# Comparing European $CO_2$ emission trends before and after the 2008 economic crisis: A case study of four European countries

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**ABSTRACT:**

The paper investigates and compares the evolution in carbon dioxide emissions in 4 major economies of the European Union (Germany, France, United Kingdom, and Spain) between the period of economic growth (2004 – 2008) and the period of economic crisis (2008 – 2012). Decomposing the Kaya identity of five inter-related factors, namely energy intensity, mix energy, carbon emission coefficient, production and population, this study shows that the $CO_2$ emission decreased most importantly between 2008 and 2012. The decline in energy intensity is the major source of $CO_2$ emission reduction in both periods, but energy intensity deteriorated in times of economic crisis. The population effect on the other hand contributed to an increase in carbon emissions.

Different scenarios to analyse the emissions reduction opportunity through successful experiences of selected countries show that the overall carbon dioxide emission in the sample could be reduced by 293 $MtCO_2$ or 16% compared to the 2012 level through more improvements in carbon emission coefficient, energy mix and energy intensity. Germany would reduce 20% of $CO_2$ emission. Spain and United Kingdom would gain 19% and 15%, respectively. The saving would be less important in France, accounting for about 6% of $CO_2$ emission compared to 2012 value.

**Keywords:**

Carbon dioxide emission; Decomposition analysis; Recession - economic growth; Energy efficiency; Climate change**.**

## *INTRODUCTION*

It is now generally agreed that the climate change is one of the biggest environmental problems of recent times and carbon dioxide ($CO_2$) emission is the primary greenhouse gas responsible for the climate change[1]. The continuous rise in global carbon dioxide emissions has attracted the attention of the international community and in December 2015 the Conference of the Parties of UNFCCC (United Nations Framework on Convention Climate Change) adopted the Paris Agreement to limit the global temperature rise to well below $2^o$ degrees Celsius above pre-industrial levels[2]. This Agreement, entered into force in November 2016, requires all Parties to follow nationally determined contributions to support the global efforts. The European Union has ratified the Agreement and is actively working towards reducing carbon emissions from all sectors of its economy. It's Energy climate Roadmap provides to reduce greenhouse gas emissions by 80 – 95% by 2050 below 1990 levels .Intermediate targets of a 20% reduction by 2020, 40% by 2030 and 60% by 2040 were also adopted[3].

Carbon emissions however significantly depend on economic performance of a country or group of countries. For example, the total carbon emissions in the European Union ( 28) has decreased by 553 $MtCO_2$ or 13.64% between 2004 and 2012. But the overall reduction masks the temporal variation between the pre-crisis (2004-2008) and crisis (2008-2012) periods. Almost 76% of the emission reduction was achieved (421 $MtCO_2$) during the period of economic crisis whereas only 24% (or 132 Mt) came from the period of economic growth (2004 to 2008). This paper attempts to understand why this was the case and what its implications are for the environmental policy?

The evolution of carbon emission has been widely investigated in the literature and the decomposition analysis is a popular approach used for the analysis of energy-environment policies[4].Two variations of decomposition analysis, namely Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA) are the most commonly used methods. Since the study of Kaya[5], empirical studies using IDA for analyzing GHG and $CO_2$ emissions proliferated and different authors have examined a wide range of cases. Albrecht et al[6] studied historical evolutions of carbon emissions in four countries over the period 1960 – 1996. Using the Shapley decomposition without residuals the authors concluded that the fuel mix changes and decarbonization of economic growth were the main targets of climate policy. According to Paul and Bhattacharya[7], economic growth influenced the changes in the $CO_2$ emissions in all economic sectors of India during the period 1980 – 1996. They suggested that energy policies of developing countries like India should be oriented more towards a reduction in energy intensity of economic activity for reducing $CO_2$ emissions. Bhattacharyya and Matsumura[8] adopted the log-mean Divisia index decomposition (LMDI) approach to decompose the rate of reduction of the GHG emission intensity of EU-15 over the period 1990 – 2007 to determine the contribution of different States. Outcomes stressed the dominant role of Germany and United Kingdom in the environmental performance of the UE- 15.

The multiplicative Logarithmic Mean Divisia Index (M – LMDI) technique has been applied by Choi and Ang[9] to analyse the changes in the aggregate energy intensity for US manufacturing industry. They found the aggregate energy index was exactly the product of industrial structure index and real energy intensity index. Mahony[10] employed the LMDI – I approach to analyse the changes in energy – related carbon emissions in Ireland for the period 1990 – 2010. The paper integrated the impact of energy renewable diffusion and concluded the negligible impact of this source.

Applying a generalized Division index approach, Vaninsky[11] factorises $CO_2$ emissions of United States and China. It considered that the energy consumption, population and Gross domestic product per capita effects were the major factors driving carbon dioxide emissions in two countries during the period 1980 – 2012, and made proposals with a view to improving environmental performance of surveyed countries.

A recent research by Cansino et al[12] investigated the variations in $CO_2$ emissions in the Spanish economy over the period 1995 – 2009. They authors discovered that the evolutions in the energy mix and energy efficiency contributed to reduce the carbon emissions, and recommended that government offers tax benefits to companies to reduce their energy intensity.

Finally, Streimikiene and Balezentis[13] surveyed the main factors of GHG emissions as well as the practicability to implement the 20 – 20 – 20 targets in four Baltics States. Results showed that economic growth and intensity energy were the principal determinants influencing the change in GHG emission per capita in all studies countries expect Lithuania. The authors concluded that the increasing of energy efficiency was the most important policy for reducing GHG emission and carrying out the 20 – 20 20 targets.

