Universidade de Aveiro Departamento de Economia, Gestão e Engenharia Industrial
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Essays on the determinants of energy related CO2 emissions

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Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Sistemas Energéticos e Alterações Climáticas, realizada sob sua exclusiva responsabilidade.

o júri

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Agradecimentos

Primeiro que tudo, os meus sinceros agradecimentos a todos os que de uma forma ou de outra tornaram possível esta investigação que resultou no desenvolvimento de um grupo de artigos científicos.

Aos colegas do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro, Doutora Margarita Alves-Robaina, Doutor António Carrizo Moreira e Mestre Jorge Humberto Mota, agradeço o entusiasmo e motivação para a elaboração dum conjunto significativo de trabalhos que integra esta tese de doutoramento. As propostas e ideias discutidas, a colaboração na preparação dos artigos bem como os incentivos demonstrados ao longo do tempo foram para mim um incentivo para não desistir, independentemente das adversidades enfrentadas.

Quero estender os meus agradecimentos aos editores e revisores do Energy Journal, Applied Energy Journal e Renewable and Sustainable Energy Reviews pela troca de ideias, cujos desenvolvimentos e propostas de revisão deram contributos para esta tese tendo resultado em artigos já publicados e aceites para publicação e que integram este trabalho de doutoramento.

Estou também grato à minha família, especialmente aos meus filhos João Filipe e Ana Mafalda e também aos meus amigos, agradeço-lhes pela sua compreensão, afeto e estabilidade proporcionada ao longo deste trabalho de investigação.

palavras-chave

Intensidade das emissões de CO2, intensidade da energia, intensidade dos combustíveis fósseis, análise de decomposição, análise de convergência, Funções Impulso-resposta, painel corrigido dos erros padrão, painel com analise da cointegração

Resumo

De uma forma geral, entre os fatores mais apontados para o crescimento das emissões de Gases de Efeito de Estufa (GEE), estão o crescimento económico e o crescimento das necessidades energéticas. Para identificar os determinantes das emissões de GEE, esta dissertação propôs e desenvolveu uma nova análise que liga a intensidade das emissões aos seus principais responsáveis.

No primeiro ensaio, foi utilizada a técnica da 'decomposição total' para examinar a intensidade das emissões de CO2 e os seus componentes, considerando 36 setores económicos e o período entre 1996-2009 em Portugal. A indústria (em particular cinco setores industriais) contribui fortemente para os efeitos da variação da intensidade de CO2. Conclui-se, entre outros, que a intensidade das emissões reage mais significativamente a choques no peso dos combustíveis fósseis no consumo total da energia, comparativamente a choques em outras variáveis.

No segundo ensaio, conduziu-se uma análise para 16 sectores industriais (Grupo A) e para o grupo dos cinco setores industriais mais poluentes (Grupo B), baseada no estudo da convergência para a intensidade das emissões e para os seus principais determinantes, bem como numa análise econométrica. Concluiu-se que existe convergência sigma para todos os efeitos, à exceção da intensidade dos combustíveis fósseis, enquanto a convergência gama se verificou para todos os efeitos com a exceção das emissões de CO2 por combustível fóssil e intensidade de combustível fóssil, no Grupo B. A partir da abordagem econométrica, concluiu-se que as variáveis consideradas têm uma importância significativa na explicação da intensidade das emissões de CO2.

No terceiro ensaio foi analisada a indústria do turismo em Portugal durante o período de 1996-2009, em particular para dois grupos de subsetores que afetam a intensidade das emissões de CO2. A decomposição generalizada de variância e as funções de impulso-resposta apontaram uma causalidade bidirecional entre intensidade de emissões e intensidade de energia para setores que afetam o turismo mais diretamente. O efeito da intensidade de emissões é positivo na intensidade da energia e o efeito da intensidade da energia na intensidade das emissões é negativo. A percentagem de combustíveis fósseis utilizados reage positivamente à estrutura económica e à intensidade do carbono, isto é, quando um setor ganha importância económica, tende a usar mais combustível fóssil e quando aumenta a intensidade do carbono, no futuro, o uso de combustíveis fósseis pode aumentar. Por outro lado, choques positivos na intensidade de energia tendem a reduzir a percentagem de combustíveis fósseis utilizados.

O objectivo do quarto ensaio é identificar os efeitos que contribuem para a intensidade dos gases de estufa na agricultura, bem como a sua evolução, Para isso, utilizou-se a técnica de 'decomposição total' no período 1995-2008 para um grupo de países europeus. Ficou demonstrado que o uso de nitrogénio por área cultivada é um fator importante nas emissões e naqueles países cuja produtividade do trabalho aumenta, a intensidade das emissões tende a aumentar. O resultado implica que o caminho para reduzir as emissões na agricultura pode passar por uma melhor formação dos trabalhadores ligados à agricultura para melhorar a sua produtividade, o que pode conduzir a uma menor necessidade e uso de nitrogénio.

O objectivo do último ensaio é examinar a causalidade de longo e curto prazo da quota de fontes renováveis na relação ambiental entre o desenvolvimento económico (PIB) e as emissões de CO2 por KWh de eletricidade produzida num conjunto de 20 países Europeus no período de 2001-2010. Esta nova abordagem sugere que a quota de fontes renováveis na produção de eletricidade é um determinante importante para explicar as diferenças na relação Rendimento-emissões de CO2 por Kwh nos países Europeus e que as evidências empíricas suportam a relação ambiental da curva de Kuznets.

As contribuições desta dissertação para os assuntos relacionados com as emissões de CO2 a um nível setorial são as seguintes: primeiro, oferece uma nova abordagem econométrica da decomposição para analisar a evolução das emissões de CO2 que pode servir como um ponto de partida para futuras investigações. Segundo, apresenta uma abordagem híbrida, juntando a matemática e a economia de energia e um modelo econométrico para relacionar as emissões de CO2 na Europa e, em particular, em Portugal com base em teorias económicas. Terceiro, contribui para explicar as mudanças nas emissões de CO2 em setores económicos importantes para Portugal, conjugando considerações normativas aberta e explicitamente, com implicações políticas no comprometimento europeu, ao nível energético-ambiental.

Keywords

CO2 emissions intensity, energy intensity, fossil fuel intensity, decomposition analysis, convergence analysis, Impulse Response Function, panel corrected standard errors estimator, panel cointegration analysis

Abstract

Overall, amongst the most mentioned factors for Greenhouse Gases (GHG) growth are the economic growth and the energy demand growth. To assess the determinants GHG emissions, this thesis proposed and developed a new analysis which links the emissions intensity to its main driving factors.

In the first essay, we used the 'complete decomposition' technique to examine CO2 emissions intensity and its components, considering 36 economic sectors and the 1996-2009 periods in Portugal. The industry (in particular 5 industrial sectors) is contributing largely to the effects of variation of CO2 emissions intensity. We concluded, among others, the emissions intensity reacts more significantly to shocks in the weight of fossil fuels in total energy consumption compared to shocks in other variables.

In the second essay, we conducted an analysis for 16 industrial sectors (Group A) and for the group of the 5 most polluting manufacturing sectors (Group B) based on the convergence examination for emissions intensity and its main drivers, as well as on an econometric analysis. We concluded that there is sigma convergence for all the effects with exception to the fossil fuel intensity, while gamma convergence was verified for all the effects, with exception of CO2 emissions by fossil fuel and fossil fuel intensity in Group B. From the econometric approach we concluded that the considered variables have a significant importance in explaining CO2 emissions and CO2 emissions intensity.

In the third essay, the Tourism Industry in Portugal over 1996-2009 period was examined, specifically two groups of subsectors that affect the impacts on CO2 emissions intensity. The generalized variance decomposition and the impulse response functions pointed to sectors that affect tourism more directly, i. e. a bidirectional causality between the intensity of emissions and energy intensity. The effect of intensity of emissions is positive on energy intensity, and the effect of energy intensity on emissions intensity is negative. The percentage of fossil fuels used reacts positively to the economic structure and to carbon intensity, i. e., the more the economic importance of the sector, the more it uses fossil fuels, and when it raises its carbon intensity, in the future the use of fossil fuel may rise. On the other hand, positive shocks on energy intensity tend to reduce the percentage of fossil fuels used.

In fourth essay, we conducted an analysis to identify the effects that contribute to the intensity of GHG emissions (EI) in agriculture as well as their development. With that aim, we used the 'complete decomposition' technique in the 1995-2008 periods, for a set of European countries. It is shown that the use of Nitrogen per cultivated area is an important factor of emissions and in those countries where labour productivity increases (the inverse of average labour productivity in agriculture decreases), emissions intensity tends to decrease. These results imply that the way to reduce emissions in agriculture would be to provide better training of agricultural workers to increase their productivity, which would lead to a less need for energy and use of Nitrogen.

The purpose of the last essay is to examine the long and short-run causality of the share of renewable sources on the environmental relation CO2 per KWh electricity generation- real GDP for 20 European countries over the 2001-2010 periods. It is important to analyze how the percentage of renewable energy used for electricity production affects the relationship between economic growth and emissions from this sector. The study of these relationships is important from the point of view of environmental and energy policy as it gives us information on the costs in terms of economic growth, on the application of restrictive levels of emissions and also on the effects of the policies concerning the use of renewable energy in the electricity sector (see for instance European Commission Directive 2001/77/EC, [4]).

For that purpose, in this study we use Cointegration Analysis on the set of cross-country panel data between CO_2 emissions from electricity generation (CO2 kWh), economic growth (GDP) and the share of renewable energy for 20 European countries. We estimated the long–run equilibrium to validate the EKC with a new approach specification.

Additionally, we have implemented the Innovative Accounting Approach (IAA) that includes Forecast Error Variance Decomposition and Impulse Response Functions (IRFs), applied to those variables. This can allow us, for example, to know (i) how CO2 kWh responds to an impulse in GDP and (ii) how CO2 kWh responds to an impulse in the share of renewable sources.

The contributions of this thesis to the energy-related CO2 emissions at sectorial level are threefold: First, it provides a new econometric decomposition approach for analysing and developing CO2 emissions in collaboration with science societies that can serve as a starting point for future research approaches. Second, it presents a hybrid energy-economy mathematic and econometric model which relates CO2 emissions in Portugal based on economic theory. Third, it contributes to explain the change of CO2 emissions in important economic sectors in Europe, in particular in Portugal, taking normative considerations into account more openly and explicitly, with political implications at energy-environment level within the European commitment.

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Chapter 1

1. Introduction

The massive development of modern societies has led to increasing power consumption on a global scale, as a result, the rational use of energy has become a key measure for the global economies and socio-economic development in a scenario of growing globalization.

Today's global warming is unequivocal, and most of the increase in global average temperature since the mid-50s is due to anthropogenic emissions. The emissions of air pollutants are closely related to the same origin (fossil fuel combustion), interacting physically and chemically in the atmosphere, causing a variety of environmental impacts at a local, regional and global scale.

In China, the world's most populous country, the average emissions of CO2 increased by 9% to7.2 tonnes per capita. China is now within the range of 6 to 19 tonnes per capita emissions. The United States remain one of the largest emitters of CO2, with 17.3 tonnes per capita, despite a decline due to the recession in 2008-2009, when oil prices were high and and the use of natural gas increased. In the European Union, CO2 emissions dropped by 3% to 7.5 tonnes per capita, according the report 'Long-Trend in global CO2 emissions', by the European Commission's Joint Research Centre (JRC) and the Netherlands Environmental Assessment Agency [1].

According to the IPCC report [2] the total annual emissions of GHG have increased steadily during the last three decades at an average rate of 1.6% a year, especially carbon dioxide (CO2) emissions which in that period represented a growth rate of nearly 1.9% a year, mostly because of fossil fuel consumption. The energy consumption of fossil fuels (such as coal, oil and natural gas) as the main European and worldwide energy production sources, led to an increase of greenhouse gas emissions and pollutants including carbon dioxide (CO2).

