between GDP and renewable energy consumption found that 2% of the countries confirm the conservation hypothesis. In Turkey renewable energy has a negative effect on economic growth, simultaneously supporting the conservation hypothesis [41]. Finally, Tugcu et al. [39] found evidence of conservation hypothesis for Germany and of feedback hypothesis for England and Japan.

There is a strong association between population and carbon emissions. Satterthwaite [42], Hamilton and Turton [43], Hatzigeorgiou et al. [44] and Jian and Hardee [45] argue that countries with low per capita emission rates have the highest rates of population growth. On the other hand, Harte [46] claims that there is a significant multiplier effect between population growth and carbon emissions, while York [47] concluded that an increase of 1% in the population induced an increase in energy by about 2.665% postulating, based on this observation, that the degree of intensity of consumption of energy in societies is influenced by the level of growth of the population, ceteris paribus. For example, during 2001–2008 period, there is a positive population effect in Germany, France, Italy, the United Kingdom, Spain and Poland, while there is a small change in Cyprus, Latvia, Luxembourg Lithuania and Slovenia [48].

There is a vast literature explaining the changes in emission using the decomposition of an additive or multiplicative effect, which provides a better effect to relate the significance of these drivers in the form of decomposed ratios. Two main methodologies are used when implementing the Index Decomposition Analysis (IDA): Laspeyres IDA and Divisia IDA [49,50]. As referred before, the Kaya identity is used to assess the determinants of carbon intensity. Two approaches have been used in the literature about the decomposition of the effects of the emission intensity and energy intensity: the structural decomposition analysis (SDA) and the IDA. IDA uses index number concept in decomposition [49,51–58].

The advantage of the IDA is that it can readily be applied in a period-wise or time-series manner to any available data at any level of aggregation [59]. While the former includes basic Laspeyres index, Paasche index, Fisher ideal index, Shapley index and Marshall–Edgeworth index, among others, the latter includes the Arithmetic Mean Divisia Index (AMDI) and the Logarithmic Mean Divisia Index (LMDI) [60]. As the Laspeyres decomposition led to a residual of a considerable size, Sun and Zhang et al. [50,60] proposed a complete decomposition analysis where the residual term is distributed among the considered effects.

The Kaya identity, that links the carbon intensity to its main driving factors, has been extensively used as it is useful not only for understanding the methods of decomposition of energy-related CO_2 emissions, but also for identifying the factors that have influenced the changes in the level of energy-related CO_2 emissions [50,56,57,61–66].

The comparison of the factors depicting the differences of CO_2 emissions per capita of different regions or groups of countries has used the cross-sectional decomposition analysis [51,53]. On the other hand, time-series decomposition has been used to analyse the CO_2 emissions from several perspectives: analysing different economic sectors [56], analysing a group of countries [43] and for a single country [57,67].

In order to answer the four questions proposed in the introduction we proposed a LMDI method that addresses two different periods, 1999–2004 and 2005–2010. The aim is to capture the effects of the Directive 2001/77/EC [6] and Directive 2003/36/EC [7] for a four-group country panel.

3. Data and methodology

3.1. Data

This study is composed of annual data from 21 European countries ranging from 1995 to 2010. This data included two distinct periods: the 1999–2004 period (pre-Kyoto protocol) and the 2005–2010 period (post-Kyoto protocol), which data were aggregated in four different groups of countries: The Northern European Group includes Finland, Denmark, Ireland, United Kingdom and Sweden; the Southern European groups is composed by Italy, Spain, Greece, Slovenia and Portugal; the Western Europe includes France, Netherlands, Belgium, Austria, Germany and Luxembourg; finally, the Central/Eastern European group includes Poland, Czech Republic, Hungary, Slovakia, Estonia.

The following variables are going to be used: CO_2 emissions (CO_2) is defined as total carbon dioxide emissions caused by the consumption of energy [3]; fossil fuel consumption (Fos) gathered from OECD [68]; energy consumption (Ene) retrieved from BP and

Eurostat [69,70]; growth domestic product (GDP) in billions of dollars, 2005, is the growth of real Gross Domestic Product, based on World Bank and International Monetary Fund [2,71]; renewable capacity (CRes) presents the capacity installed of energy produced from renewable energy sources comprising hydroelectric sources (excluding pumping), wind, solar, geothermal and electricity from biomass/wastes, based on Eurostat and IEA [72,3]; and finally, population (Pop) with data from The World Bank [73].

3.2. Methodology

In literature revisited, the most common effects are the output effect, the energy mix effect, the energy intensity effect and the structural effect. One of the hand, it is possible to identify groups of countries for their contribution to one or various of the different components of energy-related CO_2 emissions; other hand, it is possible to analyse the relevant factors that have influenced the changes in the level of CO2 emissions among that Country-groups in order to disclose the following components: the carbon intensity effect, the energy mix effect, the energy intensity effect, the renewable productivity effect, renewable capacity per capita effect and the change in population effect.

We expect that the results on our decomposition analysis proposed show what effects are crucial in the reduction of CO_2 intensity both for each of the four groups of countries as well as for the EU-21 countries overall. Following a period-wise analysis it is possible to compare the performance between one determined year and the base year. The advantage is that it makes the analysis sensitive to the choice of these years, although it does not disclose the evolution of the clarifying factors throughout time. On the other hand, the times series analysis can produce an annual decomposition of the factors, which allows seeing its evolution throughout time.

As such, following Ang [74], the various effects on CO_2 emissions were decomposed using the Kaya Identity and the Logarithmic Mean Divisia Index (LMDI). As referred by Ang and Liu [75], as the results are free from residuals, the results considered robust and consistent.

The change in CO_2 emissions is going to be decomposed into six effects for each EU country-group and for each year for two distinct periods: pre-Kyoto (1999–2004) and post-Kyoto (2005–2010). The six effects are the following ones: (i) the carbon intensity (CI) effect that measures the changes in CO_2 emissions vis-à-vis fossil fuels consumption for each country group; (ii) the energy mix (EM) effect that measures the changes in fossil fuels consumption compared to total energy consumption; (iii) the energy intensity (EI) effect; (iv) the average renewable capacity productivity (RP) effect in each EU country group; (v) the change in capacity of renewable energy per capita, denoted by CP effect; and (vi) the change in population by each on EU country group, denoted as PC effect.

The CO_2 emissions are decomposed into the following six effects:

$$\mathrm{CO}_{2_i} = \frac{\mathrm{CO}_{2_i}}{\mathrm{Fos}_i} \times \frac{\mathrm{Fos}_i}{\mathrm{Ene}_i} \times \frac{\mathrm{Ene}_i}{\mathrm{GDP}_i} \times \frac{\mathrm{GDP}_i}{\mathrm{CRes}_i} \times \frac{\mathrm{CRes}_i}{\mathrm{Pop}_i} \times \mathrm{Pop}_i = \mathrm{CI}_i \times \mathrm{EM}_i \times \mathrm{EI}_i \times \mathrm{RP}_i \times \mathrm{CP}_i \times \mathrm{PC}_i$$

where i is the number of the European country group.

The changes from $\mathrm{CO}_{2_i}^0 = \left(\frac{\mathrm{CO}_{2_i}}{\mathrm{Fos}_i}\right)^0 \times \left(\frac{\mathrm{Fos}_i}{\mathrm{Ene}_i}\right)^0 \times \left(\frac{\mathrm{Ene}_i}{\mathrm{GDP}_i}\right)^0 \times \left(\frac{\mathrm{GDP}_i}{\mathrm{CRes}_i}\right)^0 \times \left(\frac{\mathrm{CRes}_i}{\mathrm{Pop}_i}\right)^0 \times \mathrm{Pop}_i^0$ for period 0 to $\mathrm{CO}_{2_i}^t = \left(\frac{\mathrm{CO}_{2_i}}{\mathrm{Fos}_i}\right)^t \times \left(\frac{\mathrm{Fos}_i}{\mathrm{Ene}_i}\right)^t \times \left(\frac{\mathrm{Ene}_i}{\mathrm{GDP}_i}\right)^t \times \left(\frac{\mathrm{GDP}_i}{\mathrm{CRes}_i}\right)^t \times \left(\frac{\mathrm{CRes}_i}{\mathrm{Pop}_i}\right)^t \times \mathrm{Pop}_i^t$ for period t are decomposed in the multiplicative decomposition as follows:

$$D_{\mathrm{tot}} = \mathrm{CO}_{2_{\mathrm{KWh}t}} / \mathrm{CO}_{2_{\mathrm{KW\ h0}}} = \mathrm{DCIeff} \times \mathrm{DEMeff} \times \mathrm{DEIeff} \times \mathrm{DRPeff} \times \mathrm{DCPeff} \times \mathrm{DPCeff}$$

In additive decomposition is decomposed as follows:

$$\Delta\mathrm{CO}_2 = \mathrm{CO}_{2_t} - \mathrm{CO}_{2_0} = \Delta\mathrm{CIeff} + \Delta\mathrm{EMeff} + \Delta\mathrm{EIeff} + \Delta\mathrm{RPeff} + \Delta\mathrm{CPeff} + \Delta\mathrm{PCeff}$$

The LMDI formulae for each effect in the additive decomposition are presented in Table A1 of the appendix. The LMDI formulae for each effect in the multiplicative decomposition are presented in Table A2 of the appendix.