Despite the above-mentioned studies, to the best of our knowledge, there is no study that has explored the changes in carbon emissions in European countries between 2004 and 2012 to focus on crisis and growth periods. To bridge the above knowledge gap, this paper uses IDA/Kaya identity to identify, quantify, analyze and compare the main factors explaining the changes in carbon dioxide emissions between economic growth period (2004 – 2008) and crisis period (2008 – 2012). The paper presents an analysis of 4 selected EU economies: Spain, France, United Kingdom and Germany. The choice to study these countries is motivated by the importance of their emissions and of their economic weight in the Europe. Together they account for about 51% of the $CO_2$ emissions and 61% of the Gross Domestic Product in EU – 28.

The structure of the paper is as follows. Following the introduction, Section 2 describes the research methodology used in the study. Section 3 presents and discusses the data. The results from the analysis are presented in Section 4. Finally, Section 5 concludes the paper.

## *METHOD*

The approach applied here combines the IDA method and the Kaya identity established on the environmental impact equation IPAT

Where:

I, represents the quantity of emissions of the pollutant;

P, population;

A, the affluence, formalised by the production per capita

T, Pollutant emissions per unit produced, dependent on technology used

The IPAT equation is formulated in the context of a controversy between Ehrlich and Holdren[14][15] and Commoner [16] on the role of population growth in the degradation of the natural environment. The analysis of carbon dioxide emission using Kaya identity[17]equates environmental impact in IPAT formula to carbon dioxide emissions. The technology parameter is broken down into two factors, namely the energy intensity (E/Y) and the intensity of energy use (C/E). The Kaya identity then involves four factors as follows:

$CO_2$ emissions = $P \times \frac{Y}{P} \times \frac{E}{Y} \times \frac{C}{E}$ (1)

Where

P = Population

Y = Total output

E = Total Energy Consumption of all fuel types

$E_j$ = Total Energy of fuel type j

C = $CO_2$ emissions form all fuel types

$C_j$ = $CO_2$ emissions from fuel type j

In which *j* denotes fuel type (coal, oil, peat, gas, and other).

Given that total energy use is the sum of different types of energy products, Eq. (1) can be rearranged as Eq. (2) as follows:

$$C = \sum_{ij} C_{ij} = \sum_{ij} P_i \times \frac{Y_i}{P_i} \times \frac{E_i}{Y_i} \times \frac{E_{ij}}{E_i} \times \frac{CO_{2ij}}{E_{ij}} = \sum_{ij} P_i\, G_i I_i M_{ij}\, U_{ij} \quad (2)$$

Where

P = Population

G = Y/P the production per capita or affluence -

I = E/Y the energy intensity

M = $E_{ij}/E_i$ is the portion of fossil fuel type j, in total fuels

U = $CO_{2ij}/E_{ij}$ the emission coefficient

The aggregate $CO_2$ emission changes between the initial period (0) and the end period (T). The total variation in carbon emissions ($\Delta C_{tot}$) by time (0 to T) can be decomposed as the addition of variations in each element, namely population ($\Delta C_{pop}$), production ($\Delta C_{pdn}$), energy intensity ($\Delta C_{int}$), fossil fuel substitution ($\Delta C_{mix}$) and carbon emission coefficient ($\Delta C_{emf}$). Thus the variation in total $CO_2$ emissions ($\Delta C_{tot}$) can be stated as follows (Eq. 3):

$$\Delta C_{tot} = C^T - C^0 = \Delta C_{pop} + \Delta C_{pdn} + \Delta C_{int} + \Delta C_{mix} + \Delta C_{emf} \quad (3)$$

Following the Logarithmic Mean Divisia Index (LMDI) technique, each element in Eq. (3) is computed as follows:

The population effect:

$$\Delta C_{pop} = \sum_i \frac{C_{ij}^T - C_{ij}^O}{lnC_{ij}^T - lnC_{ij}^O} \ln\left(\frac{P^T}{P^O}\right) \quad (4)$$

The economic production effect:

$$\Delta C_{pdn} = \sum_i \frac{C_{ij}^T - C_{ij}^O}{lnC_{ij}^T - lnC_{ij}^O} \ln\left(\frac{G_i^T}{G_i^O}\right) \quad (5)$$

The energy intensity effect:

$$\Delta C_{int} = \sum_i \frac{C_{ij}^T - C_{ij}^O}{lnC_{ij}^T - lnC_{ij}^O} \ln\left(\frac{I_i^T}{I_i^O}\right) \quad (6)$$

The energy mix effect:

$$\Delta C_{mix} = \sum_i \frac{C_{ij}^T - C_{ij}^O}{lnC_{ij}^T - lnC_{ij}^O} \ln\left(\frac{M_{ij}^T}{M_{ij}^O}\right) \quad (7)$$

Finally the carbon emission coefficient effect:

$$\Delta C_{emf} = \sum_i \frac{C_{ij}^T - C_{ij}^O}{lnC_{ij}^T - lnC_{ij}^O} \ln(\frac{U_{ij}^T}{U_{ij}^O}) \qquad (8)$$

Where, the carbon emission coefficient effect ($\Delta C_{emf)}$ is the proportion of carbon dioxide emission produced through energy use. The carbon emission coefficient of each fuel represents the quantity of carbon generated per unit of energy employed for that fuel. The coefficient of carbon emissions changes by energy source, and it is well known that coal has bigger carbon content, followed by oil and natural gas, while renewable energies and the nuclear energy generate small or negligible quantities of carbon dioxide. Thus changes in the energy mix influence the global carbon emission coefficient. A decrease in this component can signify a contraction in the consumption of fossil fuels or/ and a transfer to less carbon – intensive fossil fuels.