While for much of the twentieth century, greenhouse gases emissions (GHG) were neglected, their effects resulted in constant climate changes. At the beginning of the 90s this problem gathered the world's attention because of the global warming, converging in 1997 to the preparation of the Kyoto Protocol, whose measures among others sought for a commitment to force a drastic reduction in GHG emissions for all countries that approved it.

1.1. Motivation

The greenhouse gases emissions, (GHG) particularly the dioxide carbon emissions (CO2) of an economy, are directly correlated with energy consumption (particularly with fossil fuels consumption). Power consumption is determined by the aggregated consumption of the various sectors of the economy, and by the size and structure reflected in the economy's added-value. All this, combined with the various ways of producing energy, from conventional fossil fuels to the newer renewable sources, is a complex chain of driving determinants that may explain the bigger or the smaller variability of GHG emissions.

Today CO2 emissions account for around 75% of global GHG emissions. While global CO2 emissions decreased in 2009 (by 1.5%) due to the economic slowdown, trends varied depending on the country's context: in developing countries (non-Annex I, see Section 3.3) emissions continued to grow by 3%, led by China and India, while emissions from developed countries fell sharply (by 6.5%), IEA [3]. Most CO2 emissions come from energy production, with fossil fuel combustion representing two-thirds of global CO2 emissions. Indications of trends for 2010 suggest that energy-related CO2 emissions will rebound to reach their highest level ever at 30.6 gigatonnes (GtCO2), a 5% increase from the previous record in 2008.

Under the OECD *Environmental Outlook*, [4] demand for energy is projected to increase by 80% between 2010 and 2050. Transport emissions are projected to double between 2010 and 2050, due in part to a strong increase in the demand for cars in developing countries, and to the growth in aviation. However, CO2 emissions from land use, land-use change and forestry (LULUCF), driven in the last 20 years by the rapid conversion of forests to grassland and cropland in tropical regions, are expected to decline over time and even become a net sink of emissions in the 2040-2050, timeframe in OECD countries by the European Commission’s Joint Research Centre (JRC) and the Netherlands Environmental Assessment Agency [5].

The carbon intensity of gross world product (GWP), defined as the ratio *Fossil* Fuel/GDP, provides a measure of the CO2 emissions required to produce a unit of economic activity at a global scale. In the 3 decades before 2000, the carbon intensity of GDP declined from 0.35 kilograms of carbon (kgC)/dollar in 1970 to 0.24 kgC/dollar in 2000. This trend represents a decrease (improvement) of 1.3% per year.

Since 2000, however, the carbon intensity of GDP stopped decreasing and has increased (deteriorated) at 0.3% per year, according Raupach MR, Marland G, Ciais P, Le Que´re´ C, Canadell JG, Klepper G, and Field CB, [6].

Continuous improvements in the carbon intensity of the world economy are postulated in practically all scenarios for future emissions. The effect of these projected improvements is to hold the rate of global emissions growth below the rate of global economic growth. The recent combination of rapidly increasing emissions and deteriorating carbon intensity of GDP amplifies the challenge of stabilizing atmospheric CO2, according Nakicenovic N and Swart S. [7].

It is then of utmost importance to focus on the analysis and evaluation of the mitigation of emissions issue, and how the emission intensity drivers or explanatory determinants may contribute to later reflections on the instruments, measures and targets achieved for local domestic, regional or supranational economies.

It is important to analyze the effects, especially CO2 emissions of the driving determinants, on how both sectorial emissions intensity and pollutant gases developed over time. In the European Union (EU15) the energy-related Carbon Dioxide emissions, produced by the manufacturing sector, changed in the period 1990-2010 between 37% and 30%. Both the direct effect (fuel driven) and the indirect effect (due to industrial electricity consumption) contributed to these emissions. At worldwide level, the manufacturing sector accounted for 26% of the global energy use and for 18.5% of global CO2 emissions in 2010, (European Environmental Agency, [8]).

When we realize that most of the energy used comes from fossil fuels (coal, oil and natural gas), which in percentage is far greater in the manufacturing and energy sectors than the average for the Portuguese economy, this issue becomes highly relevant and highlights the relative high value of intensity of emissions in these sectors. For example, in 2009 this percentage was of 95.3% for the manufacturing and energy sectors compared with 82.4% of the average of the economy. However, this path is changing with an increasing use of renewable sources of energy, in particular, the expansion of windmills, [8]. The differences in the emissions intensity at sectorial level in Portuguese subsectors show the important disparities between the energy mix in the different activities affected by nature in the long-term differences among the fossil fuel intensity consumption.

For instance, the tourism industry has dramatically changed in the past decade, combining and accelerating the environmental degradation with a steadily increasing energy demand, which is raising the concern of policy makers regarding the adverse effects of energy use. More recently, the impact of tourism on environment and climate changes has attracted the attention of international and national institutions. According to the World Travel and Tourism Council [9], the travel and tourism industry contributed with 7.8% of the total EU GDP and created over 8.4% of the total employment.

Although tourism makes a relevant contribution to the economy and involves the transportation and hosting of tourism consumers, it depends on a wide range of service infrastructures such as ports, airports, roads, railways and telecommunications, which heavily contribute to the consumption of energy and to the emission of carbon dioxide. These tourism activities motivated the research concerning the relationships between the energy consumption, share of fossil fuel consumption and dioxide emissions.

Agriculture, another important economic sector, has been responsible, in the last two decades, for about 10% of the total annual emissions of greenhouse gases emitted in Europe, [8]). The agricultural sector is not included in the EU Trading Scheme as part of the negotiations of carbon credits. Nevertheless, countries are concerned about adopting other environmental policies that aim at reducing GHG emissions in the agricultural sector, thereby contributing to the achievement of Kyoto Protocol goals. In order to design a policy to address this issue, it is important to analyze how the intensity of Greenhouse Gases emissions (GHG emissions/ agricultural value added) has evolved and what factors influence the variation of that intensity.

In this research, the decomposition analysis techniques and the convergence analysis techniques associated to or supplemented with econometric techniques (as described in the contributions of the methodology, in subsection 12.4 of this chapter) were used to analyze and estimate the relationship between emissions and their determinants. These approaches will allow the identification of causality and main drivers' relationships as well as their variability and convergence, thus contributing to a plausible explanation to changes in emissions and pollutants. Hereby being enhanced as an evolution and a convergence or divergence relationship and over time a causality at the sectorial level of economy.

1.2. Context for the research

1.2.1. Kyoto Protocol, policies and measures for climate changes

In order to face the climate changes, the Kyoto Protocol has been established as the main objective by the European Union, signed in 1997 under the United Nations Convention on Climate Change (United Nations Framework Convention on Climate Change, UNFCCC). This Protocol had to be ratified technically in 2005 by the governments of Russia, Japan, Canada and New Zealand that jointly accounted 55% of global CO2 emissions, according to the base year of 1990.

One of the fundamental principles arising from the United Nations Convention on Climate Changes which sustains the Protocol is the unilateral agreement of ‘’common differentiated responsibility''. It is the commitment where developed countries take the lead in mitigating emissions compared to developing countries, recognizing with this differentiation that industrialized countries are responsible for most of the current percentage of greenhouse gases in the atmosphere. However, at the same time they have the financial and technological capacity to decrease emissions and therefore reduce climate changes.

For all countries in the UNFCCC, there is a set of listed obligations, the most important being: (i) preparation of inventories of greenhouse gas emissions, (ii) formulation and implementation of national mitigation programs, (iii) encouragement to technological innovation in production processes and (iv) investments in environmental education and civic awareness towards Global Climate Changes.

Annually, deviations are analyzed and discussed so that corrective mechanisms can be proposed in order to control GHG emissions and meet the agreed variable targets between the industrialized countries that signed the protocol. The effort to diminish global GHG emissions was set to at least 5% below the level observed in 1990 for the period of 2008-2012, seeing as some countries could increase their emissions, while others compromised in reducing them. That cut in the emissions could be achieved with the use of flexible measures such as: (i) carbon trading scheme, (ii) joint implementation and (iii) clean development mechanisms.

The international carbon trading scheme was created with the purpose of allowing a country (company) ''Annex I'', to sell a portion of its emission share to another country (company) ''Annex I''. The main mechanism of trading emissions currently in use is the EU ETS, in force since 2005. In the initial phases, a limited number of sectors were included: energy activities (combustion, refineries, coke ovens); iron and steel (production and processing); mineral industries (cement, glass, ceramic products); and pulp and paper, (see report Environmental Portuguese Agency, 2008). This was followed by a second stage, Phase II, starting in 2008 and ending in 2012, linked to the first period after the Kyoto Protocol ratification. In this second stage, in the CO2 emission system, the following sectors were covered: the petrochemical industry, ammonia, aluminium and aviation,[10] Currently we are in the last stage, Phase III (started in 2013 and ending in 2020), in which Member States of the EU ETS will have greater flexibility in excluding small production facilities that emit up to 25.000 tons of CO_2 in a period of three years from the system. It is also expected to cover 6% more of the emission sources than in Phase II, EU [11]

The measures of joint implementation (JI) allow countries (companies) ''Annex I'' to implement projects based on clean technologies within the territory of other countries ''Annex I''. For this mechanism, the emission reduction (with respect to the base line in the countries where the project originated), can be used to reduce the emissions which the target country compromised to, thus, its purpose is mainly: (i) to enhance the option of developed countries to fund projects for GHG emission reduction in other countries, (ii) to work as an element of exploitation of new energy sources, (iii) to be a first step to the establishment of an international system of tradable GHG shares between countries which compromised to reach emission targets.

The projects of clean development mechanisms allow countries (companies) from "Annex I" to fund projects based on clean technologies in "non Annex I" countries. If the emission reduction is additional, it may be excluded from the "Annex I" country (company) objective, responsible for the implementation of the project.

Portugal signed and ratified the Kyoto Protocol in 1998 and 2002 respectively. It was then settled, according to the sharing agreement, that Portugal should bound its emissions in that period 2008-2012 to no more than 27%, comparatively to the reference year 1990, which in absolute terms means the amount of GHG emissions could not exceed the value of 382 million tons of CO_2 during the regulatory period.

According to the information presented in Table 1 which shows the emission reduction targets for the EU countries, including 12 countries that joined the EU after the ratification, all except Cyprus and Malta have individual emission targets under agreement. The common objective of a collective reduction in 8% emissions is guaranteed by the contribution of each member of the EU-15.

Table 1 - Burden-sharing target of the EU – Target 2008-2012

EU 15 – Countries	Emissions allowed above 1990 level (%)	EU – Others Countries	Emissions allowed above 1990 level (%)
Austria	-13	Bulgaria	-8
Belgium	-7,5	Slovakia	-8
Denmark	-21	Slovenia	-8
Finland	0	Estonia	-8
France	0	Hungary	-6
Germany	-21	Latvia	-8
Greece	25	Lithuania	-8
Ireland	13	Poland	-6
Italy	-6,5	Czech Republic	-8
Luxembourg	-28	Romania	-8
Netherlands	-6		
Portugal	27		
Spain	15		
Sweden	4		
UK	-12,5		
EU 15 Kyoto target	-8	EU Kyoto target	-8

Source: UNFCC (2008)

In order to fulfill the targets of the Kyoto Protocol, Portugal drew the following tools for mitigating CO2 emissions: (i) The National Climate Change Program (NCCP), where a group of measures and internal policies at various economic sector levels are developed in order to mitigate GHG emissions, (ii) The National Plan for Attributing Emission Licenses (PNALE) applicable to an identified group of GHG emitting facilities listed in the EU ETS – European Union Emission Trading System; (iii) The Portuguese Carbon Fund, aimed at developing activities for achieving GHG emission credits through the investment in flexibility mechanisms of the Kyoto Protocol, specifically, joint implementation or projects for clean development mechanisms.