According to Ang [74], the multiplicative and additive relationship for the CI effect can be given by the following expression: $\Delta\mathrm{CO}_2 / \ln D_{\mathrm{tot}} = \Delta\mathrm{CIeff} / \ln \mathrm{DCIeff}$

The results for each effect and for each group are presented in Tables 1–8.

4. Results and discussion

The results for Central/Eastern Europe Group (Czech Republic, Poland, Hungary, Slovakia and Estonia) are presented in Figs. 1 and 2 in both periods, 1999–2004 and 2005–2010.

The results for this group show that in the 1999–2004 period (pre-Kyoto), there is a decrease (−24.41 tons) in the variation of emissions of approximately 4.1%. On the other hand, in the post-Kyoto period (2005–2010) the decreasing trend in the variation of CO_2 (−38.53 tons) continues with a decrease of 6.8%.

During the pre-Kyoto period, the decrease in emissions was the result of a significant and negative impact of two effects, the emissions intensity and energy intensity, which were larger than the positive energy mix effects, the renewable capacity productivity and renewable capacity per capita. During the post-Kyoto period, there is a predominant significant contribution of energy intensity effect that compensates the positive and significant impact of the renewable capacity per capita.

According to Tables 1 and 2, it is possible to witness that during the pre-Kyoto period, the decrease in the aggregated emission behaviour for the Central/Eastern European group of countries is also confirmed by a decrease of 14.5% in the carbon intensity effect and by a decrease of 13.7% in the energy intensity effect. During the post-Kyoto period there is a decrease of 18.3% in the energy intensity effect.

The behaviour of the variation of emissions in this group of countries for Western Europe (France, Netherlands, Belgium, Austria, Germany and Luxembourg) is presented in Figs. 3 and 4. Clearly, there is a slight increase of 0.4% in the pre-Kyoto period. On the other hand, during the post-Kyoto period there is a decrease in the variation of the carbon emissions (−174.02 tons), which corresponds to a decrease of 9.5%.

This change of behaviour in emissions can be explained by the change of the energy mix effect that together with the negative and significant increase in the energy intensity effect and renewable capacity productivity effect, exceeded the increase positive variation of the renewable capacity per capita and the positive decrease of the effect of the population structure during the post-Kyoto period.

Based on Tables 3 and 4 for the group of countries of Western Europe it is possible to claim that there is a change in behaviour of the energy mix effect, from an increase of about 4,3% in the pre-Kyoto period to a decrease of about 2% in the post-Kyoto period.

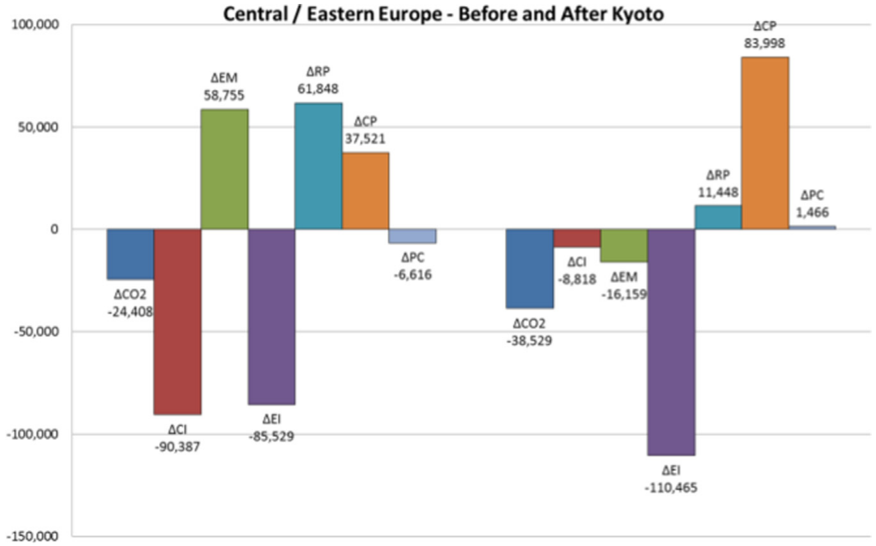

Fig. 1. Results of additive decomposition for the Central/Eastern European group.

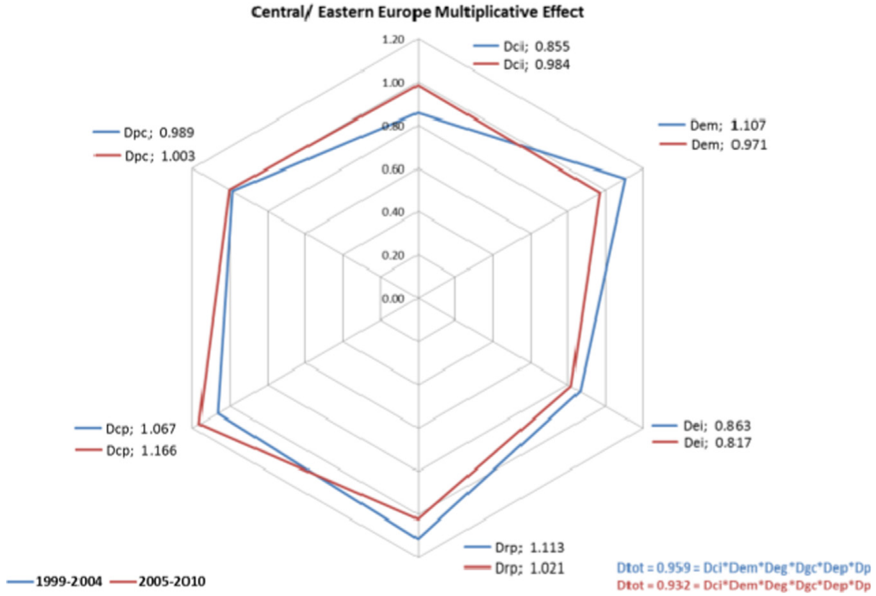

Fig. 2. Results of multiplicative decomposition for the Central/Eastern European group.

Table 1
Results of energy-related CO_2 emissions additive decomposition for the Central/Eastern European group for pre- and post-Kyoto periods.

Central/Eastern Europe group	ΔCIeff	ΔEMeff	ΔEIeff	ΔRPeff	ΔCPeff	ΔPC	Sum of effects	ΔCO2
1999–2004	−90,386.81	58,754.77	−85,529.22	61,848.03	37,521.37	−6616.04	−24,407.9	−24,407.9
2005–2010	−8817.53	−16,158.62	−110,464.65	11,448.36	83,997.55	1466.37	−38,528.5	−38,528.5

Table 2
Results of energy-related CO_2 emissions multiplicative decomposition for the Central/Eastern European group for pre- and post-Kyoto periods.

Central/Eastern Europe group	Dci	Dem	Dei	Drp	Dcp	Dpc	Multiplication of effects	CO_{2t}/ CO_{20}
1999–2004	0.86	1.11	0.86	1.11	1.07	0.99	0.96	0.96
2005–2010	0.98	0.97	0.82	1.02	1.17	1.00	0.93	0.93

Moreover, there is negative and significant increase in the energy intensity effect and in the renewable capacity productivity effect, that change from 4.7% and 12.7%, respectively, for the pre-Kyoto period to a decrease of 9.2% and 19%, respectively, for the post-Kyoto period.