The energy mix effect ($\Delta C_{mix}$) indicates the effect of changes in the contribution of fossil fuel sources (gas, coal and oil) in total energy. The energy intensity effect ($\Delta C_{int}$) captures changes in carbon emission due to changes in energy intensity of the economy (where energy intensity is energy use per unit of production). Finally, the production effect ($\Delta C_{pdn}$), and population effect ($\Delta C_{pop}$) represent the effects of variation in production per capita, and the variation in number of population, respectively on carbon emission.

The above methodology decomposes the carbon dioxide emission into economic, energy and demographic factors and helps explain the variation in carbon emission between the economic growth period and the crisis period. This again permits to assign to each factor a negative or positive impact on the change of carbon emissions in the sample as a whole and per country.

## *DATA DEFINTIONS AND SOURCES*

We use annual data for four European Union countries, Spain, France, United Kingdom and German for the period between 2004 and 2012.

The environmental and population data are obtained from the World Development Indicators[18]. The total $CO_2$ emissions and $CO_2$ by source are defined in million tons of $CO_2$, while population is defined in million persons. Data on total output and sectoral production are collected from the World Input - Output Tables (WIOT)[19] in the World Input – Output Database (WIOD)[20]. They are measured in millions of dollars**.**

All energy data derive from the Eurostat Database[21]. The total and sectoral energy consumption are described in million tons of energy (Mtoe).

Analysis for each country as well as the comparative analysis was carried out using Excel Worksheets.

## *EMPIRICAL RESULTS*

This section comprises four parts. The first displays and discusses the results for four countries (Germany, UK, France and Spain) between 2004 and 2008 (see Table 1). The second part presents the cumulative results for the entire sample from 2008 to 2012 (see Table 2). Part three discusses the final result for each country by effects and sub – periods for 2 – year period from 2008 to 2012. Thus, we have four 2- year periods from 2008 – 2009 to 2011-2012 connected to each country and Tables 3, 4, 5, 6 report the $CO_2$ emission change and its components.

Finally, part four (What-if cases) examines different scenarios in order to estimate the additional saving in carbon emissions if all the countries implemented the best practices in terms of energy use.

**Period 2004 – 2008**

Table 1 exposes the total variation in $CO_2$ emission for four countries and the components driving $CO_2$ emissions using the Kaya identity/ IDA method.

For the sample as a whole, $CO_2$ emission decreased by 80 $MtCO_2$ (Million tons of carbon dioxide equivalent) or 4% between 2004 and 2008. Germany contributed most with a decline in $CO_2$ of 35.56 $MtCO_2$ followed by United Kingdom (17.62$MtCO_{2)}$ and France (16.67 $MtCO_2$). The smallest reduction of $CO_2$ emissions was recorded by Spain (10.15 $MtCO_2$).

For the sample countries as a whole the total energy intensity effect (ΔCint) contributed most to the emission reduction (233.43 $MtCO_{2.}$). This means that improvements in energy efficiency have played an important role in reducing $CO_2$ emissions.

The total energy mix (ΔCmix) effect contributes to $CO_2$ emissions decrease in three countries (Spain, Germany and France), while it contributes to $CO_2$ increase in United Kingdom. As a result the total energy mix effect is associated with a $CO_2$ reduction of 38.59 $MtCO_2$.

On the other hand, the cumulative production effect (ΔCprod) is positive for each country; this effect is associated with overall increase in $CO_2$ emissions of 132.84 $MtCO_2$ in the sample as a whole. Although the total population effect (ΔCpop) contributes to $CO_2$ decrease in Germany, it is associated with complete increase in $CO_2$ emissions of 44.61 $MtCO_2$ for the sample countries as a whole**.** Finally, except France the emission coefficient effect (ΔCemf) contributes to $CO_2$ augmentation in all countries, as a result, it is associated with total increase in $CO_2$ emissions of 14.57 $MtCO_2$ for the sample as a whole.

Therefore during the period of economic growth (2004 – 2008), the energy intensity effect largely explains the decline in carbon emissions, while the economic effect has contributed to an increase in CO2 emission and hence to degradation of the environment.

At the country level, the picture changes significantly. For Germany, three factors (intensity, fuel mix and population) contributed to emission reduction while the output effect and carbon emission coefficient of fuels increased emission. For UK only energy intensity effect contributed to emission reduction whereas four other factors positively influenced emissions. But the intensity effect was stronger than the combined effect of other factors. Spain managed to reduce the least amount of carbon emission among the four countries. This is because the positive contribution of energy intensity was largely offset by the output effect, the population effect and the emission factor effect. France also reports a similar pattern of effects as Spain, except that the emission factor effect was negative (i.e. contributed to emission reduction).