Being a significant element for public policy and State Members economies, the Energy-Climate Package sets the main targets to achieve in 2020 as follows:

(i) A change in the current system of EU ETS, in particular regarding the definition of emission bounds for the various sectors at a European level, integration of other greenhouse gases other than CO2, and an annual reduction in order to achieve the goal of a global reduction of 20% comparatively to 2005 emissions;

(ii) A target to diminish emissions of greenhouse gases (GHG) for the sectors not covered by the emissions trading scheme (construction, transport, wastes), so that all contribute jointly for Portugal to achieve a limit of +1% growth in GHG emissions compared to 2005;

(iii) Legally binding targets to increase the share of renewable energy in the energy mix, reflecting the needs and potential of each country, with Portugal aiming at 31% energy coming from renewable sources, including 10% bio fuel in transports;

(iv) New rules on carbon capture, storage and environmental subsidies.

Regarding the supranational goals, stands the importance of meeting the objectives of the global Climate Changes and the exposure of the European countries to the international volatility of oil prices, since according to the report from the IEA [8] near 85% of the oil consumed in the EU is imported.

To achieve the efficiency objectives set by the European Commission, this supranational entity seeks to establish a group of measures or guidelines in order to develop improvements in energy performance. It also seeks higher standards for the labeling of equipment, use of more efficient vehicles with incentives for the use of public transport, penalty fees for the inefficient use of energy, and incentives to promote public policies that support the use of renewable energy sources and the consequent increase in efficiency with the use of bio fuels.

There is consensus that concerted efforts of the EU to diminish its emissions are prime focus in the energy sectors, since over 80% of GHG emissions in the EU are due to activities in these sectors. To identify the most efficient policies and measures to reduce GHG emissions, in 2009 the European Commission launched the European Climate Change Programme, EU [11].

In the first program, there is a set of policies and measures to diminish GHG emissions based on cost-benefits that must be highlighted: (i) Emissions Trading, (ii) Joint Implementation (JI), (iii) Clean Development Mechanism (CDM), and (iv) Demand and supply of energy. In the second program, the outcome was mainly of transversal policies such as the creation of a system of emission trading licenses in the EU, namely the EU ETS.

Portugal recently approved (in 2008 and 2010) an important plan to meet the 2020 targets, designated National Strategy for Energy. This Strategy set the most relevant policies to the key area of energy with the fundamental operating principles: (i) Competitiveness, growth and financial independence, (ii) Investment in renewable energy resources, (iii) Promotion of energy efficiency, (iv) Insurance of the security of the energy supply, (v) Promotion of the sustainability of the National Strategy for Energy 2020.

In the area of renewable energies and bio fuels, the Portuguese Plan sets the following targets for 2020, (see Resolution of Board of Ministers nº29/2010 de 15 de April) [12]:

(i) Hydropower: 8600 MW of installed capacity by 2020; implementation of an action plan for small hydro for the licensing of 250 MW and the development of reversible installed capacity;

(ii) Wind energy: installation of 2000 MW already allocated in 2010, with a target of 8500 MW in 2020;

(iii) Solar: Installation of 1500 MW by 2020; review and update of the Micro-generation Program and introduction of a new Mini-generation Program; inclusion of a new industrial ''Cluster'' based on concentrated solar energy for promotion projects and solar thermal demonstration;

(iv) Biomass: effective installation of 250 MW already allocated; introduction of flexible mechanisms for the implementation of projects to promote the production of forest biomass;

(v) Waves, geothermal and hydrogen: implementation of the pilot zone for wave energy with an installation capacity of 250 MW up to 2020; promotion of a new range in the geothermal field, also with an installed capacity of 2050 MW in 2020 exploiting the hydrogen potential;

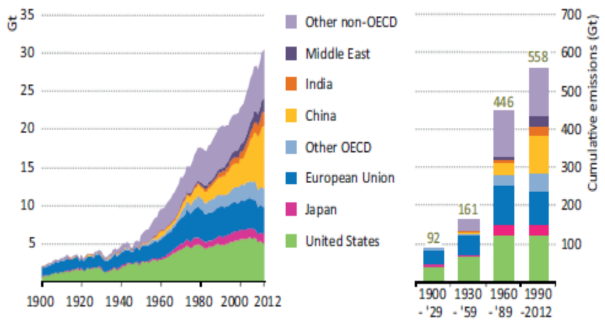
(vi) Bio fuels and Biogas: implementation of European directives and best practices associated with bio fuels; exploration of the potential of the biogas from the anaerobic digestion of wastes.

Summing up, at a European level, with the specificities for the Portuguese case, the priorities and requirements regarding the efficient use of resources are related to the commitment to reduce GHG emissions. As previously described, there are goals, instruments, national and supranational measures that can mitigate emissions with the definition of targets. For these objectives, targets, instruments, measures and policies to be achieved, a greater effort is necessary to control the environment in all energy sectors. The growing demands for environmental and climate changes control may however be seen as an opportunity to adapt and innovate, finding new solutions that are more environmentally and economically efficient. One of the relevant issues that arises is to what extent the fossil reserves will be able to meet the growth in energy consumption, particularly in the energy-intensive sectors and in what way the climate and environmental changes will be felt locally, regionally, nationally and globally due to their use.

1.2.2. The Energy- related CO2 emissions

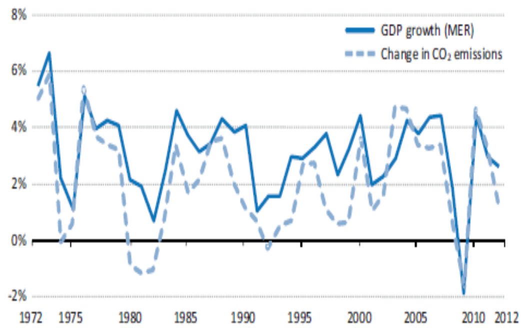
Since 1990, the reference year for the Kyoto commitment, the levels of emissions of greenhouse gases geographically have changed significantly in some countries. In 1990, OECD countries were responsible for most of the emissions, while in 2012 they were responsible for about 40% of the emissions related specifically to the global energy consumed (Figure 1.1).

Figure 1.1 – Energy-related CO2 emissions by country



Source: Redrawing the energy-climate map, International Energy Agency, 2013

Figure 1.2 – Growth in global GDP and in energy-related CO2 emissions

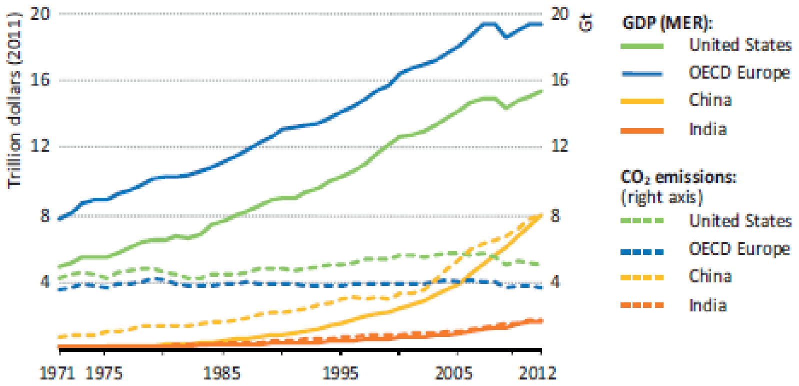


Source: Redrawing the energy-climate map, International Energy Agency, 2013

Also, according to this graph there is a drop of approximately55% in emissions in 2000, while the primary energy demand reaches 53% of global GDP measured in purchasing power parity terms. It is essential to highlight the importance of the weight of China in the remaining group of countries belonging to the BRIC (including Russia, Brazil, India and South Africa) whose emissions have high levels, reaching, in 2012, an emission level which was greater than the sum of emissions from all remaining members. Regarding India, in 2012 its emissions strengthened its position making it the third largest country emitter. Meanwhile, developing countries present growing emission level rates in the last years analyzed, due to being countries which export contents with significant greenhouse gases.

According to Figure 1.2, IEA [13], the progress and trends in the behaviour of CO2 emissions is closely related to the levels of growth of global economies, whose descendent trend in the last 40 years is closely connected to the oil price crisis in the late 70s and more recently to the financial crisis and consequent economic recession of the global economies. From the analysis of the progress between the GDP and CO2 trend, it is observed that the levels of GDP are higher than the emission levels for the graphically analysed years, especially in the last decade 2000-2010. At this time some behaviours were close in the uptrend and downtrend for both, exceeding CO2 and GDP levels in 2002-2005, the years before the Kyoto Protocol entered into force (2005). Those facts in this last decade are associated, on one hand, to the growth of global energy demand and on the other hand, interconnected with the fossil fuel demand growth in developing countries.

Figure 1.3 – GDP and energy-related CO2 emissions in selected countries



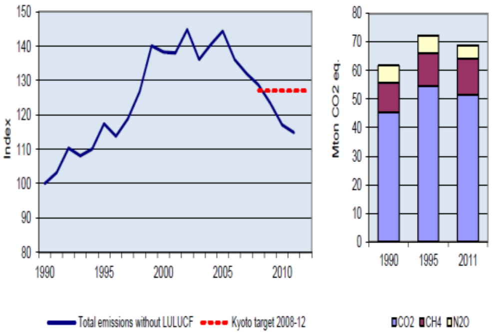
Note: MER = market exchange rate.

Source: Redrawing the energy-climate map, International Energy Agency, 2013

Emphasizing what was previously mentioned, [13], Figure 1.3 shows the levels of emissions and economies growth, where a significant difference over time between GDP and CO2 emissions can be observed. After observing the graph, one can say the GDP doubled and tripled their levels over the 40 years of analysis, while CO2 emissions grew at a rate of 2% and 18% respectively for the OECD Europe and United States. In turn, in China and India, these levels of growth rates of economic activity and emissions were close, despite the countries presenting different stages of economic development. Emission levels of CO2 in China in 2006 were higher than the emissions observed in the United States despite the fact that the Chinese economy represents only a third of the size of the U.S. economy.

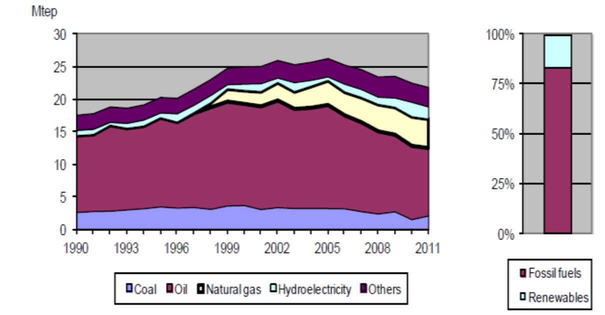
Given that Chapter 2, Chapter 3 and Chapter 4 of this research focus on the problem of power consumption, level of economic activity, consumption of fossil fuels and emissions of greenhouse gases at a sectorial level in Portugal, below we present a descriptive subsection regarding the evolution of these variables:

Figure 1.4 – GHG emissions (without LULUCF)



Source: Portuguese National Inventory Report on Greenhouse Gases, 1990-2011, Agência Portuguesa do Ambiente, 2013

Figure 1.5 – Primary energy consumption trends and share of fossil/renewables in 2011



Notes: Hydroelectricity: domestic production. Others: includes fuelwood, wastes, and biogas. Fossil fuels: includes coal, oild and natural gas. Renewables: includes domestic hydroelectricity and others.
Source: DGGE.

Source: Portuguese National Inventory Report on Greenhouse Gases, 1990-2011, Agência Portuguesa do Ambiente, 2013

According to Figure 1.4, we can see that in the 90s there was a steady growth in total CO2 emissions. Portugal showed moderate growth behaviour at the beginning of 2000 but after the entry into force of the Protocol Kyoto in 2005, there was a downward trend in emissions. Most recently (in 2011) the emissions estimated at about 70 Mt of CO2 which represented a growth rate of 15% compared to the levels of the base year 1990, (Portuguese Environmental Agency, [14]).