Figs. 5 and 6 present the results for the group of countries in Northern Europe (Finland, Denmark, Ireland, United Kingdom and Sweden) for the two periods (pre- and post-Kyoto). The pre-Kyoto period is dominated by the positive and significant effects of energy mix, renewable capacity productivity and renewable capacity per capita, overpowering the negative effects of emissions intensity and energy intensity and contributing to an average increase of 22.01 tons, or a 2.7% change in the carbon emissions. However, the post-Kyoto period saw a significant volte-face in the emissions behaviour, with a decrease of 102.77 tons—a 12.2% decrease compared to the pre-Kyoto period.

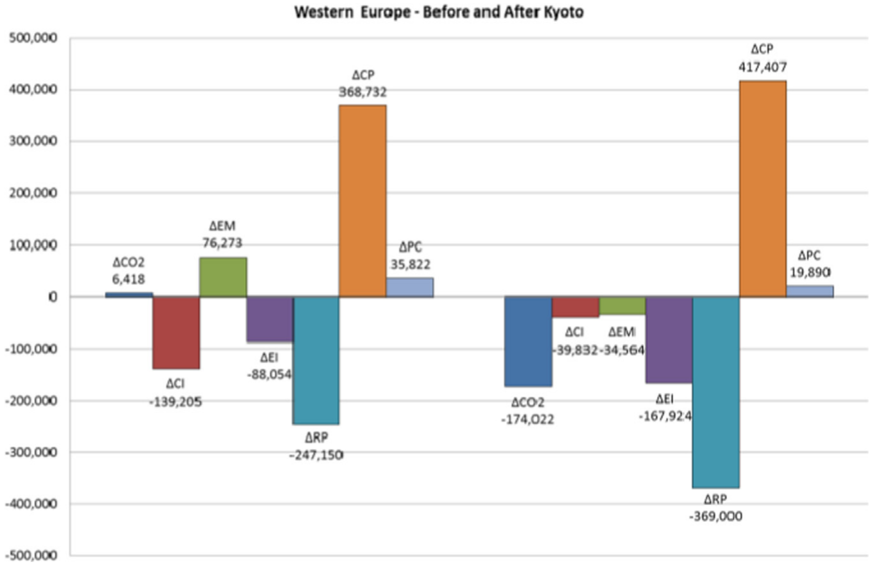

Fig. 3. Results of additive decomposition for the Western European group.

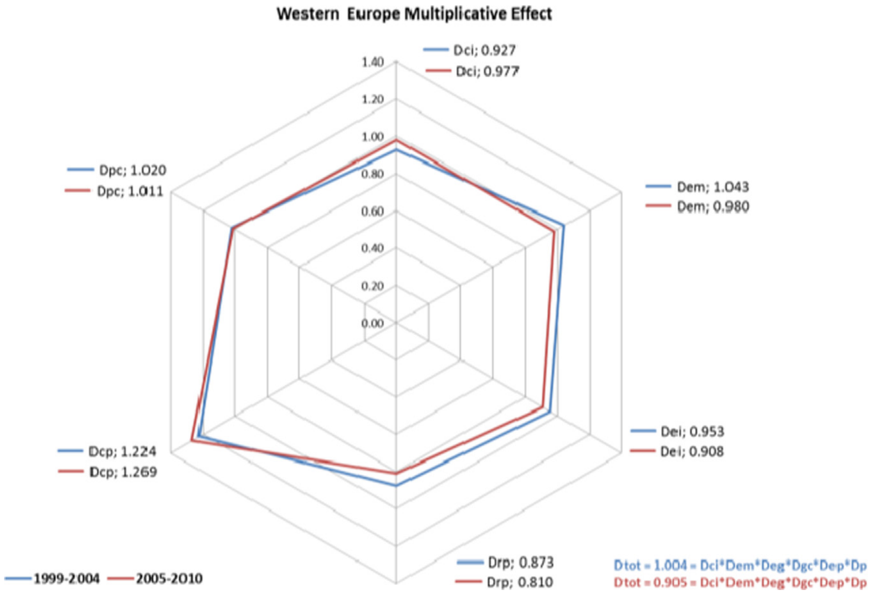

Fig. 4. Results of multiplicative decomposition for the Western European group.

Table 3
Results of energy-related CO_2 emissions additive decomposition for the Western European group for pre- and post-Kyoto periods.

Western Europe group	ΔCIeff	ΔEMeff	ΔEIeff	ΔRPeff	ΔCPeff	ΔPC	Sum of effects	ΔCO2
1999–2004	– 139,205.13	76,272.80	– 88,053.90	– 247,149.94	368,731.85	35,822.27	6417.9	6417.9
2005–2010	– 39,832.03	– 34,564.47	– 167,923.74	– 368,999.56	417,407.47	19,889.92	– 174,022.4	– 174,022.4

Table 4
Results of energy-related CO_2 emissions multiplicative decomposition for the Western European group for pre- and post-Kyoto periods.

Western Europe group	Dci	Dem	Dei	Drp	Dcp	Dpc	Multiplication of effects	CO_{2t}/CO_{20}
1999–2004	0.93	1.04	0.95	0.87	1.22	1.02	1.00	1.00
2005–2010	0.98	0.98	0.91	0.81	1.27	1.01	0.91	0.91

The energy intensity and renewable capacity productivity effects help to explain the change in behaviour given that they overshadow, most importantly, the positive and significant impact of the effects of renewable capacity per capita and the population effect.

According to Tables 5 and 6, it is evident that the pre-Kyoto period saw an increase of 7.5% in the energy mix effect, which subsequently dropped by 4% in the post-Kyoto period. Energy intensity saw a decrease of approximately 13%, which has maintained relatively constant. We can also point to the importance of the contribution made by the renewable capacity productivity effect; having risen by 6.5% in the pre-Kyoto period this then changes to a 15.1% drop in the post-Kyoto period, indicating a fall in the carbon emissions.

The Southern European countries (Italy, Spain, Portugal, Greece and Slovenia) have been characterized by their significant efforts

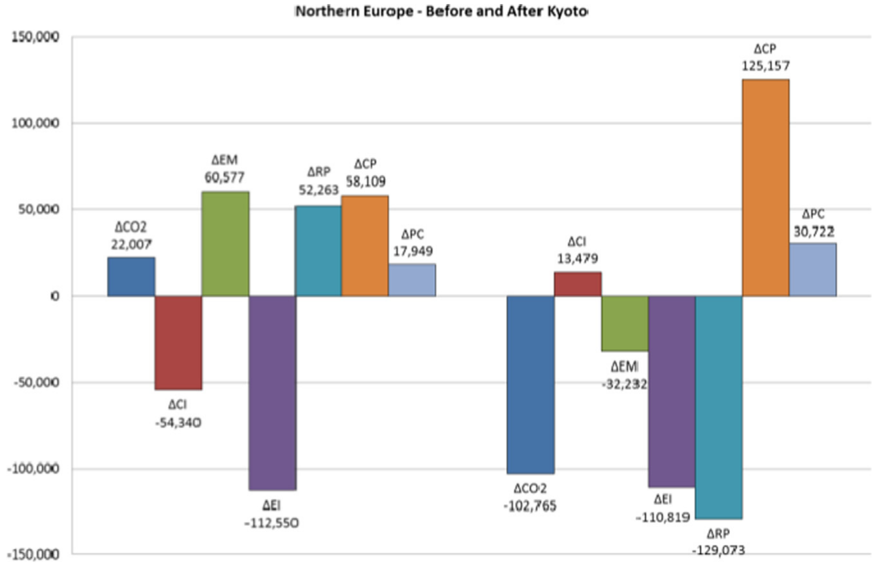

Fig. 5. Results of additive decomposition for the Northern European group.