**Table 1: Total decomposition of $CO_2$ emissions changes for 4 countries from 2004 to 2008**

| Countries | $\Delta C_{tot}$(%) | $\Delta C_{mix}$(%) | $\Delta C_{emf}$(%) | $\Delta C_{int}$ (%) | $\Delta C_{prod}$(%) | $\Delta C_{pop}$(%) |
|---|---|---|---|---|---|---|
| Germany | - 35. 56 (44) | - 17. 67 (22) | 6. 07(-8) | - 92. 83 (116) | 72. 81 (-91) | -3.95 (5) |
| UK | - 17. 62 (22) | 9. 66 (-12) | 2. 66 (-3) | -72. 12 (90) | 26. 34 (-33) | 15.84 (-20) |
| France | - 16. 67 (21) | - 6. 19 (8) | - 1. 98 (2) | - 33. 08 (41) | 14. 61 (-18) | 9. 98 (-12) |
| Spain | - 10. 15 (13) | - 24. 39 (30) | 7. 83 (-10) | - 35. 39 (44) | 19. 08 (- 24) | 22. 73 (-28) |
| **Total** | **- 80. 00 (100)** | **- 38. 59 (48)** | **14. 57(-18)** | **-233. 43 (292)** | **132. 84 (-166)** | **44. 61(-56)** |

**Period 2008 - 2012**

Table 2 shows the results of total decomposition for four countries (Spain, UK, France and Germany)

Overall carbon dioxide emission for the selected countries fell by 175.63 $MtCO_2$ between 2008 and 2012. It is twice the volume of emission reduction for the period 2004 – 2008. It is noteworthy the steepest decrease in $CO_2$ was recorded by Spain with 63.06 $MtCO_2$ reduction. This situation may be explained by the contraction of the Spanish economy, as the GDP has shrunk by 6.16% during the investigated period. Four sectors have been particularly affected: construction (- 62%), other non-metallic mineral (-55%) and Wood and products of wood and cork (- 49%), and manufacturing, recycling (- 33%). United Kingdom comes at the second position with 47.51 $MtCO_2$. France and Germany have contributed less to the overall carbon emission reduction for about 38.35 $MtCO_2$ and 26.71 $MtCO_2$, respectively.

Although the population effect (ΔCpop) contributes to $CO_2$ emission decrease in Germany by 15.93 Mt $CO_2$, it is associated with total increase in $CO_2$ emissions of 11.16$MtCO_2$ for the sample as a whole. The production effect (ΔCprod) of each country (except Germany) is negative with a global reduction in $CO_2$ emissions of 10.69 Mt $CO_2$ during this period.

The intensity effect (ΔCint) contributes to an aggregate decrease in $CO_2$ emissions of 96.70 $MtCO_2$. The emission coefficient effect (ΔCemf) is negative in three countries, contributing a decrease in $CO_2$ emissions of 35.60 $MtCO_2$. Finally, while the fuel mix effect (ΔCmix) contributes to $CO_2$ emission rise in United Kingdom; it helps reduce $CO_2$ emission for the sample as a whole. As a result, energy mix is associated with an overall decrease in $CO_2$ emissions of 43.81 Mt $CO_2$ during 2008–2012. Among the four components supporting $CO_2$ emission reduction**,** the change in energy intensity makes the highest contribution (55%).

**Table 2: Total decomposition of $CO_2$ emissions changes for 4 countries, 2008 – 2012**

| Countries | $\Delta C_{tot}$(%) | $\Delta C_{mix}$(%) | $\Delta C_{emf}$(%) | $\Delta C_{int}$ (%) | $\Delta C_{prod}$(%) | $\Delta C_{pop}$(%) |
|---|---|---|---|---|---|---|
| Spain | - 63. 06 (36) | - 12. 46 (7) | - 26. 79 (15) | - 4.96 (3) | -24.09 (14) | 5.24 (-3) |
| UK | - 47.51 (27) | - 16.59 (9) | 0. 34 (0) | - 30.15 (17) | - 16.12 (9) | 15.01 (- 9) |
| France | - 38.35 (22) | - 15.06 (9) | - 4.44 (3) | - 23. 08(13) | -2.62 (1) | 6.85 (- 4) |
| Germany | - 26.71 (15) | 0. 30 (0) | - 4.71 (3) | - 38.51 (22) | 32.14 (-18) | - 15.93 (9) |
| **Total** | **- 175. 63(100)** | **- 43. 81 (25)** | **- 35. 60 (20)** | **- 96.70 (55)** | **- 10. 69 (6)** | **11.16 (-6)** |

## Country level analysis

Tables 3 – 6 present the decomposition of change in $CO_2$ across the analysed countries by effects and sub – periods from 2008 to 2012.

- *Spain*

In Spain, carbon emission ($\Delta C_{tot}$) fell from 329 Mt of $CO_2$ in 2008 to 266 Mt of $CO_2$ in 2012 or 19% between 2008 and 2012. It is remarkable that $CO_2$ emissions decreased clearly from 2008 to 2010. The strongest decrease in $CO_2$ emissions occurred during 2008 – 2009 (see table 3). The contraction of Spanish economic, and notably, the decline of the production in sectors of construction ( - 62%), other non-metallic mineral (-55%) , wood and products of wood and cork (- 49%) and financial intermediation ( - 30%) was responsible about 37% of the overall emission reduction for the total period (table 3). The production effect $\left(\Delta C_{prod}\right)$ is the dominant component driving the $CO_2$ emission reduction.

The emission coefficient effect ($\Delta C_{emf}$ ) has also contributed to the reduction in $CO_2$ emissions which derives from the composition in energy mix and the quality of fuel used[22]. As regards the energy mix, it is recognized that the substitution of fossil fuel to renewable energy contributes to decreasing carbon dioxide emissions. This is what happened in Spain during the investigated period. In 2008 the energy mix was 51% oil, 23% gas, 9% coal, and 17% nuclear and renewables; in 2012, these portions had changed to 45%, 20%, 11%, and 24% respectively. Clearly Spain was over-reliant on oil and, the decrease in oil and gas consumption has been compensated by increasing renewables and nuclear. The Spanish Government supported the transition to renewable energy sources such as wind and solar energy through economic incentives such as feed-in tariffs, tax credits and investment grants[23].