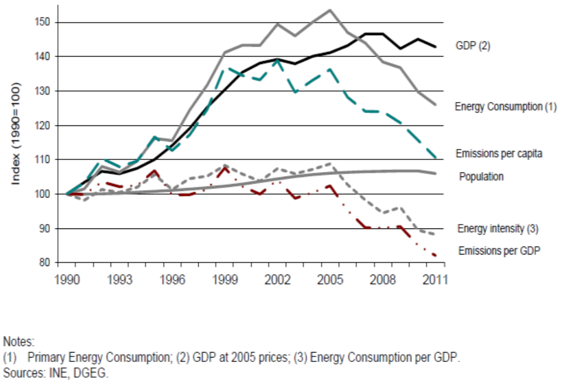
It is important to highlight that for the analysis period, the average annual rate of emissions was less than 1%, however, there are different behaviours of that evolution for the three periods. Thus, in the period 1990-1995 the average rate of emission was around 3.7%, in the second period from 1995-1999 it reached about 4.7% average annual growth and in the last period there are two distinct trends, for the sub-period 2000-2005 a moderate growth rate and from 2005 onwards we have a decline in the emissions pace.

In the Portuguese National Inventory Report [14], the following are mentioned as factors for the growth of emissions among others: (i) the economic growth and the growth of primary energy demand, (ii) the increase of the volume of road transport and distance supported by strong infrastructure development (road infrastructure and fast growth in private car ownership).

The determinants of climate change with reference to the rainfall, varied significantly for some of the years of analysis. This involves significant changes in hydropower production and as a result of these determinant, substantial inter-annual variations in emissions of greenhouse gases are produced.

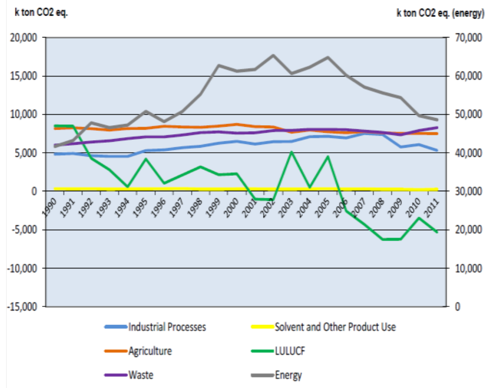
It appears that most of these emissions are related to the energy sector, which is responsible for about 93% of total CO2 emissions due to the consumption pattern of fossil energy sources used. According to the graph in Figure 1.5, we can assume that on average, over the period of analysis from 1990-2011, about 83% of the energy consumed was produced using conventional non-renewable sources, that is, fossil fuels, (coal, oil and natural gas). The renewable sources represented on average about 17%, although, this scenario is changing due to progressive increments of these renewable sources, including energy from sources of natural gas and wind power plants (Portuguese Environmental Agency, [14].

Figure 1.6 – GHG emissions per capita, per unit of GDP and energy consumption



Source: Portuguese National Inventory Report on Greenhouse Gases, 1990-2011, Agência Portuguesa do Ambiente, 2013

Figure 1.7 – GHG emissions and renovals by sector

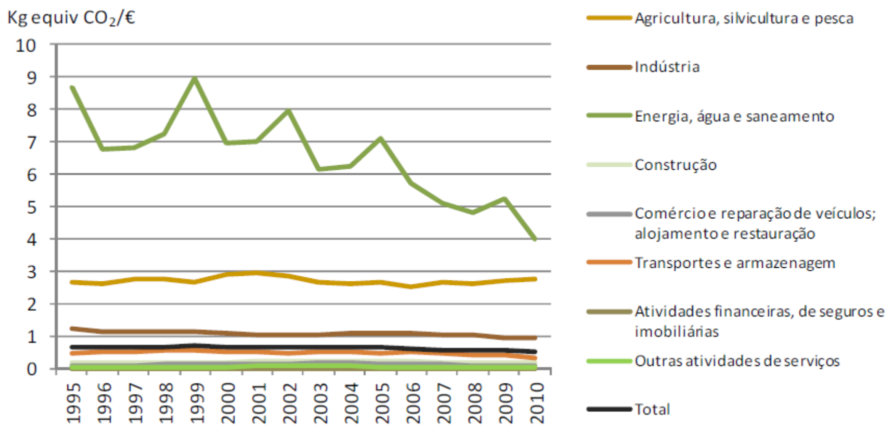


Source: Portuguese National Inventory Report on Greenhouse Gases, 1990-2011, Agência Portuguesa do Ambiente, 2013

Regarding Figure 1.6, we observe that during the 1990s, Portugal experienced a significant economic growth with a GDP growth of about 43% in the period 1990-2011, which corresponds to an average annual increase of 2.0%. The strongest growth occurred from the years 1993 to 2000 where the average annual growth rate reached 4.0%. Since 2001, the economic growth slowed down considerably, contributing at least partially, for the more moderate emissions growth recorded in recent years. Despite that, in the year 2010, there was a reduction in emissions of greenhouse gases of about 6.6% reaching a record low since 1995. At the sectorial level, complementing the analysis with Figure 1.8, the energy sector, in the category " other sectors ", shows a significant increase in emissions in the 1990-2005 period of about 55.5% but with a downward trend of at least 1% in the overall period 1990-2011. This development is in line with the trend recorded since 2006, of dissociation between the evolution of the economic activity and the emission of greenhouse gases. This was due to the decisive fact that 2010 was the year of highest rainfall since 2001, along with the continued growth in the use of other forms of cleaner energy emissions, namely the natural gas and wind power. Fuel burning, either fossil or not is the main source of emission of air pollutants. Nevertheless, in recent years this situation seems to be changing with the decrease of the growing rate, essentially by the gain of value in the renewable energy supply chain. We can also add the fact that the increase in activity, the transfer of fossil fuels and the energy produced and consumed in the markets or economies, increased associated greenhouse gas emissions, see Institute National Statistic- INE [15].

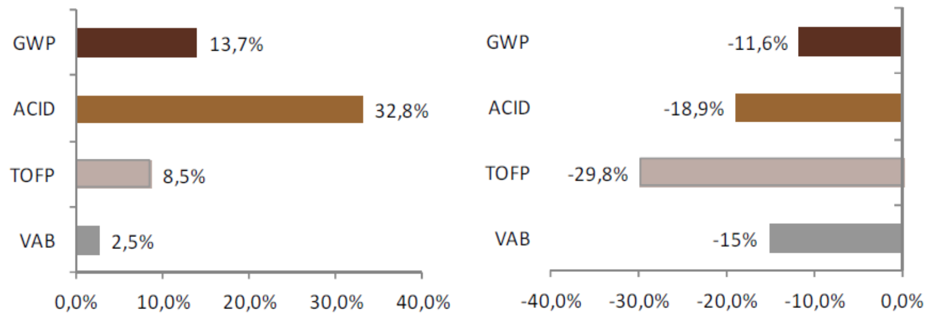
It is also noted (Figure 1.9), for the reporting period, that the Agriculture sector registered a level close to 11% of total emissions in 2011, although this level represents a decrease of about 8% compared to the base year of 1990. This development is related with the small livestock production (especially pigs), the decrease in fertilizer consumption and the loss of importance of the sector in the economy. On one hand, the wastes display a significant growth of approximately 38% since 1990, reaching a level of about 12% of the total emissions in the year 2011. On the other hand, we highlight the importance of industrial processes growth of 10% since 1990 and representing about 7.6% of total emissions in 2011, see INE. [15]

Figure 1.8 – GHG emission intensity per GAV generated unit, per sector/activity



Source: Conta das emissões atmosféricas – 1995-2010, Instituto Nacional de Estatística, 2012

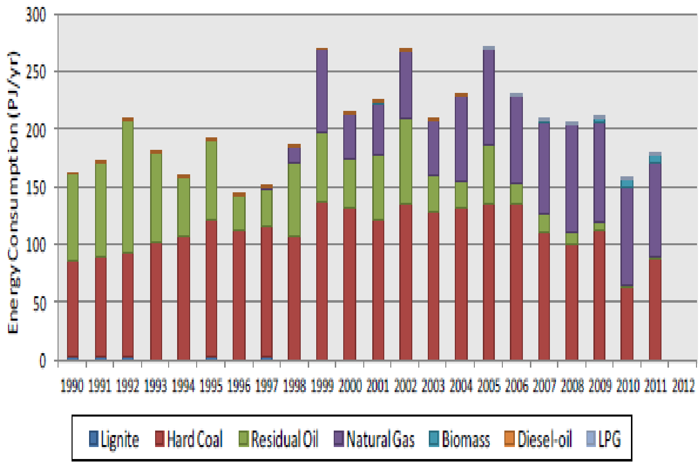
Figure 1.9 – Agriculture, forestry and fishing on GAV and on environmental indicators



Source: Conta das emissões atmosféricas – 1995-2010, Instituto Nacional de Estatística, 2012

Similarly to agriculture, forestry and fishing, (fig.1.9), this branch also records, in the environmental indicators, a weight which is higher than that observed in the economic activity. The energy, water and sanitation along with the industry, is in 2010 the highest contributor to the potential level of the greenhouse gas effect (26.1%). Examining the variation between the years 1995 and 2010, there was a decrease in the level of emissions of greenhouse gases (-18.4%). Between these years there was a considerable decline in the level of emissions of acidifying gases (-85.4%) and its weight in the acidification potential. In 2010 it was 10.8% compared to36.2% in 1995. Despite a significant increase in GVA of this sector (78.1%) between 1995 and 2010, its weight in the economy (2.9%) was significantly reduced compared to the relative weight of the three environmental indicators, INE [15]

Figure 1.10 – Trends of fuel consumption per fuel type

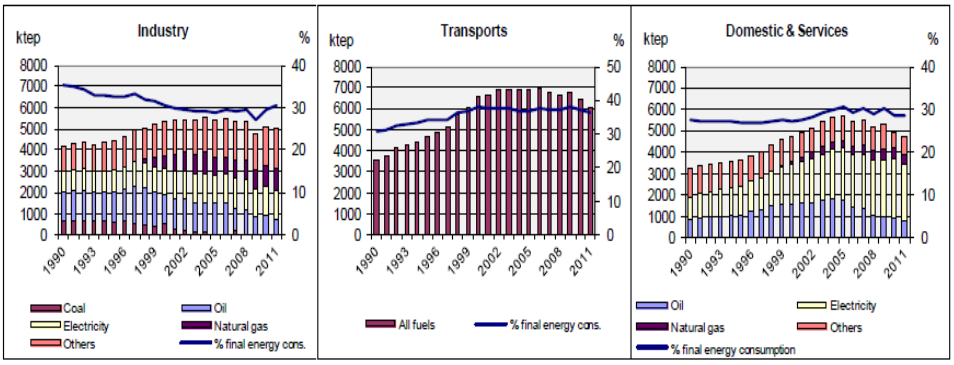


Source: Portuguese National Inventory Report on Greenhouse Gases, 1990-2011, Agência Portuguesa do Ambiente, 2013

Regarding Figure 1.10, IEA [13],whose analysis refers to the structure of the energy consumption in Portugal by fuel type in 2010, the most used form of energy by the economy is diesel (26.6%), followed by natural gas (22.1%) and biomass (14.8%) which represent more than 60% of the total energy (associated with emissions) consumed by the country. Comparatively to the five-year period 1995-1999, it is concluded that natural gas is not bet on by the country due to its practically nonexistence in the period (3.1%) and the fact that in 2010 it is considered the second most important form of energy. Natural gas has been replacing the expensive and very polluting fuel oil (19.3% of importance for 1995-1999 and only 7.0% in 2010) and coal (17.1% in 1995-1999 and 8.1% in 2010), which is a source of electricity production with high environmental impact.