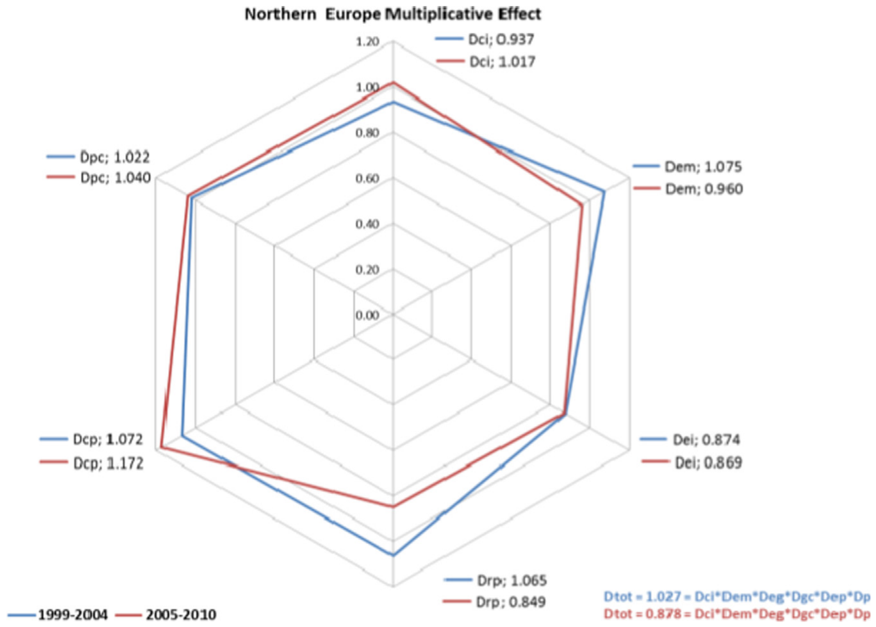

Fig. 6. Results of multiplicative decomposition for the Northern European group.

Table 5
Results of energy-related CO_2 emissions additive decomposition for the Northern European group for pre- and post-Kyoto periods.

Northern Europe group	ΔCIeff	ΔEMeff	ΔEIeff	ΔRPeff	ΔCPeff	ΔPC	Sum of effects	ΔCO_2
1999–2004	−54,340.44	60,576.98	−112,550.47	52,263.23	58,108.85	17,948.72	22,006.9	22,006.9
2005–2010	13,479.24	−32,231.89	−110,818.67	−129,072.62	125,157.00	30,721.69	−102,765.2	−102,765.2

Table 6
Results of energy-related CO_2 emissions multiplicative decomposition for the Western European group for pre- and post-Kyoto periods.

Northern Europe group	Dci	Dem	Dei	Drp	Dcp	Dpc	Multiplication of effects	CO_{2t}/CO_{20}
1999–2004	0.94	1.08	0.87	1.06	1.07	1.02	1.03	1.03
2005–2010	1.02	0.96	0.87	0.85	1.17	1.04	0.88	0.88

to comply with the Kyoto protocol. Our results, as can be seen in Figs. 7 and 8, testify to the fact that there was a major reversal in the variability of the carbon emissions behaviour.

The pre-Kyoto period shows a positive and significant change in the emissions of 13.4% (i.e. a rise of 127.92 tons). In the post-Kyoto period the emissions behaviour changes markedly, falling by 12.7% (a drop of 140.55 tons). This improvement can be explained by the energy intensity and renewable capacity intensity effects which proved much larger than the

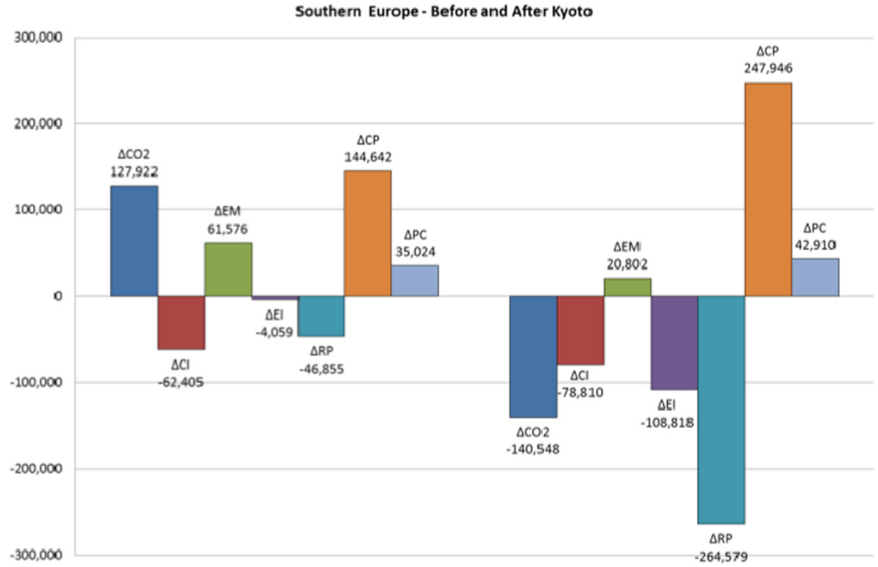

Fig. 7. Results of additive decomposition for the Southern European group.

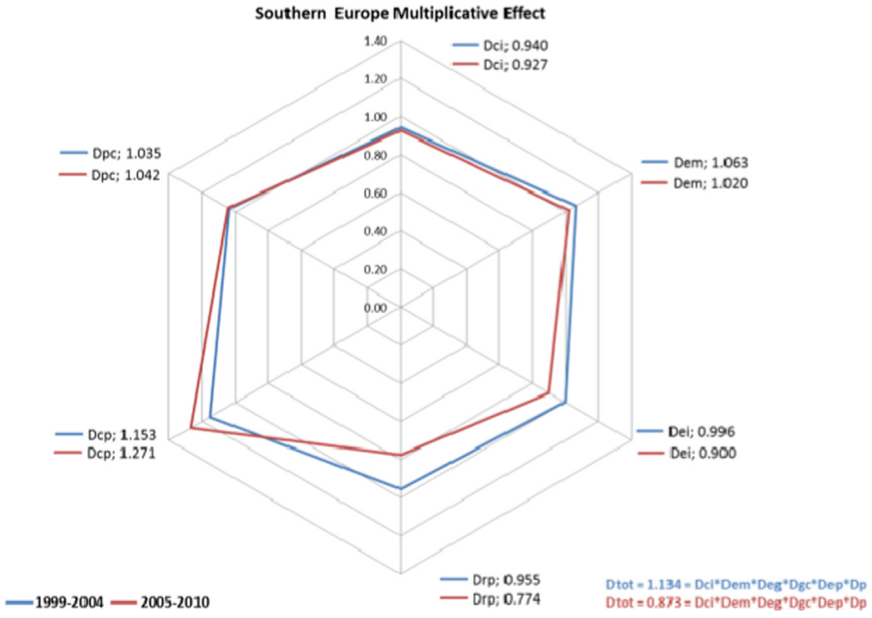

Fig. 8. Results of multiplicative decomposition for the Southern European group.

Table 7
Results of energy-related CO_2 emissions additive decomposition for the Southern European group for pre- and post-Kyoto periods.

Southern Europe group	ΔCIeff	ΔEMeff	ΔEIeff	ΔRPeff	ΔCPeff	ΔPC	Sum of effects	ΔCO2
1999–2004	−62,405.12	61,576.00	−4059.10	−46,855.23	144,642.01	35,023.65	127,922.2	127,922.2
2005–2010	−78,809.77	20,802.47	−108,817.87	−264,578.54	247,946.38	42,909.77	−140,547.6	−140,547.6

major positive effects of renewable energy capacity per capita and energy mix.

Tables 7 and 8 show that in the pre-Kyoto period the renewable per capita effect rose by 15.3%, extending this tendency in the post-Kyoto period, rising by a further 27.1%. Notably, in this second period, the rise was counterbalanced by the significant decrease in the renewable capacity productivity effect (22.6%) which helped contain the emissions in this group of countries in the post-Kyoto period.

4.1. *Comparison of the results with other studies*

All the evidence found reflects the fundamental fact that there was a substantial reduction in the energy intensity of the economic sectors over the post-Kyoto period, reflecting a restructuring of the energy mix used for producing energy. This finding is in alignment with other studies [76,77].

Hatzigeorgiou et al. [77] claim that the energy intensity effect makes a moderate contribution in Portugal (−16%) whereas for

Table 8
Results of energy-related CO_2 emissions multiplicative decomposition for the Northern European group for pre- and post-Kyoto periods.