The decrease in energy intensity is the fourth component in contributing to the reduction of carbon emissions. Several studies such as Voigt et al[24] attribute variations in energy intensity to evolution in the structure of the economic activity (structural effects) or/and improvements in sectoral energy efficiency (technology effects). In this case, 82% of the decline of energy intensity is attributable to structural effects, reflecting a strong evolution of the weight of services from 55% in 2008 to 60% in 2012 to the detriment of industry (45% - 40%). The remaining (18%) comes from technology effect, thanks to improvements in the sectoral energy efficiency, in particular transport (-14%)[25].

The population effect ($\Delta C_{pop}$) is, on the other hand, contributing to an increase in carbon emissions. This is due to rise in population by 2% between 2008 and 2012.

**Table 3: $CO_2$ emission change and its components (Mt $CO_2$), Spain from 2008 to 2012**

| Period | $\Delta C_{tot}$(%) | $\Delta C_{mix}$(%) | $\Delta C_{emf}$(%) | $\Delta C_{int}$ (%) | $\Delta C_{prod}$(%) | $\Delta C_{pop}$(%) |
|---|---|---|---|---|---|---|
| 2008 - 2009 | - 41. 04 (65) | -18. 70 (30) | 0.24(0) | -11.36(18) | -13.94(22) | 2.73(-4) |
| 2009 -2010 | -17.36(28) | - 26.11 (41) | 7.12(-11) | 1.60(- 3) | -1. 25(2) | 1.29 (-2) |
| 2010-2011 | - 0.21(0) | 25.74 (-41) | - 24.40(39) | 0.12(0) | -2. 64(4) | 0.96(-2) |
| 2011-2012 | - 4. 46(7) | 2.67 (- 4) | - 5.21(8) | 3.75(-6) | -5. 84(9) | 0.17 (0) |
| **Total** | **- 63.06 (100)** | **- 16.41 (26)** | **- 22.26(36)** | **- 5.89(9)** | **- 23.66(37)** | **5. 15(-8)** |

- *United Kingdom*

Decomposition results for the United Kingdom are presented in table 4, from which the following observations are noted:

The overall emission of $CO_2$ has changed from 521.513 Mt$CO_2$ in 2008 to 474.004 Mt$CO_2$ in 2012, which represents a reduction of 47.50 Mt$CO_2$ or 9.11%. As Spain most reduction in emission was recorded during 2008- 2009.

The decomposition underlines that three factors, namely energy intensity effect ($\Delta C_{int}$), energy mix effect ($\Delta C_{mix}$) and production effect ($\Delta C_{prod}$) contributed positively to emission reduction, while the emission coefficient ($\Delta C_{emf}$) and the population effect ($\Delta C_{pop}$) influenced negatively on the carbon emissions.

The energy intensity component has a major influence in UK emissions, which declined emission levels in 2 out from 4 periods. The greatest impact is marked between 2010 and 2011. The assessment of energy intensity reveals that this domination is largely due to the technology effect and accounted for 92% of the reduction. All sectors improved their energy efficiency, industry sector (- 11%) realized the best performance. Otherwise, the structural effect explains just 8% of reduction because of the low rise of the share of services (70% to 71% in the period).

Regarding energy mix**,** the composition of energy use between 2008 and 2012 indicates a decrease in the share of fossil fuels from 92% to 87%, distributed as follows: oil (36% - 35%), natural gas (39% -33%), and coal (17% - 19%). These changes have had a positive repercussion on carbon dioxide emissions.

The production effect is globally negative, in particular from 2008 to 2009. It explains about 35% in total in CO2 emissions. Air transport (- 20%), construction (- 19%), Pulp, paper, paper products, printing and publishing (- 18%) and mining and quarrying (- 18%) have played an essential role on the total result.

As in the case of Spain, the population effect has contributed to the expansion in emissions. This is the consequence of enlargement of about 2 million people or 3% over the entire period.

**Table 4: $CO_2$ emission change and its components (Mt $CO_2$), UK from 2008 to 2012**

| Period | $\Delta C_{tot}$(%) | $\Delta C_{mix}$(%) | $\Delta C_{emf}$(%) | $\Delta C_{int}$(%) | $\Delta C_{prod}$(%) | $\Delta C_{pop}$(%) |
|---|---|---|---|---|---|---|
| 2008-2009 | - 48.28(102) | - 19.68(41) | -2.88(6) | -3.82(8) | - 25.65(54) | 3.76(-8) |
| 2009-2010 | 18.95(- 40) | 4.93 (-10) | 2.01(- 4) | 2.87(-6) | 5.35(-11) | 3.78 (-8) |
| 2010-2011 | - 43.96(93) | -7.04(15) | -7.29(15) | - 37.29 (78) | 3.99 (-8) | 3.67 ( -8) |
| 2011-2012 | 25.77(-54) | 4.68(-10) | 8.60(-18) | 9.46 (-20) | - 0.18(0) | 3.21(-7) |
| **Total** | **- 47.50(100)** | **- 17.11(36)** | **0.45(0)** | **- 28.78(60)** | **-16.48(35)** | **14.42 (-31)** |

- *France*

In France, $CO_2$ emissions were 371.734 Mt $CO_2$ in 2008. This has declined to 333.384 Mt$CO_2$ in 2012, thereby recording a decline of 38.35 Mt$CO_2$ or 10.32%. From table 5, it can be seen that $CO_2$ emissions have dropped in most of the periods under consideration, with the highest drop realized during 2010 - 2011.