In Figure 1.11, INE [15], sectorial developments in energy consumption show that the sectorial structure has changed over the period of analysis. The services sector recorded the most significant increase in the sectorial energy consumption with an increase of 145% during the analysis period of 1990-2011, with an important reference to the level of 218% reached in the period 1990-2005. However, in 2011 the service sector together with the household sector represented 28% of total energy consumption. Equally important is the contribution of the industrial sector, showing a slight decrease of 4% of energy consumption, that is, the industrial sector accounted for 35% of the final energy demand in 1990, reaching a rate of 31% in 2011.In contrast to the increasing importance of the transport sector with changes of the levels of 31% in 1990 to the level of 38% in early 2000, with the behaviour of the final demand in the sector representing 91% between 1990-2005 but alternating with a counter-cycle with a decline of about 12% in the period 2005-2011, INE [15].

Figure 1.11 – Final energy consumption by main sectors and fuel



Source: Portuguese National Inventory Report on Greenhouse Gases, 1990-2011, Agência Portuguesa do Ambiente, 2013

In terms of energy consumption by type of fuel, in accordance with Figure 1.11 we can focus on a sectorial level where the resources of fossil fuels, particularly petroleum derived products tend to represent a growing importance in the analysed period 1990-2011, especially in road transport. The fuel gas was 29% in 2004, representing the loss of importance of this type of fuel, as in 1990 it was responsible for nearly 40% in the energy consumption structure.

1.3. Methodologies Options

1.3.1. Decomposition analysis

To assess the determinants of carbon intensity, analysts often use the Kaya identity, which links the carbon intensity to its main driving factors. In the literature about decomposition of the effects of the emission intensity and energy intensity, there are mainly two approaches: the structural decomposition analysis (SDA) and the index decomposition analysis (IDA).

IDA uses index number concept in decomposition[1]. The advantage of the IDA is that it can readily be applied to any available data at any level of aggregation (Ma and Stern, [16]). Each IDA can be applied in a period-wise or time-series manner. In a period-wise analysis there is a comparison between one determined year and the base year, which makes the analysis sensitive to the choice of these years. On the other hand, it does not disclose the evolution of the clarifying factors throughout time. The times series analysis makes an annual decomposition of the factors, which allows seeing its evolution throughout time.

In IDA approach there are mainly two methodologies: Laspeyres IDA and Divisia IDA. Ang and Zhang [17] and Sun [18] give/provide, respectively, details on these two methodologies. The Laspeyres IDA include basic Laspeyres index, Paasche index, Fisher ideal index, Shapley index and Marshall–Edgeworth index, etc. The Divisia IDA includes the Arithmetic Mean Divisia Index (AMDI) and the Logarithmic Mean Divisia Index (LMDI).

Initially, the Laspeyres decomposition approach always led to a residual, which could be of a considerable size. To illustrate this see Zhang et al [19]. Sun [18] who proposed a complete decomposition analysis where the residual term is distributed among the considered effects. This decomposition has long been used in the empirical literature because it can be simply calculated and easily understood. Zhang and Ang [20] refer to this as the refined Laspeyres method.

These techniques constitute a widely accepted analytical tool for policy making in energy and environmental issues. In the case of the European Union (EU), several studies have used IDA techniques in economic sectors[2]. For instance, Diakoulaki and Mandaraka [21], refined Laspeyres model to determine the impact of output effect, the utility mix effect, the energy mixed effect, the energy intensity effect and the structural effect in the EU manufacturing sector for the period 1990-2003.

[1] See Ang and Zhang [16], Sun [17], Paul and Bhattacharya [22], Wang et al.[23], Wu et al. [24], Lee and Oh [25], Lise [26], and Diakoulaki and Mandaraka [21] for some applications, and Liu et al [27] and Ang and Zhang [28] for reviews about works that use this methodology.

[2] See for instance Liaskas et al., [29]; Sun [18] and [30], Bhattacharyya and Matsumura [31].

1.3.2. Convergence analysis

Given all these specific objectives, we believe that the use of the convergence analysis, allows us to evaluate, in the long-term, the existence of differences between the CO_2 emission intensities and its main drivers in the Portuguese activities or sectors and subsectors; and also allows to reach some conclusive evidence on the frequency in the changes of these differences of the intensities of emissions and their drivers. As usual, the decomposition analysis leaves a residual term, which is the unexplained portion of the change in an aggregate variable, and the decomposition analysis is an expansion series truncated after the first order terms.

Although, the European market for emissions permits and imposes different caps to the various sectors, for analysis of the effects on this market in Portugal, they are exposed to a common commitment and to the uniformity of public policies, for example, among others, the policy of reducing fossil fuel intensity and promoting renewable energy sources supporting the mitigation of CO_2 emissions intensity. Therefore it is important to: (i) know if there is a common pattern of emissions intensity, fuel intensity and energy intensity, between industries (convergence), to know if it justifies a more specific application of energy policies between sectors; (ii) study the long term effects of those specific variables on the mitigation of CO_2 emissions. These two approaches, decomposition analysis and convergence analysis can give relevant information for the policy making with regard to the timing of policy interventions and to the choice of policy instruments.

Specific in sectorial industrial studies, among others, Strazicich and List [32], examined a time path (1960-1997) of carbon dioxide emissions in twenty-one industrial countries and tested the convergence for stochastic and conditional convergence. Using both panel unit root tests and cross-section regressions, they found significant evidence that CO_2 emissions converged. Liddle [33], analyzed the aggregated and sectorial convergence in the electricity intensity and energy intensity in IEA/OECD countries, and concluded that there was convergence, since the countries with the highest intensities exhibited downward trends, and many of the other countries showed slight increasing trends. Aggregate electricity intensity converged among countries, but less dramatically than aggregate energy intensity. The three analyzed sectors (residential, industry and commercial) converged at different rates. Commercial electricity intensity has a distribution that is most characterized by a bell-shape while industry and residential electricity intensity have more bimodal distributions. Camarero et al. [34] using Phillips and Sul [35] methodology, tested the convergence of CO2 emissions intensity and their determinants among OECD countries over the period 1960-2008, and they found that differences in emissions intensity convergence were more determined by differences in convergence of the carbonization index rather than differences in the energy intensity.

1.3.3. Econometric techniques

In some issues of this research it is normal to use the decomposition analysis, that leaves a residual term, which is the unexplained portion of the change in an aggregate variable, and the decomposition analysis is an expansion series truncated after the first order terms. For that limitation, and their contribution to the literature to study the influence of determinant variables of energy related on CO2 emissions we used the Panel Corrected Standard Errors (PCSE) estimator. This methodology allows, on the one hand, to observe whether there is a common behaviour among the variables determining the emissions for the two groups of industries. If so, then it is useful to study the influence in terms of elasticity, of these same variables, on emissions. This allows us to evaluate the effect that energy policies affecting the variables studied will have on emissions, and if common policies will have the same effect on the behaviour of the variables for the various industries.

On the other hand, there are no known studies with Vector Autoregressive (VAR) models nor with Innovative Accounting Approach (IAA), that is, advanced generalized forecast error variance decomposition and generalized impulse response techniques using ratios of decomposition of emissions intensity. However, it is important to mention some recent studies applied to variables, such as energy consumption, emissions and GDP.

The generalized forecast variance decomposition approach estimates the simultaneous shock effects using a VAR system to test the strength of causal relationship between some variables, for example, among others, in the study of energy related CO2 emissions: dioxide emission intensity, emissions by fossil fuels ratio, fossil fuel intensity, energy intensity and economic structure. The variance decomposition approach indicates the magnitude of the predicted error variance for a panel series accounted by innovations from each of the independent variables over different time horizons. We also provided a rough analysis of how long it takes for the variable to go back to the equilibrium after the long run relationship has been shocked. The IRFs show the dynamic responses of time series to a one period standard deviation shock and indicate the direction of the response to each of the shocks. Thus, a random shock in one innovation in the VAR sets up a chain reaction over time in all variables in the VAR. IRFs calculate these chain reactions [36].

In last issue of this thesis, we analyzed the existence of differences between the CO2Kwh emission and their main drivers, including the economic growth measure and the share of renewables allows some conclusive evidence on the frequency in the changes of the CO2 Kwh emissions and their factors. In order to confirm the validity of the panel data model estimation the following tests are going to be conducted: panel unit root tests, a panel cointegration test and dynamic panel causality tests. The ECM is a comprehensive linear regression equation that provides a description of the possible nature of interdependence of the short run movements of cointegrated variables under study. It also characterizes the nature of interdependence of the short-run movements of CO2 Kwh emissions, real GDP and share of renewable sources. To investigate these relationships, based on error correction models, the Full Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) methods will also be considered in this study.

We begin the cointegration analysis with the application of panel unit root tests to verify whether or not the variables are nonstationary. Panel unit root tests are often grouped into two main categories: first-generation tests, which assume cross-sectional independence [37–40]; and second generation tests, which explicitly allow for some form of cross-section dependence [41]. Once assured the non-stationarity, one must test the cointegration hypothesis of the series. The Engle-Granger [42] methodology is usually used in testing cointegration. After assuring both the nonstationarity of the variables of the equation and the presence of cointegration between them, it is possible to infer what deviations from the long-term equilibrium of the variables influence the short-term dynamics. In this last issue, particular attention will be directed to the following two parameters: ϕ_i and θ_i, the speed of adjustment from the error correction term and the vector of parameter of long-run equilibrium relationship. It is expected that the term ϕ_i would different from zero and that this parameter would be significantly negative under the assumption that the variables return to their long-run equilibrium. In this last issue, the Environmental Kuznets Curve model is estimated following several approaches, according to the assumptions made regarding the homogeneity of the short and long-term parameters among the panel of European countries.

1.4. Structure of the Thesis

This doctoral thesis is divided into six chapters, including this introduction in chapter 1. This section provides a brief abstract of extended essays, their contribution to the literature and their implications.

Chapter 2: Decomposition analysis and Innovative Accounting Approach for energy-related CO2 emissions intensity over 1996-2009 in Portugal

In Portugal, GHG emissions were about 74.6 MT of CO2 in 2009, an increment of 26% compared with the 1990 levels[3], which puts this country within the limits imposed by Burden Sharing Agreement (27%). This accomplishment was possible due to the significant inflexion in emission path over the last years, explained, not only by the economic crisis, but also by the efficiency gains of the economy (lowering the carbon intensity of the national product). It is highly relevant to identify the factors that influence global changes in CO2 emissions intensity and also to individualize them at sectorial level. In this research Issue, we used the 'complete decomposition' technique developed by Sun [18] and applied by Zhang et al. [19] to examine CO2

[3] See Agência Portuguesa do Ambiente [8].

emissions intensity and its components. We considered CO2 intensity for 36 economic sectors as well as its reflecting changes over the 1996-2009 period. In addition, we have implemented the Innovative Accounting Approach (IAA) that includes forecast error variance decomposition and Impulse Response Functions (IRFs), applied to the factors in which emissions intensity was decomposed. It is always interesting to know how one variable responds to an impulse in another variable ceteris paribus, that is, in an exercise of comparative statics. We used the 'complete decomposition' technique to examine CO2 emissions intensity and its components, considering 36 economic sectors in the 1996-2009 period. In addition, we have implemented the Innovative Accounting Approach that includes forecast error variance decomposition and Impulse Response Functions, applied to the factors in which emissions intensity was decomposed. It is shown that CO2 emissions intensity diminished significantly in the considered period. Energy intensity of economic sectors is the most important effect in the determination of the CO2 emissions intensity. The technologies used are more efficient and less polluting, for the same amount of fuel used. Moreover, there was a substitution between fossil fuels in favour of less polluting fuels, but the technologies related to fossil fuels may still have a significant role. After making the decomposition analysis we observed that the emissions intensity decreased, and the effect that contributed more to this was energy intensity. The sectors that have contributed more to reduce the intensity of emissions through the reduction of energy intensity are the Manufacture of coke, refined petroleum products and Construction. Yet, there are sectors that contributed to reduce energy intensity because they lost importance in the economy such as Agriculture, Forestry and Fishing, Electricity, gas, steam and air-conditioning supply, the Manufacture of chemicals and chemical product, the Manufacture of rubber and plastics products, and other non-metallic mineral products, the Manufacture of wood and paper products, and printing.