Southern Europe group	Dci	Dem	Dei	Drp	Dcp	Dpc	Multiplication of effects	CO_{2t}/CO_{20}
1999–2004	0.94	1.06	1.00	0.95	1.15	1.04	1.13	1.13
2005–2010	0.93	1.02	0.90	0.77	1.27	1.04	0.87	0.87

the EU-25 the energy intensity effect is expected to amount to −40%, and for Greece to −17%. A significant effect of energy intensity on CO_2 emissions is observed for Ireland (−47%), which reflects fuel switching towards a less carbon intensive macroeconomic production and consumption.

The impact of the energy mix and population effects on the change in carbon emissions are partly a reflection of the results of the study by Hatzigeorgiou et al. [77] – these authors find that the fuel share effect has a relatively small negative impact on CO_2 emissions for Greece (−6%) and for the EU-25 (−9%), during the 1990–2020 time period. For Belgium, this effect makes a moderate contribution to reducing CO_2 emissions (−15%), which potentially reflects the country's remarkable share of carbon-free nuclear power, projected to reach 14% in 2020. The population effect is projected to have a stable and positive influence on the increase in CO_2 emissions in Greece (10% from 1990 to 2020), while for Ireland, Portugal and Belgium the population effect ranges from 10 to 20%.

The study by Bhattacharyya and Matsumura [76] finds that Germany and the UK have contributed significantly to the overall reduction of GHG emissions from energy use. Germany has accounted for about one half of the reduction in the EU-15 energy-related emissions intensity, while the UK has contributed another 8% reduction. France and Italy were responsible for 4% of the reduction in emissions intensity from energy use. On the other hand, the United Kingdom achieved one of the lowest energy intensities in the EU-15 in 2007. If all 15 countries had achieved the same level of energy intensity, the energy-related GHG emission could have been reduced by 23% from the 2007 level. Germany, France, Italy and Spain would be the major contributors to the emissions reduction, accounting for more than 70% of emissions savings. Other evidences Hatzigeorgiou et al [77] show that the population effect is projected to have a stable and positive influence on the increase in CO_2 emissions in Greece (10% from 1990 to 2020), while for Ireland, Portugal and Belgium the population effect ranges from 10% to 20%. Moreover, the population growth effect, mainly as a consequence of immigration, might induce an increase in CO2 emissions [48].

All these facts are in accordance with the results found. However, it is necessary to take into consideration that our results are based on four groups of countries, while the two studies referred to use a panel of 25 and 15 European countries covering different time periods – their methodology does; however, employ decomposition of the effects to explain the changes in the emissions.

Based on the results of Filippini and Hunt [78] from estimating a stochastic frontier for all the European countries in their sample, we can state that a high degree of negative correlation exists between energy efficiency and energy intensity, namely for some countries that make up the group of Eastern European Countries, as in particular the Czech Republic, Hungary, Poland and the Slovak Republic. This contrasts with countries such as Italy, Portugal, and Spain where the opposite is true and the estimated underlying energy efficiency generally decreases. In these cases Filippini and Hunt [78] illustrate that the estimated underlying energy efficiency would appear to be negatively correlated with energy intensity for most countries (i.e. the level of energy intensity decreases with an increase in the level of energy efficiency).

5. Discussion

It is clear that the GHG emissions—with emphasis on the CO_2 emissions—of a group of countries is directly correlated with the energy consumption of the economy for that group of countries, which in turn is determined by the population change of the various component countries. The results of this study suggest that the population increases in Eastern, Western, Northern and Southern Europe, despite their different evolutions in terms of population and structural behavioural, will not be enough to redirect carbon emissions.

In a similar way, renewable energy consumption is also determined by the size and structure of the population in European countries, as reflected by the value added to the economy. Those facts are, on the one hand, associated with the growth in the global mix of energy demanded and, on the other hand, interconnected with the growth in the mix of energy demand in different European countries.

All the results of the decomposition method used in this study for the four groups of European countries show that the energy intensity effects contributed to explaining the positive and negative variations in carbon emissions for each group of countries, and for each country within each group, for both periods analysed.

In order to understand how the emissions intensity and pollutant gases have evolved over time, namely CO_2 emissions across Europe, it is necessary to evaluate their determinants at country level. However, it is assumed that the behavioural differences in CO_2 emissions change between countries or groups of countries, reflecting disparities in the levels of efficiency associated with the use of energy resources between the economies of different countries and between groups of countries.

According to Figs. 9 and 10, the analysis of the 1993–2010 period for the group of Northern European countries shows that Finland and Sweden followed a contrarian tendency, as for a high (low) average level of CO_2 emissions there is a low (high) level of economic growth.

The result in Southern Europe (Figs. 11 and 12) for the same period seems *a priori* paradoxical—contrary to what is expected theoretically, Greece and Portugal have both a low level of emissions and economic growth, and hence low levels of installed renewable energy capacity per capita. On the other hand, Italy behaves differently, as high levels of emissions are related to both high levels of economic growth and installed renewable capacity.

Out of the Western European group (Figs. 13 and 14), Ireland has the lowest level of carbon emissions with low levels of economic growth and installed capacity of renewable energy per capita. On the other hand, although the UK and France show the highest levels of economic growth, France has a higher level of installed capacity per capita and lower level of emissions intensity than the UK.

In Central Europe (Figs. 15 and 16), Germany emerges with the highest level of economic growth associated with the lowest level of installed capacity from renewable per capita, but contrary to what was expected it also is found to have the highest level of CO_2 emissions. Luxembourg, Hungary, Slovakia and Estonia recorded low levels of economic growth and installed renewable capacity per capita, but also the lowest level of carbon emissions.

Summing up, one might argue that there might be intertwined effects as a high economic growth and a low (high) level of CO_2 emissions may result in high (low) average level of renewable energy capacity per capita, with the Netherlands and Slovakia the countries with the highest energy intensity score in the 2nd phase of the 2008–2012 Kyoto period. Conversely, Luxembourg and Slovenia show the lowest levels of energy intensity and, to a lesser extent, Latvia, Austria, Germany and Italy. One of the factors that may help explain these results is the increased GDP per capita and the effects of population changes that occurred in Central and Eastern Europe

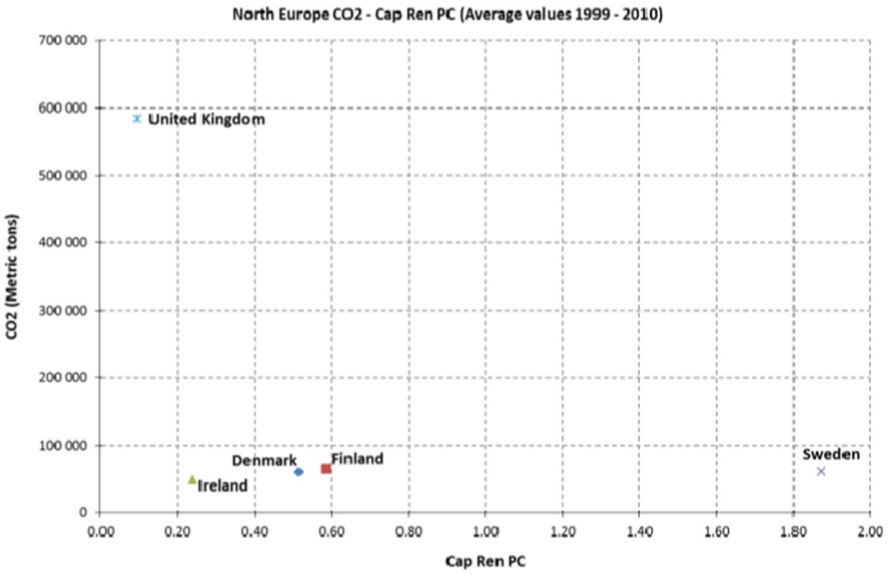

Fig. 9. Average values of CO_2 emissions and renewable capacity for the Northern European group.