Energy intensity effect ($\Delta C_{int}$ ) and energy mix effect($\Delta C_{mix}$) are the principal components responsible for the reduction in $CO_2$, but the product effect ($\Delta C_{prod}$) and the emission coefficient effect ($\Delta C_{emf}$) had also contributed marginally. On the other hand, the population effect ($\Delta C_{pop}$) contributed to rise of carbon dioxide emissions. This is line with those of Spain and United Kingdom.

Variation in the energy intensity had a positive impact upon limiting the growth in carbon emission. This variation in energy intensity is related to modifications in GDP structure (structural effect) and/or changes in sectoral energy efficiency (technology effect). During the investigated period, the share of industry in gross domestic product fades from 30% in 2008 to 28% in 2012. The structural effect accounts for 58% of intensity changes. On the other hand, the analysis of technological effect shows an improvement of energy efficiency in all sectors. The services sector has the greatest improvement rate about of 14% compared to the industry (6%). As a result the technology effect represents 42% of gain in intensity effect.

The second component with a positive influence on $CO_2$ emissions is the energy mix effect. In 2008 consumption of fossil fuel constituted 55% in total final energy, in 2012, it reduced to 53%. The primary energy consumption in France is dominated by nuclear power, which accounts for about 40%. According to the Energy Law n°2005-781 of 13 July 2005[26], called "Law *of program*" the French government intends to maintain its greatness in the energy mix and to support the promotion of low cost renewable energies.

The product effect ($\Delta C_{prod}$) have had a limited impact on the global result. Textiles and textiles products (- 29%), machinery and equipment (- 24%) wood and products of wood and cork (- 23%) and construction (-23%) are the principal drivers of carbon emissions reduction over the studied period.

**Table 5: $CO_2$ emission change and its components (Mt $CO_2$), France from 2008 – 2012**

| Period | $\Delta C_{tot}$(%) | $\Delta C_{mix}$(%) | $\Delta C_{emf}$(%) | $\Delta C_{int}$(%) | $\Delta C_{prod}$(%) | $\Delta C_{pop}$(%) |
|---|---|---|---|---|---|---|
| 2008 -2009 | - 15.11 (39) | 0.71(-2) | 3.65(-10) | - 8.60(22) | - 12.74(33) | 1.87(-5) |
| 2009 - 2010 | 0. 81(-2) | - 5.18(14) | - 5.88(15) | 4.93(-13) | 5.19(-14) | 1.76(-5) |
| 2010 - 2011 | - 18. 63(49) | -12. 93(34) | 6 62(-17) | - 19.49(51) | 5.48(-14) | 1.68(-5) |
| 2011- 2012 | - 5. 42(14) | 2.04(-5) | - 8.17(21) | 0.09(0) | - 0. 91(2) | 1.52(-4) |
| **Total** | **- 38.35(100)** | **- 15. 36(41)** | **- 3.77 (9)** | **- 23.07(60)** | **- 2.99 (8)** | **6. 84(-18)** |

- *Germany*

In 2012, Germany emitted 782.153 $MtCO_2$, which meant a slowdown of 3% compared to its emissions in 2008. The most important decrease was achieved between 2008 and 2009 (table 6).

The reduction in energy intensity was the most dominant factor towards a massive reduction in carbon emissions. About 88% of German energy intensity performance result from improvements of energy efficiency in four sectors and, especially industry (- 30%) and transport industry (- 27%) sectors. The remaining (12%) constitutes the structural effect arising from a reduction in the share of services sector from 64% in 2008 to 62% in 2012 in favour of industry.

The emission coefficient effect ($\Delta C_{emf}$) has a positive impact in three sub- periods indicating an improvement in energy mix and the quality of energy used. The impact is relatively stronger in the period 2008 – 2009 compared to 2009 – 2010 and 2010 – 2011. The German energy policy based on the energy transition supports substitution of fossil fuels and nuclear by renewables, and intensification of energy saving.

The population effect ($\Delta C_{pop}$) has also contributed to the reduction in emission, due to the decrease in population by 2.5% between 2008 and 2012. The decrease in population reduced energy demand and therefore the carbon emission.

Finally the production effect ($\Delta C_{prod}$) contributed to increasing emissions. Contrary to Spain, France and United Kingdom, the value added of construction rises in Germany of 13%. Machinery and equipment also rises of 11%, between 2008 and 2012.

**Table 6: CO2 emission changes and its components (Mt $CO_2$), Germany from 2008 to 2012**

| *Period* | $\Delta C_{tot}$(%) | $\Delta C_{mix}$(%) | $\Delta C_{emf}$(%) | $\Delta C_{int}$(%) | $\Delta C_{prod}$(%) | $\Delta C_{pop}$(%) |
|---|---|---|---|---|---|---|
| 2008 - 2009 | - 61. 09 (229) | - 7.73(29) | - 8.23 (31) | -1.54(6) | - 41. 69 (156) | - 1.90 (7) |
| 2009 - 2010 | 29.63 (-111) | 0.95 (-4) | - 6.66 (25) | 5.85(-22) | 30. 63(-115) | - 1.13(4) |
| 2010 - 2011 | - 21. 24 (80) | 9.54 (-36) | - 0.05 (0) | - 56.83 (213) | 25. 91(-97) | 0.19 (-1) |
| 2011-2012 | 25.99 (-97) | -2.52(9) | 10.27(-38) | 15.44 (-58) | 15.35(-57) | - 12.56 (47) |
| **Total** | **- 26. 71(100)** | **0.24 (- 1)** | **- 4.67(18)** | **- 37.08 (139)** | **30.20(-113)** | **- 15.40(57)** |

## What-if cases

Given the specific features of each country as concerns energy consumption and carbon emissions, it is important to review if the reduction of carbon emissions could be improved if the four countries learnt lessons from one another. Thus what would happen if all countries achieved a similar level of energy intensity, best practice fuel mix, similar emission coefficients?[27] How much additional saving is possible theoretically?