There is bidirectional causality between CO2 emissions intensity and the share of fossil fuels in total energy consumption. Emissions by fossil fuel and energy intensity affect the structure of the economy in behalf of less energy intensive sectors. Emissions intensity reacts more significantly to shocks in the weight of fossil fuels in total energy consumption compared to shocks in other variables.

Chapter 3: Carbon Dioxide Emissions Intensity of Portuguese Manufacturing Industry: A Convergence Analysis and Econometric Approach

Portugal managed to meet the Kyoto Target for the period 2008-2012. In 2011 it showed a level of emissions which was 16% higher than the 1990 level (its limit was 27%), Portuguese Environmental Agency, [14]. However, the goals of reducing emissions are not restricted to this period. In 2009 a new package of environmental measures was adopted at the EU level, known as the 20-20-20 targets: by 2020 there should be a 20% reduction of Greenhouse Gases (GHG) emissions compared with 1990, 20% share of renewable energy in EU energy consumption, and energy improvement by 20%.

To meet these goals, it is important to realize which variables affect GHG emissions, particularly the intensity of emissions (emissions by unit of output). It is important to understand the evolution and influence between emissions intensity, energy intensity, and the share of fossil fuels in total energy consumption.

The purpose of this issue is to study: (i) the existence of convergence (sigma and gamma) of some relevant ratios as Carbon Dioxide (CO2) emissions intensity, CO2 emissions by fossil fuel consumption, fossil fuel intensity, energy intensity and economic structure, between manufacturing sectors in Portugal, and (ii) the influence that the consumption of fossil fuels, the consumption of aggregate energy and GDP have on CO2 emissions, and the influence that the ratios in which CO2 emissions intensity decomposes can affect that variable, using an econometric approach, namely Panel corrected standard errors estimator.

From this analysis we can highlight two sets of conclusions. The first one is related with convergence. In what concerns sigma convergence, emissions and energy intensity, sectors tend to have similar behaviour, even these similarities are greater for industries in group B. There is also convergence in the economic structure, higher for group A. In fact, in 1999 there were more discrepancies between sectorial GDP than in 2009. Sectors with great importance in 1999, as CB, CC and CG decreased their importance significantly. Particularly in group B, the sectors CG, EC and D lost relative importance in consideration of the CD sector. In terms of the mix of fossil fuels used, industrial sectors are not yet harmonized, that is, there is not a common behaviour between sectors. CI factor is also irregular in its pattern of convergence for the two groups but the trend is to converge, which is more evident for group A. Therefore, for the intensity of emissions and for energy intensity, there is a trend towards harmonization of sectors for the whole period, which is most evident in group B. The harmonization is greater in group B for the intensity of emissions and for energy intensity. Gamma convergence verifies for all ratios, with exception of CO2 emissions by fossil fuel and fossil fuel intensity in group B. For emissions by fossil fuel and the structure of the economy there is more harmonization in group A.

From the econometric approach we concluded that the considered variables have a significant importance in explaining CO2 emissions and CO2 emissions intensity. In the latter, elasticities of CO2 emissions by fossil fuel consumption, fossil fuel consumption by energy consumption, energy intensity and the economic structure, are respectively of 113%, 97%, 96% and 98% on the dependent variable, ceteris paribus. For group B the magnitude of the impacts is greater.

These results of this issue show that these ratios are crucial to reducing the CO2 intensity of Portuguese sectors, especially in the industries listed in Group B, particularly in what concerns increasing energy efficiency and the use of renewable energy, both points focusing on European policy (2009/28/CE directive) [43]. On the other hand, the results of the two methodology approaches can give relevant information for the policy making with regard to the timing of policy interventions and to the choice of policy instruments.

Chapter 4: Is there convergence and causality between the drivers of energy - related CO2 emissions among the Portuguese Tourism Industry?

The Portuguese strategic plan for tourism for 2007-2015 period has proposed to increase the tourism contribution to the Portuguese economic activity (measured by GDP). For that purpose, one of the challenges is the reduction of the tourism energy consumption and CO_2 emissions. On the other hand, Portugal has integrated EU Directives and Decisions related to mitigation (2008/101/EC], [44] and 2009/406/EC) [45] into national law. Mitigation is seen as a way to reduce expected negative impacts on climate change. Furthermore, there is national financial support and incentive systems for investments in energy efficiency and renewable energies, moreover, environmental policies are also expected to encourage technological progress, the use of alternative fuels, infrastructures and improvements in operations. More sustainable tourism practices are also expected to meet emerging tourist demands, (OECD, [46]).

This study examines the impacts on CO_2 emissions intensity in two distinct group activities or sectors, namely: group 1, including accommodation and food, transportation, wholesale retail and shopping; and group 2, including entertainment and recreation, postal and communication services and others services in Portugal over 1996-2009 period. Using two different methodologies, in the first phase we used the convergence analysis with two measures proposed called Sigma-convergence and Gamma-convergence. In the second phase, to assess the ability to forecast values, we developed the Innovative Accounting Approach. We included the driving forces, as follows: CI effect can be expressed by the ratio CO_2/Fossil fuel; CE effect can be expressed by the ratio Fossil fuel/Energy consumption; EI effect is measured by the ratio Energy Generation/GDP; ES effect is explained by the ratio GDP of tourism activity /GDP total. We can see in group 1, the highest degree of convergence is presented by the CE effect as this value in 2009 is close to zero. ES and EI effect present a similar convergence pattern, although not as pronounced as the CE effect, while for group 2, once again the CI effect shows some strong divergence between 1996 and 1998, although, thereafter it starts to converge. ES, EI and CE effect convergence pattern is similar, with all three effects slightly diverging between 2001 and 2004 when they start to converge again. On the other hand, in the results of Innovative Accounting Approach, the bidirectional causality was found between CO_2 emissions intensity to EI effect between CO_2 emissions intensity to CI effect in group 1, between CO_2 emissions intensity to ES effect, and between CO_2 emissions intensity to EI effect in group 2.

We also found the unidirectional causality in Group 1 from CO2 emissions intensity to CI effect, from CO2 emissions intensity to CE effect, from CO2 emissions intensity to ES effect, from CE effect to CI effect and from EI effect to ES effect, while in Group 2 there is unidirectional causality from CO2 emissions intensity to CI effect, from CO2 emissions intensity to CE effect and from CE effect to CI effect.

Chapter 5: Decomposition of energy-related GHG emissions in agriculture over 1995-2008 for European countries

According to the EEA, [47] agriculture has been responsible, in the last two decades, for about 10% of the total annual emissions of greenhouse gases emitted in Europe. The EU Trading Scheme does not consider the agricultural sector as part of the negotiations of carbon credits, nevertheless countries are concerned about adopting other environmental policies that aim at reducing GHG emissions in the agricultural sector, thereby contributing to the achievement of the Kyoto Protocol goals. For the design of a policy of this kind, it is important to understand how the intensity of Greenhouse Gases (GHG) emissions (GHG emissions/ agricultural value added) has evolved and what factors contribute to the variation of that intensity.

The objective of this issue is to identify the effects in which the intensity of GHG emissions (EI) in agriculture can be broken down and analysed, as well as their evolution and which of them has more importance in determining the intensity of emissions in agriculture. Considering the previous analysis, we decided to use the 'complete decomposition' technique developed by Sun [18] and applied by Zhang et al. [19] to examine agriculture GEE emissions intensity and to decompose it in several effects or components, based on the variables presented above. We considered agriculture emissions intensity for 15 countries as well as its reflecting changes over the 1995-2008 period. The change of EI can be decomposed into five effects: (i) the changes in GHG emissions compared to the fossil fuels consumption (EF effect), (ii) the changes in fossil fuels consumption compared to the use of Nitrogen in agriculture (FN effect), (iii) the change in use of Nitrogen in agriculture by ha of utilized agricultural area (NA effect), (iv) the change in utilized agricultural area per worker (AL effect) and the inverse of average labour productivity in agriculture

(LVA effect). It is shown that NA effect and LVA effect were the ones that had a greater contribution to the variation of EI. This means that the use of Nitrogen per cultivated area is an important factor of emissions and in those countries where labour productivity increases (LVA decreases), emissions intensity tends to decrease. It is shown that NA effect and LVA effect were the ones that had a greater contribution to the variation of EI. This means that the use of Nitrogen per cultivated area is an important factor of emissions and that in those countries where labour productivity increases, emissions intensity tends to decrease.

These results imply that the way to reduce emissions in agriculture could be by a better training of agricultural workers to increase their productivity, which would lead to a less need for energy and use of Nitrogen. On the other hand, there may be an exaggerated focus on the use of fossil fuels as a source of emissions, while this study shows that the use of Nitrogen represents a more important role in determining emissions than the use of fossil energy. Apart from their relation to GHG emissions, nitrates are also a major source of water pollution, so it is important to establish a European strategy for the effective adoption of sustainable agricultural practices, specifically by reducing the use of nitrates and other fertilizers or their application in divided doses.

Chapter 6: Is the share of renewable sources determining the relation CO2 Kwh- Income in electricity generation?

There are several articles that have studied the connection between economic growth and emissions, testing the hypothesis of the Environmental Kuznets Curve (EKC). However, the relation between emissions from electricity production and GDP is not focused on literature. Those studies that include electricity are based on the amount of energy consumed, which is inherently linked to a volume of emissions, but don't directly include the emissions resulting from its production. Studies focus specifically on the relationship between economic growth and energy consumption, in particular electricity consumption. The study of the latter relationship is important because electricity production is, as we have seen, a major source of emissions, but on the other hand it is also an important way to reduce them, if there is a replacement of fossil fuels with renewable energy in electricity production. It is then important to analyze, how the reduction of emissions in this sector may undermine the economic growth of European countries. Moreover, it is important to analyze how the percentage of renewable energy used for electricity production affects the relationship between economic growth and emissions from this sector. The study of these relationships is important from the point of view of environmental and energy policy as it gives us information on the costs in terms of economic growth, on the application of restrictive levels of emissions and also on the effects of the policies concerning the use of renewable energy in the electricity sector (see for instance European Commission Directive 2001/77/EC, [4]).

For that purpose, in this study we use Cointegration Analysis on the set of cross-country panel data between CO_2 emissions from electricity generation (CO2 kWh), economic growth (GDP) and the share of renewable energy for 20 European countries. We estimated the long–run equilibrium to validate the EKC with a new approach specification. Additionally, we have implemented the Innovative Accounting Approach (IAA) that includes Forecast Error Variance Decomposition and Impulse Response Functions (IRFs), applied to those variables. This can allow us, for example, to know (i) how CO2 kWh responds to an impulse in GDP and (ii) how CO2 kWh responds to an impulse in the share of renewable sources.

We can also infer that the share of renewable energy in electricity output will have significant influence on the shape of the EKC, which will shift downward as RES increases, suggesting lower (environmental) costs of development. From Panel Granger Causality tests we can highlight the bidirectional causality between GDP and RES (positive from GDP to RES and negative from RES to GDP). From Variance Decomposition analysis we confirm the relation of causality from GDP to RES. This shows that richer countries will naturally have more willingness to invest in renewable energy. The negative causality from RES to GDP, claims that the leading countries in renewable energy are less technically efficient than renewable energy laggards that are among the most technically efficient countries in Europe.

At the end of thesis, in chapter 7, we provide some concluding remarks, limitations of this research and suggestions for future research.