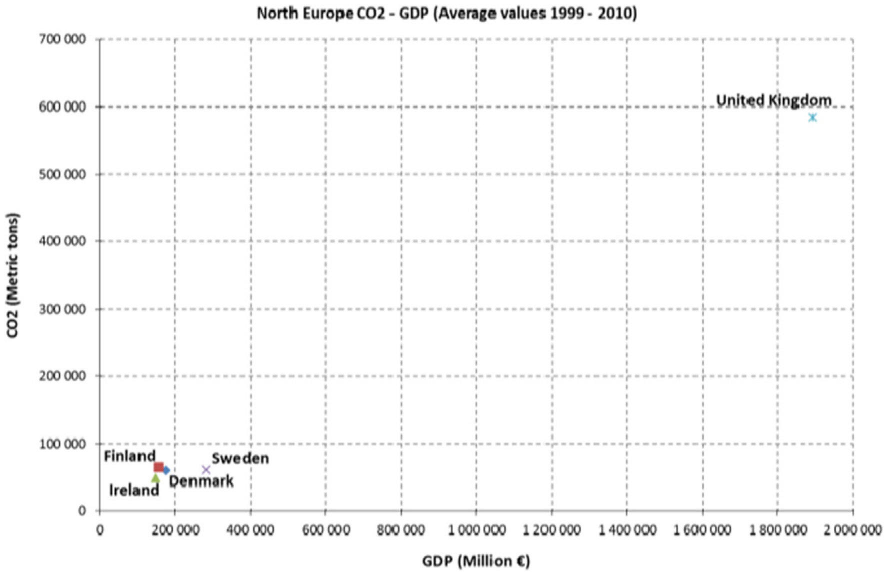

Fig. 10. Average values of CO_2 emissions and growth of domestic product for the Northern European group.

[48]. Moreover, the following two facts that also contributed: firstly, some of the Central and Eastern Europe economies had low GDP values; and secondly, in the middle of the 2000s, those countries entered the EU, which pushed up their economic growth, as market size grew up and foreign investment increased, attracted by lower labour costs and freedom of capital and population movements.

Overall, comparing the results of the post-Kyoto period to the previous period for the group of European countries analysed shows clear improvements in the reductions of emissions. This resulted primarily from changes to the energy mix, switching to cleaner fuels for end-user energy production (a volte-face in the behaviour of the energy mix effect), while the changes in the factors driving emissions resulted from a reduction in the usage of fossil fuels for producing energy. In general, the relative contributions of these two factors show the importance of the impact of changing the structure of the mix for producing energy, with a view to complying with the targets for reductions in CO_2 emissions, reflecting the value placed on the significant impact assigned to emissions levels. As such, it seems evident that both groups of Northern European countries and Southern European countries essentially increased their renewable resources in the second period studied and increased their utilization of less polluting fossil fuels in the production process, increasing their production of hydroelectric power, nuclear power and combined cycle gas energy and reducing their reliance on coal.

It is surprising that some technological yields with the development of unconventional technologies, such as solar, wind and biomass, showed a slow development process and a slow implementation progress. For that reason they did not respond as expected to the population increases as evidenced (see Figs. 9, 11, 13 and 15) by the analysis of both the per capita renewable capacity and the evolution of carbon emissions of the four groups of European countries considered.

However, a recent report of the European Commission [79] suggests that the different levels of economic, energetic and environmental efficiency might be the result of the different real energy costs that affect economic activity and their consequent implications for the levels of carbon emissions. As such, Real Unit

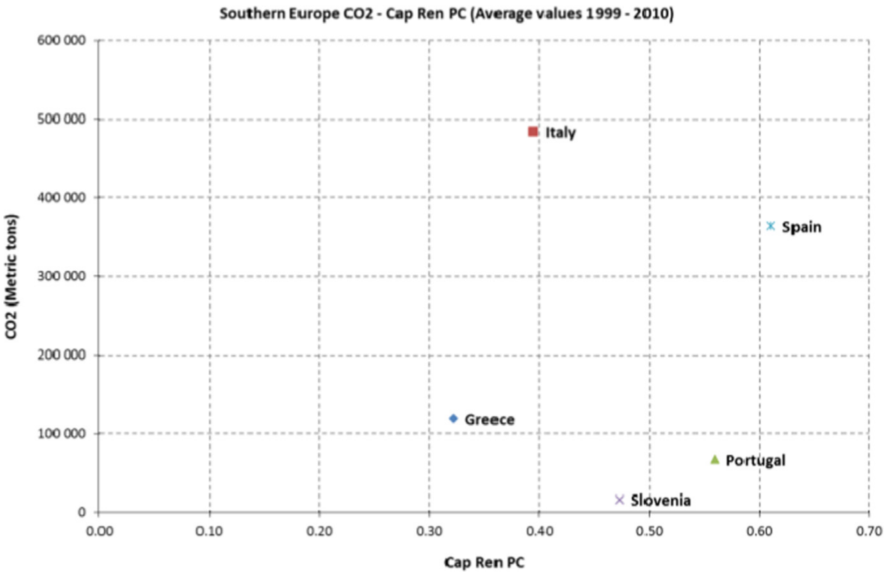

Fig. 11. Average values of CO_2 emissions and renewable capacity for the Southern European group.

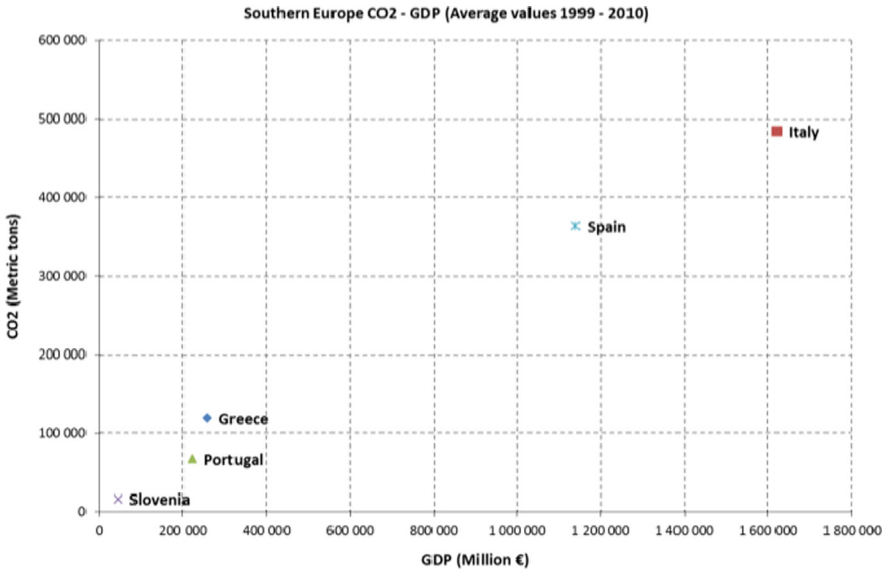

Fig. 12. Average values of CO_2 emissions and growth of domestic product for the for the Southern European group.

Energy Costs (RUEC) for EU Member States between 2000 and 2009 have been characterized by a general upward trend. With the exception of a handful of countries, most Member States saw their RUEC increase on average by 47% over this period. The biggest increases in percentage terms were recorded in Ireland (89%), followed by Malta (70%), and Sweden, France and Belgium (all at around 60%). Data for 2011 [79] shows that the upward trend has broadly continued, although Ireland and Germany both saw their RUEC reduced. Looking at the whole period between 2000 and 2011, the Member States with the greatest percentage increase were France (144%), Belgium (124%) and Finland (111%). On the other hand Cyprus, Slovakia, Romania and the Czech Republic recorded a decrease in their RUEC [79].

As already seen, the reality of the different countries might be a result of the group they belong to. This is because there are also huge fixed costs that create economies of scale, with the average cost per unit produced decreasing as the quantity increases. With subsidies, private firms can invest in renewables and benefit from similar rates of return as conventional energy sources. The objective is to compensate for the relatively high costs of such energy sources compared to other, fossil fuels. As renewables develop, one could expect that there will be further technology development, which will reduce the costs of these technologies over time and render them competitive in the longer run [80].

The differences that exist between the different Member States mean that each state should establish clear rules stipulating the conditions for taking part in the different regimes that support sources of renewable energy. Within the context of the European Union, the Member States can provide support for technologies that can improve their self-sufficiency and, as a result, their ideal energy mix. Cansino et al. [81] make reference to the IEA [82] to underline the fact that the growth in renewable energy is a result of strong political support, and subsequently their continued growth will be a growing political concern. One of the important aspects of the instruments supporting the use of renewable energy is that they should encourage the investors to select the technologies, sizes and locations such that the generation costs can be minimized. In this respect, a public policy instrument should remain in place for a period which is sufficiently long enough to provide stable planning horizons.