*- Improvements in the energy intensity*

In 2012, the United Kingdom has obtained the lowest consumption per unit production in the sample as a whole. If Spain, France and Germany realized the similar energy intensity as the United Kingdom, *all other things being equa*l, and the total carbon dioxide emission could be reduced by (73 Mt $CO_2$)[28] or 3.99% compared to 2012 level. Spain and Germany would be greater contributors to the emission reduction, covering for 75% of the emission saving (see table 7).

**Table 7: Emission saving potential through improvements in energy intensity**

| Country | Energy intensity level in 2012, Koe/$2005P (1) | $CO_2$ in 2012 ($MtCO_2$) (2) | $(CO_2)'$ ($MtCO_2$) (3) | $CO_2$ saving ($MtCO_2$) (4) = (3) – ( 2) | (%) |
|---|---|---|---|---|---|
| United Kingdom | 0.08 | 474 | 474 | 0 | - |
| France | 0.10 | 333 | 315 | -18 | 25 |
| Germany | 0.10 | 755 | 724 | - 31 | 42 |
| Spain | 0.12 | 266 | 242 | - 24 | 33 |
| **Total** | | **1828** | **1755** | **- 73** | **100** |

- *Improvements in the energy mix*

In France, energy consumption decreased by 5% between 2008 and 2012. Nuclear continued to dominate the energy mix, its share growing from 38.6% to 39.7%. The share of fossil fuel is one of the lowest in the energy mix and continued to decrease from 55% in 2008 to 53% in 2012, thus the French energy mix can be considered as the best practice fuel mix.

Keeping other components constant, if all 4 countries achieved the same energy mix, the decrease in emissions could go up to 203 $MtCO_2$ (or 11.10%) compared to that of 2012. Germany and United Kingdom would represent for about 87% of the saving in carbon emissions (see table 8). Therefore the improvement in the energy mix represents the best source to reduce the carbon emissions and fighting climate change. However, there are practical limitations in achieving this saving potential due to public acceptance of nuclear energy in many countries and the long gestation period in building nuclear plants.

**Table 8: Emission saving potential through improvements in energy mix**

| Country | Share of fossil fuels (%) in primary energy consumption, 2012 (1) | | | $CO_2$ in 2012 ($MtCO_2$) ( 2) | $(CO_2)'$ ($MtCO_2$) ( 3) | $CO_2$ saving ($MtCO_2$) (4) = (3) – (2) | (%) |
|---|---|---|---|---|---|---|---|
| | Oil | Gas | Coal | | | | |
| France | 33 | 16 | 4 | 333 | 333 | 0 | - |
| Spain | 45 | 20 | 11 | 266 | 240 | - 26 | 13 |
| Germany | 35 | 22 | 25 | 755 | 644 | - 111 | 55 |
| United Kingdom | 35 | 33 | 19 | 474 | 408 | - 66 | 32 |
| **Total** | | | | **1828** | **1625** | **- 203** | **100** |

*- Emission coefficient improvements*

According to table 9, Spain offers the best emission coefficients. All other things being equal, if all countries achieved the same emission coefficients as Spain in 2012, the results show that just 17 $MtCO_2$ (or 0.92%) could be saved.

**Table 9: Emission saving potential through improvements in emission coefficient**

| Country | emission coefficient in2012 ($tCO_2/toe$) (1) | | | $CO_2$ in 2012 ($MtCO_2$) (2) | $(CO_2)'$ ($MtCO_2$) (3) | $CO_2$ saving ($MtCO_2$) (4) = (3) - (2) | % |
|---|---|---|---|---|---|---|---|
| | Coal | Gas | Oil | | | | |
| Spain | 3.01 | 2.29 | 2.24 | 266 | 266 | 0 | - |
| UK | 3.12 | 2.56 | 2.47 | 474 | 470 | - 4 | 23 |
| France | 3.44 | 2.20 | 2.52 | 333 | 328 | - 5 | 30 |
| Germany | 3.84 | 2.34 | 2.37 | 755 | 747 | - 8 | 47 |
| **Total** | | | | **1828** | **1811** | **- 17** | **100** |

*- Aggregate emission saving potential*

If all countries achieved the performance level in the energy intensity as United Kingdom, the same energy mix as France, and the emission coefficients of Spain, the global emission saving potential would reach 293 $MtCO_2$, which represents a 16% reduction compared to the 2012 level (see table 10). Germany would account for about 51% of the saving in carbon emissions.