References

[1] Olivier, J.G.J. J. Peters, G. Janssens-Maenhout and J.Wilson (2011), Long-Term Trend in global CO2 emissions. 2013 Report PBL Netherlands Environmental Assessment Agency, The Hague, 2013; European Union.

[2] IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A.(eds.)]. IPCC, Geneva, Switzerland, 04 pp.

[3] IEA (2013), Energy Statistics, 2013 Edition. International Energy Agency, Paris.

[4] OECD (2012), OECD Environmental Outlook to 2050, OECD Publishing. http://dx.doi.org/10.1787/9789264122246-en

[5] Olivier, J.G.J. J. Peters, G. Janssens-Maenhout and J.Wilson (2013), Trends in global CO2 emissions. 2013 Report PBL Netherlands Environmental Assessment Agency, The Hague, 2013; European Union.

[6] Raupach, M. R., G. Marland, P. Ciais, C. Le Quéré, J. G. Canadell, G. Klepper and C. B. Field Global and regional drivers of accelerating CO2 emissions. PNAS, 104, 10288-10293, doi:10.1073_pnas.0700609104

[7] Nakicenovic, N. and R. Swart, Eds., 2000: Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, 599 pp.

[8] European Environmental Agency. Approximated EU GHG inventory: A Early estimates for 2011. EEA Technical report No 13/2012.

[9] WTTC (World Travel & Tourism Council). 2011. Business Travel: A Catalyst for Economic Performance. Oxford, UK: WTTC and Oxford Economics. Available at http://www.wttc.org/research/benchmarking-travel-tourism/comparative-economic- impact travel-tourism.

[10] Portuguese Environmental Agency. Portuguese National Inventory Report on Greenhouse Gases 1990-2009. In: Protocol SutUNFCoCCatK, editor. 2011.

[11] European Commission EU budget 2010 — Financial Report Cover; picture: c Phovoir More information on the European Union is available on the Internet (http://europa.eu). Publications Office of the European Union, 2011.ISBN 978-92-79-19878-6 doi:10.2761/72258.

[12] Resolução do Conselho de Ministros n.º 29/2010": Diário da República, 1.ª série — N.º 73 — 15 de Abril de 2010.

[13] IEA (2013), Energy Statistics of OECD Countries, 2013 Edition. International Energy Agency, Paris.

[14] Portuguese Environmental Agency. Portuguese National Invert Report on Greenhouse Gases 1990-2011. Submitted under the United Nations Framework convention on Climate change and the Kyoto; 2013.

[15] INE- Institute National Statistics Portugal. Indicadores Económico-ambientais – Conta das Emissões Atmosféricas 1995-2010. Publicação 09 Outubro 2012

[16] Ma C, Stern DI. China's changing energy intensity trend: A decomposition analysis. Energy Economics. 2008;30(3):1037-53.

[17] Ang BW, Zhang FQ. A survey of index decomposition analysis in energy and environmental studies. Energy. 2000;25(12):1149-76.

[18] Sun JW. The decrease in the difference of energy intensities between OECD countries from 1971 to 1998. Energy Policy. 2002;30(8):631-5.

[19] Zhang M, Mu H, Ning Y, Song Y. Decomposition of energy-related CO2 emission over 1991-2006 in China. Ecological Economics. 2009;68(7):2122-8.

[20] Zhang FQ, Ang BW. Methodological issues in cross-country/region decomposition of energy and environment indicators. Energy Economics. 2001;23(2):179-90.

[21] Diakoulaki D, Mandaraka M. Decomposition analysis for assessing the progress in decoupling industrial growth from CO2 emissions in the EU manufacturing sector. Energy Economics. 2007;29(4):636-64.

[22] Paul S, Bhattacharya RN. CO2 emission from energy use in India: A decomposition analysis. Energy Policy. 2004;32(5):585-93.

[23] Wang C, Chen J, Zou J. Decomposition of energy-related CO2 emission in China: 1957-2000. Energy. 2005;30(1):73-83.

[24] Wu L, Kaneko S, Matsuoka S. Driving forces behind the stagnancy of China's energy-related CO2 emissions from 1996 to 1999: The relative importance of structural change, intensity change and scale change. Energy Policy. 2005;33(3):319-35.

[25] Lee K, Oh W. Analysis of CO2 emissions in APEC countries: A time-series and a cross-sectional decomposition using the log mean Divisia method. Energy Policy. 2006;34(17):2779-87.

[26] Lise W. Decomposition of CO2 emissions over 1980-2003 in Turkey. Energy Policy. 2006;34(14):1841-52.

[27] Liu LC, Fan Y, Wu G, Wei YM. Using LMDI method to analyze the change of China's industrial CO 2 emissions from final fuel use: An empirical analysis. Energy Policy. 2007;35(11):5892-900.

[28] Ang BW, Zhang FQ. Inter-regional comparisons of energy-related CO2 emissions using the decomposition technique. Energy. 1999;24(4):297-305.

[29] Liaskas K, Mavrotas G, Mandaraka M, Diakoulaki D. Decomposition of industrial CO2 emissions: The case of European Union. Energy Economics. 2000;22(4):383-94.

[30] Sun JW. Energy demand in the fifteen European Union countries by 2010 - A forecasting model based on the decomposition approach. Energy. 2001;26(6):549-60.

[31] Bhattacharyya SC, Matsumura W. Changes in the GHG emission intensity in EU-15: Lessons from a decomposition analysis. Energy. 2010;35(8):3315-22.

[32] Strazicich M, List J. Are CO 2 Emission Levels Converging Among Industrial Countries? Environmental & Resource Economics, European Association of Environmental and Resource Economists. 2003;24(3):263-71.

[33] Liddle B. Electricity intensity convergence in IEA/ OECD countries: Aggregated and sectorial analysis. Energy Policy. 2009;27:1470-78.

[34] Camarero M, Tadeo AJP, Tamarit C. Are the determinants of CO2 emissions converging among OECD countries. Economic Letters. 2013;118(1):159-62.

[35] Phillips PC, Sul D. Transition Modeling and Econometric Convergence Tests. Econometrica. 2007;75(6):1771-855.

[36] Robaina-Alves, M., and Moutinho, V. (2013), 'Decomposition analysis and Innovative Accounting Approach for energy-related CO2 emissions intensity over 1996-2009 in Portugal', Energy, Vol 57(1), 775-787.

[37] Baum CF. Residual diagnostics for cross-section time series regression models. Stata Journal. 2001;1:101-4.

[38] Baum CF. A review of Stata 8.1 and its time series capabilities. International Journal of Forecasting. 2004;20(1):151-61.

[39] Pesaran MH. General diagnostic tests for cross dependence in panels. Cambridge Working Papers in Economics: Faculty of Economics, University of Cambridge 0435; 2004.

[40] Frees E. Assessing cross-sectional correlation in panel data. Journal of Econometrics. 1995;69:393-414.

[41] Frees E. Longitudinal and panel data: analysis and Applications in the Social Sciences. Cambridge: University Press; 2004.

[42] Engle, R. and Granger, C., 1987, 'Cointegration and Error-correction: Representation, Estimation, and Testing,' Econometrica, 55, pp. 251–276.

[43] EU Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing directives 2001/77/EC and 2003/30/EC; 2009.

[44] EU Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amends Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community

[45] EU Directive 2009/406/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.

[46] OECD, 2012. OECD Factbook 2011-2012: Economic, Environmental and Social Statistics, OECD Publishing.

[47] European Environment Agency - EEA Report No 10/2013Trends and projections in Europe 2013 – Tracking progress towards Europe's climate and energy targets until 2020, published 09 Oct 2013.

[48] Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001on the promotion of electricity produced from renewable energy sources in the internal electricity market (OJ L 283, 27.10.2001, p. 33).

Chapter 2

Decomposition analysis and Innovative Accounting Approach for energy-related CO2 emissions intensity over 1996-2009 in Portugal

2.1 Introduction

2.1.1 Background and Motivation

Energy consumption, emissions of Greenhouse Gases (GHG), and its connection to the economic growth have led to a growing concern among politicians and academics. Their aim is to draw effective energy and environmental policies that reduce overall energy consumption and energy dependence on fossil fuels, and thereby ensure long-term environmental and economic sustainability and resilience.

The literature has several studies on the evolution of energy intensity of economies (energy use per unit of output) [1-4] and on the intensity of emissions of pollutants (emissions per unit of output), [5-7]. In addition to exploring how these intensities evolve over time and between economic sectors, it is also important to know what influences them (which factors are behind its variations). In this sense, there have been several studies that decompose the energy intensity and emissions intensity in various effects or factors, based on their temporal and sector analysis. Studies on this subject give specific information about each country or sector, in order to apply appropriate energy policies in each case. This depends on the factor that has a greater responsibility in emissions intensity, or on which is easier to reduce.

The main effects that resulted from the decomposition of the intensity of CO2 emissions are the importance of fossil fuels in total energy consumption, energy intensity and sectoral structure of the economy.

In Portugal, GHG emissions were about 74.6 MT CO2e in 2009, an increment of 26% compared with the 1990 levels[1], which puts this country within the limits imposed by Burden Sharing Agreement (27%)[2]. This accomplishment was possible due to the significant inflexion in emission path over the last years, explained, not only by the economic crisis, but also by the efficiency gains of the economy (lowering the carbon intensity of national product)[3].

Despite this, the Portuguese energy intensity in terms of total energy requirements has been above many other European countries and clearly over the European average (except for 1996)[4]. This behaviour is even more remarkable in terms of final energy consumption, as reported in Mendiluce et al. [4] and in Diakoulaki and Mandaraka [9], where the final energy intensity was steadily increasing during that decade in some countries like Portugal and Spain. Therefore, the Portuguese economy has diverged from other European counterparts. That fact should induce a stronger political action by the Portuguese government in order to curve the energy intensity path.

Regarding the importance of fossil fuels in Portuguese energy consumption, despite the downward trend[5] (resulting from the replacement by renewable energies, with a particular expansion of windmills[6]), its importance is still significant (82.4% in 2009).

Concerning the sectoral frame, we can see through data analysis[7], that there is a weak positive linear relationship between the production of each sector and the consumption of fossil fuels, and between the production of each sector and its emissions. For

[1] See Agência Portuguesa do Ambiente [8].
[2] Climate Action Network Europe in http://www.climnet.org/resources/euburden.htm. Per decision of EU Environment Council 16th June 1998. Reaffirmed by joint ratification of the
Kyoto protocol on May 31st 2002: Council Decision 2002/358/EC
[3] As showed by data from INE. Statistics Portugal. National Accounts
[4] As showed by data from Eurostat
[5] As showed by data from INE, Statistics Portugal, National Accounts.
[6] See APA, 2012
[7] INE statistic Portugal, National Accounts.

industries with low level of Gross Domestic Product (GDP) this relationship is stronger. However, there are some sectors that break that relationship, because they have a relatively low GDP and a high level of fossil fuel consumption and emissions (such as electricity, gas, steam and air-conditioning supply), or because they have a relatively high GDP, with a fuel consumption and emissions to a relatively low level (as wholesale and retail trade, repair of motor vehicles and motorcycles).

It's very relevant to identify the factors that influence changes in CO2 emissions intensity and also to individualise at sectoral level. In this research paper, we used the 'complete decomposition' technique developed by Sun [10] and applied by Zhang et al. [11] to examine CO2 emissions intensity and its components. We considered CO2 intensity for 36 economic sectors as well as its reflecting changes over the 1996-2009 period. In addition, we have implemented the Innovative Accounting Approach (IAA) that includes forecast error variance decomposition and Impulse Response Functions (IRFs), applied to the factors in which emissions intensity was decomposed. It is always interesting to know how one variable responds to an impulse in another variable ceteris paribus, i.e., in an exercise of comparative statics.