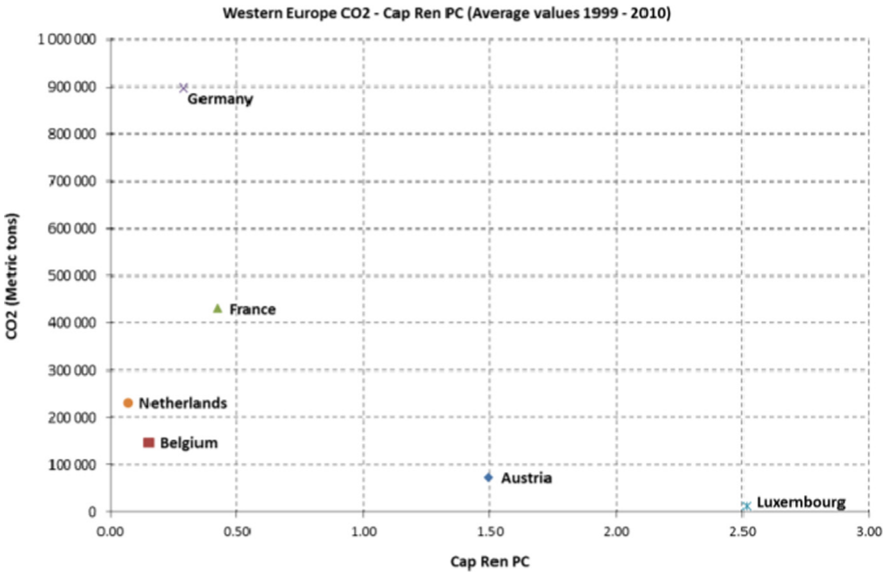

Fig. 13. Average values of CO_2 emissions and renewable capacity for the Western European group.

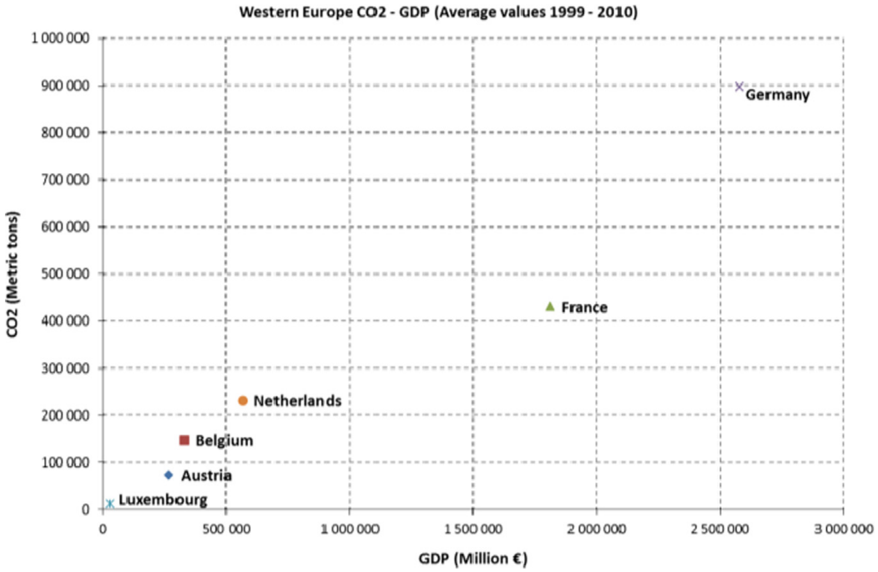

Fig. 14. Average values of CO_2 emissions and growth of domestic product for the for the Western European group.

Investors face uncertainties regarding the expected profit from investments in renewable energy, coming from different factors resulting from political, technological and market risks. One important aspect of optimizing the regimes used for future support programs for renewable energy is the need to develop an understanding of how risk can be reduced from the point of view of the investor. Moreover, due to the high costs associated with renewable energy, Member States typically provide various forms of support to increase their share of renewables in energy production and consumption to the levels required by the Renewable Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009, covering incentives for the use of energy from renewable sources [83]. The importance of encouraging renewable energy, primarily following the Kyoto agreement, affected economic activity in-line with the established targets. At the same time, the political position of governments towards the level of public investment and support for private investment in the energy sector influenced the rate of expansion of installed capacity for producing renewable energy.

6. Conclusions

The variability of CO_2 emissions can be explained by different country effects and levels of energy efficiency. This is seen as a major reason for analysing the decomposition of the effects driving the variability of the emissions, given the benefit associated with isolating the different levels of economic, energy or environmental efficiency for all the countries that comprise a certain group. On the other hand, the reality differs across Europe. In this case some reflection is needed, namely regarding the level of intensity associated with the mix of fossil energy resources, the capacity of existing renewable energy power plants, energy consumption and production and the economic or population growth that may mitigate or explain the changes in CO_2.

This study breaks down carbon emissions into six effects within the four distinct European group countries and analyses their evolution both before (1999–2004) and after (2005–2010) the Kyoto Protocol. This process helps to determine which period has most impact on the change in emissions in those country groups. Decomposition analysis, as used in this study, is not only

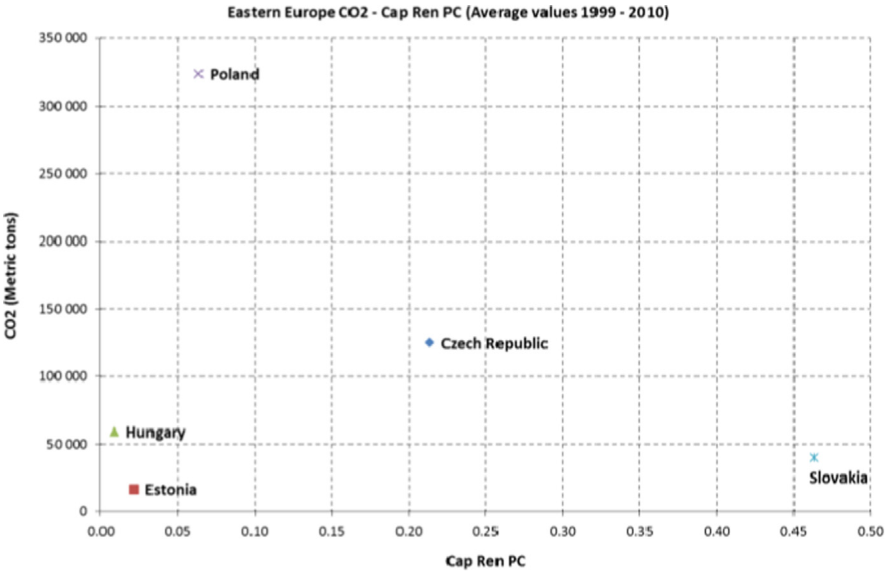

Fig. 15. Average values of CO_2 emissions and renewable capacity for the Eastern European group.

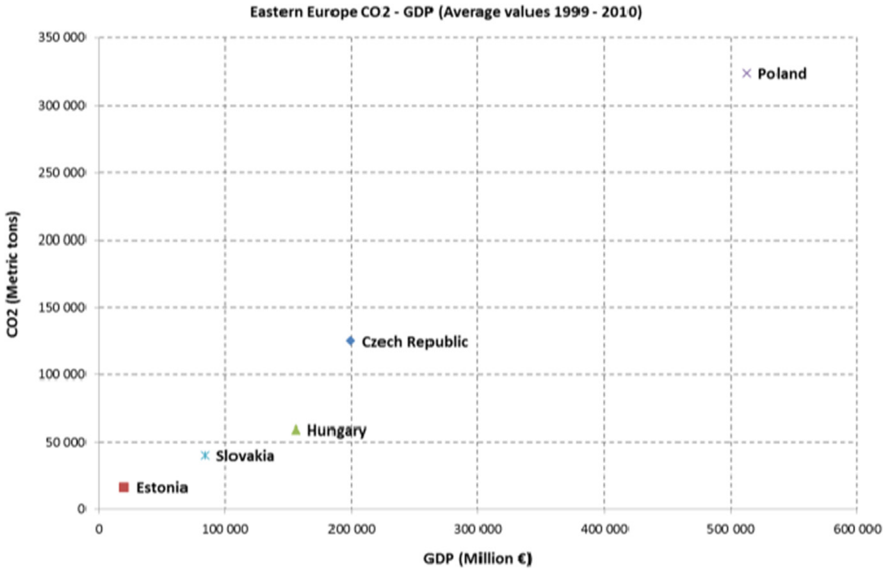

Fig. 16. Average values of CO_2 emissions and growth of domestic product for the for the Eastern European group.

economic, but also environmental, that is, we are considering production per unit of emissions, and the source of energy used (fossil or renewable) is crucial to performance. The group of countries who bet on renewable energy efficiently, gradually substituting fossil based energy, have a greater potential to move from a before Kyoto scenario to an after Kyoto scenario.