**Table 10: Aggregate emission saving potential**

| Country | $CO_2$ in 2012 ($MtCO_2$) (1) | $\Delta CO_2'$ ($MtCO_2$) (2) | $CO_2$ saving ($Mt\ CO_2$) (3) = (2) - (1) | % |
|---|---|---|---|---|
| Spain | 266 | 216 | - 50 | 17 |
| France | 333 | 310 | - 23 | 8 |
| UK | 474 | 404 | - 70 | 24 |
| Germany | 755 | 605 | - 150 | 51 |
| **Total** | **1828** | **1535** | **- 293** | **100** |

## CONCLUSIONS AND POLICY IMPLICATIONS.

The decomposition method is employed to investigate the change of $CO_2$ emissions between the period of economic growth period (2004 – 2008) and the period of crisis (2008 – 2012) in four European Union countries. The method that we used associates the Kaya identity and IDA method to identify, quantify and compare the components that contributed to the reduction in $CO_2$ emission**.** The quantity of reduction in $CO_2$ emissions was decomposed using the additive Logarithmic mean divisa and five factors namely energy intensity, energy mix, emission coefficient, GDP per capita, and population were considered.

The total decomposition analysis revealed interesting finding regarding the evolution of $CO_2$ emissions:

Carbon dioxide emissions in four countries of EU (France, Germany, Spain and the United Kingdom) decreased both during economic growth and economic crisis. The decrease was most important (175.63 $MtCO_2$) during the crisis period compared with that during the growth period (80 $MtCO_2$). This means that the economic slowdown contributes to the climate protection.

The reduction in energy intensity was the most important component in the reduction of $CO_2$ emissions in the two periods 2004 – 2008 and 2008 – 2012. But energy intensity effect deteriorated during the crisis period. This may arise as the focus shifts to maintaining economic activities rather than improving energy efficiency. As a result policies aiming to increase energy efficiency in all sectors of economy are necessary during the downturn.

On the other hand, if the economies maintained the same level of economic activity as during 2004-2008, the outcomes would have been much different and the slow rate of intensity reduction during this period would not have generated the emission reduction achieved. This implies that EU economies have got a windfall gain in CO2 reduction that is not a result of any policy design.

Energy intensity plays an important role in reducing the CO2 emission in all countries. The analysis suggests that Germany and UK achieved better energy efficiency through technical improvements – which offers the potential for Spain and France to learn some lessons for improving energy efficiency. While structural change can also reduce energy intensity by shifting the economic activities towards the service sector, this effect was less important in these countries. Technology driven and service driven energy intensity reduction potential perhaps still remains in all European countries and could offer opportunities, particularly through adoption of green growth pathways.

For the two investigated periods, energy mix effect contributed to the smoothing in $CO_2$ emissions, however the impact is relatively low between 2004 and 2008. Consequently, the promotion of renewable sources should be privileged during the time of economic expansion.

The production effect is contrasted; it is positive and contributed to the growth in $CO_2$ emission between 2004 and 2008 and negative and led to the contraction in carbon emission over the period 2008 – 2012. These findings confirm the positive relation between economic activity and carbon emissions, and globally greenhouse gases emissions.

Finally, the population effect was the only component which contributes to $CO_2$ emissions increases in both periods, resulting of the increase in population by 2% from 2004 to 2008 and 1% from 2008 to 2012. Consequently, given that the overall population is rising due to migration, the countries need to focus on containing the adverse effect of population on CO2 emission through a lower carbon footprint.

The what-if analysis offers the opportunity for learning from one another through successful experiences of each country involving further improvements in energy intensity, energy mix and carbon emission coefficient. The analysis combining these three scenarios shows that the sample countries as a whole could save 16% of $CO_2$ emission compared to the 2012 level. Germany would reduce 20% of $CO_2$ emission. Spain and United Kingdom would gain 19%

and 15%, respectively. The saving would be less important in France, accounting for about 6% of $CO_2$ emission compared to 2012 value. The scenario analysis highlights the improvement in energy mix, implying a movement in the direction of less carbon intensive fuels, as the most effective in $CO_2$ emission reduction, it would responsible for 69% of overall saving. (See table 8).

As a result, a policy combining an energy intensity reduction and a migration to low carbon energy is necessary to assure an effective accomplishment of the carbon dioxide emission reduction objectives within the context of international climate change agreements, like Paris Agreement.

The study clearly points the effect of energy intensity as a key component of carbon emission reduction, which benefits all examined countries for the two contrasted periods. In terms of directions for future research, some interesting extensions, exploring the determinants of environmental and social sectors would be interesting.

## *NOTES*

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[19] More detailed information on the building of the WIOTs, see:

- E. Dietzenbacher, B.Los, R. Stehrer, M. Timmer, G.J. deVries. "The construction of world input–output tables in the WIOD project". *Economic System Research,* Vol.25 ( 2013), pp. 71 – 127
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[20] The WIOD regroups the data for all European Union countries and 15 major economies in the world, covering the years 2000 – 2014 and comprising 35 sectors, according to the NACE classification. This project has been financed by the European Commission as part of the 7th Framework Programme, Theme 8: Socio-Economic Sciences and Humanities. Grant Agreement n° 225 281. http://www.wiod.org.

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[26] Loi n° 2005-781 du 13 juillet 2005 de programme fixant les orientations de la politique énergétique. Available here : https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000813253

[27] We selected only three components to order to limit the number of scenarios

[28] $CO_2$ is obtained from equation ( 2) – as given in the text:

$$C = \sum_{ij} C_{ij} = \sum_{ij} P_i \times \frac{Y_i}{P_i} \times \frac{E_i}{Y_i} \times \frac{E_{ij}}{E_i} \times \frac{CO_{2ij}}{E_{ij}}$$