The results of our decomposition analysis identify the most important effects, where CO_2 emissions can be broken down into two distinct periods (1999–2004 and 2005–2010) as well as charting their evolution. When comparing the results of the post-Kyoto period to the previous one for the four groups of European countries, one concludes that there are clear improvements in the reduction of emissions. This resulted primarily from changes of the energy mix, switching to cleaner fuels for end-user energy production (a volte-face in the behaviour of the energy mix effect), while the changes in the factors driving emissions resulted from a reduction in the usage of fossil fuels for producing energy. In general, the relative contributions of these two factors show the importance of the impact of changing the structure of the production energy mix, in order to comply with the targets for reducing CO_2 emissions, reflecting the value placed on the significant impact assigned to emissions levels. Moreover, the best environmental performer (as shown by the results of this study) is a group countries with low energy intensity or with a good performance in terms of energy intensity in the last decade.

Table A1
Formulae for each effect in the additive decomposition.

$\Delta \text{CIeff} = \left(\frac{CO_{2_t} - CO_{2_0}}{\ln CO_{2_t} - \ln CO_{2_0}}\right) \times \ln\left(\frac{CI_t}{CI_0}\right)$	$\Delta \text{EMeff} = \left(\frac{CO_{2_t} - CO_{2_0}}{\ln CO_{2_t} - \ln CO_{2_0}}\right) \times \ln\left(\frac{EM_t}{EM_0}\right)$
$\Delta \text{EIeff} = \left(\frac{CO_{2_t} - CO_{2_0}}{\ln CO_{2_t} - \ln CO_{2_0}}\right) \times \ln\left(\frac{EI_t}{EI_0}\right)$	$\Delta \text{RPeff} = \left(\frac{CO_{2_t} - CO_{2_0}}{\ln CO_{2_t} - \ln CO_{2_0}}\right) \times \ln\left(\frac{RP_t}{RP_0}\right)$
$\Delta \text{CPeff} = \left(\frac{CO_{2_t} - CO_{2_0}}{\ln CO_{2_t} - \ln CO_{2_0}}\right) \times \ln\left(\frac{CP_t}{CP_0}\right)$	$\Delta \text{PCeff} = \left(\frac{CO_{2_t} - CO_{2_0}}{\ln CO_{2_t} - \ln CO_{2_0}}\right) \times \ln\left(\frac{PC_t}{PC_0}\right)$

At individual country level, Germany emerges with the highest level of economic growth associated with the highest level of installed capacity renewable sources, while Luxembourg, Hungary, Slovakia and Estonia show low levels of economic growth and installed renewable capacity, but also the lowest level of carbon emissions. Finland and Sweden show a contrarian tendency, as for a high (low) average level of CO_2 emissions there is a low (high)

Table A2
Formulae for each effect in the multiplicative decomposition.

$\mathrm{DCIeff} = \exp\left(\left(\frac{\Delta \mathrm{CIeff}}{(\mathrm{CO}_{2_t} - \mathrm{CO}_{2_0})}\right) \times \ln\left(\frac{\mathrm{CO}_{2_t}}{\mathrm{CO}_{2_0}}\right)\right)$	$\mathrm{DEMeff} = \exp\left(\left(\frac{\Delta \mathrm{EMeff}}{(\mathrm{CO}_{2_t} - \mathrm{CO}_{2_0})}\right) \times \ln\left(\frac{\mathrm{CO}_{2_t}}{\mathrm{CO}_{2_0}}\right)\right)$
$\mathrm{DEIeff} = \exp\left(\left(\frac{\Delta \mathrm{EIeff}}{(\mathrm{CO}_{2_t} - \mathrm{CO}_{2_0})}\right) \times \ln\left(\frac{\mathrm{CO}_{2_t}}{\mathrm{CO}_{2_0}}\right)\right)$	$\mathrm{DRPeff} = \exp\left(\left(\frac{\Delta \mathrm{RPeff}}{(\mathrm{CO}_{2_t} - \mathrm{CO}_{2_0})}\right) \times \ln\left(\frac{\mathrm{CO}_{2_t}}{\mathrm{CO}_{2_0}}\right)\right)$
$\mathrm{DCPeff} = \exp\left(\left(\frac{\Delta \mathrm{CPeff}}{(\mathrm{CO}_{2_t} - \mathrm{CO}_{2_0})}\right) \times \ln\left(\frac{\mathrm{CO}_{2_t}}{\mathrm{CO}_{2_0}}\right)\right)$	$\mathrm{DPCeff} = \exp\left(\left(\frac{\Delta \mathrm{PCeff}}{(\mathrm{CO}_{2_t} - \mathrm{CO}_{2_0})}\right) \times \ln\left(\frac{\mathrm{CO}_{2_t}}{\mathrm{CO}_{2_0}}\right)\right)$

level of economic growth; meanwhile Greece and Portugal have low emission levels and low levels of economic growth, and hence low levels of renewable energy installed capacity and Italy has a high level of emissions accompanied by high levels of economic growth together with a high level of installed renewable capacity. Ireland records the lowest level of carbon emissions with low levels of economic growth and installed capacity of renewable energy per capita; the UK and France have the highest levels of economic growth; however, France has a higher level of installed capacity per capita and a lower level of emission intensity than the UK. The efficiency of energy use has become much more important, especially when coupled with rising prices of fossil energy resources. It becomes necessary to base economic, energy and the environmental policies on the efficient use of resources, in particular on energy efficiency and use of renewable sources.

One can observe when analysing the four groups of European countries that most countries reduced their CO_2 emissions as a consequence of promoting renewable sources in energy used and reducing both the intensity and fuel mix factors. However, Spain, Poland and Italy are remarkable exceptions to this rule as their emissions were increasing, mainly as a consequence of the GDP per capita and, to a lesser extent, of the population effect.

This body of evidences and findings cannot be dissociated from the demographic population change. It is necessary to investigate the impact of population on carbon emissions, especially regarding the EU countries that have been polluting the most and the least in recent years. For example the least polluting countries such as the UK and Germany, where moderate growth coincided with a slight increase in population and a progressive decrease in the industrial sector, will have to make greater investments in mitigation of carbon emissions both in the energy sector both in the industrial sector just as a result of their highest population growth rates. One cannot expect that Germany meets its Kyoto targets only through a reduction of the population or that the UK increases emissions at a rate of 8%, as it is predicted by the population growth.

For example, if only economic output and household income increased and the population remained stable, consumer choices would likely change to higher value added products. Furthermore, consumer attitudes might shift to "green consumption", for example promoted by environmental taxes. Significant differences in Environmental Taxation Revenues (ETR) are found for Cyprus, Malta, Bulgaria, Portugal, Iceland, Latvia and Austria, while marked discrepancies are present in all countries until 2005 [84]. Luxembourg, for instance, with highest ETR per capita, takes ninth place when ETR share is measured in the GDP. High level of ETR per capita is found in Ireland, while it is eighteenth by ETR share in the GDP. A similar situation, where the allocations per capita are higher than allocations per GDP is found in Austria, United Kingdom, Belgium and Spain [84]. Thus, in future research we intend to evaluate the resource and environment efficiency problem of European countries. To this end we have proposed a new stochastic frontier model where GDP is considered to be the desired, positive output and GHG emissions are the unwanted, negative output. Capital, Labour, Fossil Fuels and Renewable Energy consumption are regarded as inputs. The GDP/GHG ratio is maximized given the values of the other four variables. This future research thus proposes a new parametric stochastic frontier approach as an alternative to the Kaya identity discussed in this current study.

Appendix

See Tables A1 and A2.

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