Joining these two methodologies, we will not only give an overview of what has been a past reality for these variables, how they are related to each other and how they have evolved, but also how they can influence each other in the future. Therefore, the present study is relevant to the design of appropriate energy and environmental policies, including meeting the objectives for the post Kyoto period.

2.1.2 Literature review

To assess the determinants of carbon intensity, analysts often use the Kaya identity, which links the carbon intensity to its main driving factors. We have, for instance: Ang and Pandiyan [12], Sun [13], Ang and Zang [14], Choi and Ang [15-16], Paul and Bhattacharya [17], Lu et al. [18], Wang et al. [19], Oh et al. [20], Akbostanci et al. [21] and Sheinbaum-Pardo et al. [22].

In the literature about decomposition of the effects of the emissions intensity and energy intensity, there are mainly two approaches: the Structural Decomposition Analysis (SDA) and the Index Decomposition Analysis (IDA). A comparison between them can be found in Hoekstra and van der Bergh [23]. Theoretical and most relevant characteristics of SDA are reviewed by Rose and Casler [24]. IDA uses index number concept in decomposition[8] and its advantage is that it can readily be applied to any available data at any level of aggregation (Ma and Stern, [31]).
In IDA approach there are mainly two methodologies: Laspeyres IDA and Divisia IDA. Ang and Zhang [14] and Sun [10] give/provide, respectively, details on these two methodologies.

Initially, the Laspeyres decomposition approach always led to a residual, which could be of a considerable size. To illustrate this see Zhang et al [11]. Sun [10] proposed a complete decomposition analysis where the residual term is distributed among the considered effects. This decomposition has long been used in the empirical literature because it can be simply calculated and easily understood. Zhang and Ang [32] refer to this as the refined Laspeyres method.

These techniques constitute a widely accepted analytical tool for policy making in energy and environmental issues. In the case of the European Union (EU), several studies have used IDA techniques in economic sectors[9].

This technique has been also widely used for other countries outside EU. Paul and Bhattacharya [17], Wang et al. [26], Liu et al. [30], and Akbostanci et al. [21] are some examples.

[8] See Ang and Zhang [25], Sun [13], Paul and Bhattacharya [17], Wang et al.[26], Wu et al. [27], Lee and Oh [28], Lise [29], and Diakoulaki and Mandaraka [9] for some applications, and Liu et al [30] and Ang and Zhang [14] for reviews about works that use this methodology.

[9] See for instance Liaskas et al., [33]; Sun [34] and [35], Bhattacharyya and Matsumura [36], Hatzigeourgiou (10), O`Mahony et al. [37] .

Also looking at the sectoral subject, many studies in relevant literature have examined energy intensity and/or emissions intensity of the manufacturing sector. For instance, Huang [38], Sinton and Levine [39], Miketa [40], Hamilton and Turton [41] and Zhang [42], Paul and Bhattacharya [17], represented earlier studies of energy intensity or CO2 emissions intensity in industrial sectors. Recently, Liao et al. [43], Ma and Stern [31], Zhang et al. [11], Zhao et al. [44], Oh et al. [20], Akbostanci et al. [21], Sheinbaum-Pardo et al. [22], O`Mahony et al. [37], extended earlier studies to sub-sectors.

For instance, Sheinbaum-Pardo et al. [22] decomposed energy consumption and CO2 emissions for Mexican manufacturing industries in the 1990-2008 period, using the LMDI method. They found important changes in the structure effect that pushed down emissions for 10 manufacturing industries' subsectors. The energy intensity effect and the carbon index effect were negative in all subsectors, with the exception of Cement and other subsectors. Another conclusion in their study are the important changes in product mix in the case of aluminium, petrochemical, paper and pulp, basic chemicals, rubber, bottled waters and sugar.

These studies are useful for understanding the methods of decomposition of energy–related CO2 emissions and for identifying the factors that have influenced the changes in the level of energy–related CO2 emissions. The most common are the output effect, the energy mix effect, the energy intensity effect and the structural effect. Hatzigeougiou et al. [45] also use the population effect and Diakoulaki and Mandaraka [9] the utility mix effect.

There is scarce literature about emissions intensity decomposition applied to Portugal. Diakoulaki and Mandaraka [9] focus on the manufacturing sector and examine energy related CO2 emissions in 14 EU countries, including Portugal. The authors explain changes in industrial CO2 emissions and also compare and evaluate the progress made in these countries in decoupling emissions from industrial growth. The analysis is performed for the period 1990–2003 and the refined Laspeyres model is used to determine the impact of 5 explanatory factors: output, energy intensity, structure, fuel mix and utility mix. They show that Portugal presents a negative structural effect, and a stabilization or decline of more energy intensive sectors such as metal or heavy chemical industry in favour of less intensive ones. They also reveal that Portugal has a weak decoupling effect, which means that the efforts undertaken have only compensated for a small part of the emissions owed to industrial growth and therefore emissions continue their upward trend, though with lower rates compared to the respective output rates. Comparing the decoupling index to the base year conditions, Portugal has initial carbon intensity well above the EU-14 average, which means that it failed to effectively exploit the existing reduction potential.

Hatzigeourgiou, Polatidis and Haralambopoulos [45] show that during the period of 1990-2020 the improvement in energy intensity in Portugal is the most significant factor that leads to a reduction in CO2 emissions, but with a moderate contribution of 16%, while the corresponding figure for the EU-25 is 40%.

There are no known studies with Vector Autoregressive (VAR) models or with IAA (i.e., advanced generalized forecast error variance decomposition and generalized impulse response techniques) using ratios of decomposition of emissions intensity, but it is important to mention some recent studies, applied to variables such as energy consumption, emissions or the GDP.

Zhang and Cheng [46], used the VAR Granger Causality and the Generalized Impulse Response to examine the causality among urban population, economic growth, energy consumption and CO2 emissions. Lee and Chien [47], applied Toda and Yamamoto Granger Causality and IAA to examine the relationship between energy consumption, capital stock and real income in G-7 countries. Menyah and Wolde-Rufael [48] explores the causal relationship among CO2 emissions, renewable and nuclear energy consumption and real GDP for the US; they also applied the Toda and Yamamoto Granger causality approach and generalized forecast error variance decomposition to examine the causality among the variables. Alam et al [49] investigates the causality relationships among energy consumption, CO2 emissions and income in India. They applied the Toda and Yamamoto Granger causality and generalized impulse response function to examine the dynamic causality relationships among their variables. Lee and Chiu [50], applied the IAA to examine the relationship among nuclear energy consumption, real oil price, oil consumption and real income from highly industrialized countries.

The remainder of this study is as follows: in Section 2 we present the data and methodology, in Section 3 the main results and in Section 4 the conclusions and policy recommendations.

2.2 Data and Methodology

All data was collected from INE (National Accounts), with a disaggregation of 36 economic sectors (annual). The details about these sectors are in appendix (table A2.1). We considered the period 1996 – 2009, because it was the most recent period for which we had common data for all variables.

We considered data about emissions of carbon dioxide from fossil origin, in 10^3 tons, denoted by CE. To obtain fossil fuels consumption, we add INE data about natural gas, coal and lignite, petroleum coke, fuel oil, diesel oil, motor gasoline, LPG and other petroleum products, in GJ, denoted by F. Total consumption of energy (emissions relevant), in GJ, is denoted by E, and/whereas Gross Domestic Product from the production side at market and constant prices, in 10^6 Euros, is denoted by GDP.

2.2.1 Decomposition Analysis

The CO2 emissions intensity (A) can be decomposed as follows:

$$A = \frac{CE^t}{GDP^t} = \sum_i \frac{CE_i^t}{F_i^t} \frac{F_i^t}{E_i^t} \frac{E_i^t}{GDP_i^t} \frac{GDP_i^t}{GDP} = \sum_i CI_i^t \, CE_i^t EI_i^t ES_i^t$$

In the summation symbol, “i” refers to the economic sector. The index variable “t” refers to the year. The change of CO2 emissions intensity between a base year 0 and a target year t, denoted by ∆A, can be decomposed into four effects: (i) the changes in the CO2 emissions compared to the fossil fuels consumption (denoted by CI effect), (ii) the changes in the fossil fuels consumption compared to total energy consumption (denoted by CE effect), (iii) the change in energy intensity effect (denoted by EI effect) and (iv) changes in the economic structure effect (denoted by ES effect), as follows:

$$\Delta A = A^t - A^0 = CI_{effect} + CE_{effect} + EI_{effect} + ES_{effect}$$

Where the effects are calculated using a technique similar to the one used by Sun [34] and Zhang et al. [11]. We exemplify for CI effect:

$$\begin{aligned} CI_{effect} = &\sum_i \Delta CI_i CE_i^0\, EI_i^0 ES_i^0 + \frac{1}{2}\sum_i \Delta CI_i(\Delta CE_i\;\; EI_i^0 ES_i^0 + CE_i^0 \Delta EI_i\;\; ES_i^0 + CE_i^0 EI_i^0 \Delta ES_i\;\;) \\ &+ \frac{1}{3}\sum_i \Delta CI_i(\Delta CE_i\;\; \Delta EI_i\;\; ES_i^0 + CE_i^0 \Delta EI_i\;\; \Delta ES_i\;\;\; + \Delta CE_i\;\; EI_i^0 \Delta ES_i\;\;) \\ &+ \frac{1}{4}\sum_i \Delta CI_i \Delta CE_i\;\; \Delta EI_i\;\; \Delta ES_i \end{aligned}$$

To obtain the different effects in percentage of the total carbon intensity effect we calculated

$$\frac{CI_{effect}}{\Delta A} \times 100\% + \frac{CE_{effect}}{\Delta A} \times 100\% + \frac{EI_{effect}}{\Delta A} \times 100\% + \frac{ES_{effect}}{\Delta A} \times 100\% = 100\%$$

CI effect can be used to evaluate the fossil fuel quality and the substitution between fossil fuels; CE effect can be interpreted as the installation of abatement technologies and the substitution of fossil fuel for renewable energy sources; EI effect is the energy intensity effect, seen as a signal of the efficiency of the energy system, technology choices, energy prices, energy conservation techniques and investments for energy saving; finally, ES effect shows the relative position of each sector in the economy.

The effects are calculated every year in the period 1996-2009. We've also calculated the effects between the last and the first year and for 36 sectors individually, for the year 2009.

We also made two additional analysis: i) dividing the 36 sectors in 2 groups: group A which includes 16 industrial sectors and group B, the 20 remaining sectors and ii) dividing the group A sectors in 2 groups: group C, that includes 5 energy sectors and group D, with the 11 remaining sectors.

2.2.2 The Innovative Accounting Approach for Granger causality

In a second step we have implemented the IAA that includes forecast error variance decomposition and IRFs.

2.2.2.1 Generalized forecast variance decomposition

The generalized forecast variance decomposition approach estimates the simultaneous shock effects using a VAR system to test the strength of causal relationship between dioxide emissions intensity (A), emissions by fossil fuels ratio (CI), fossil fuel intensity (CE), energy intensity (EI) and economic structure (ES) in the case of group C and group D, of Portuguese industry sectors.

For instance, if the EI explains more of the forecast error variance of CO2 emissions intensity, then we deduce that there is unidirectional causality from EI to emissions intensity. The bidirectional causality exists if shocks in CO2 emissions intensity also affect EI in a significant way. If shocks occurring in both series do not have any impact on the changes in CO2 emissions intensity and in EI then there is no causality between the variables.

2.2.2.2 Impulse Response Functions

We also provided a rough analysis of how long it takes for the variable to go back to the equilibrium after the long run relationship has been shocked.

One can determine how CO_2 emissions intensity responds due to its shock and to shocks in other ratios (CI, CE, EI and ES). For instance, we support the hypothesis that EI causes CO_2 emissions intensity if the impulse response function indicates significant response of CO_2 emissions intensity to shocks in EI according to shocks in other ratios.

2.3 Results and Discussion

2.3.1 Decomposition Analysis

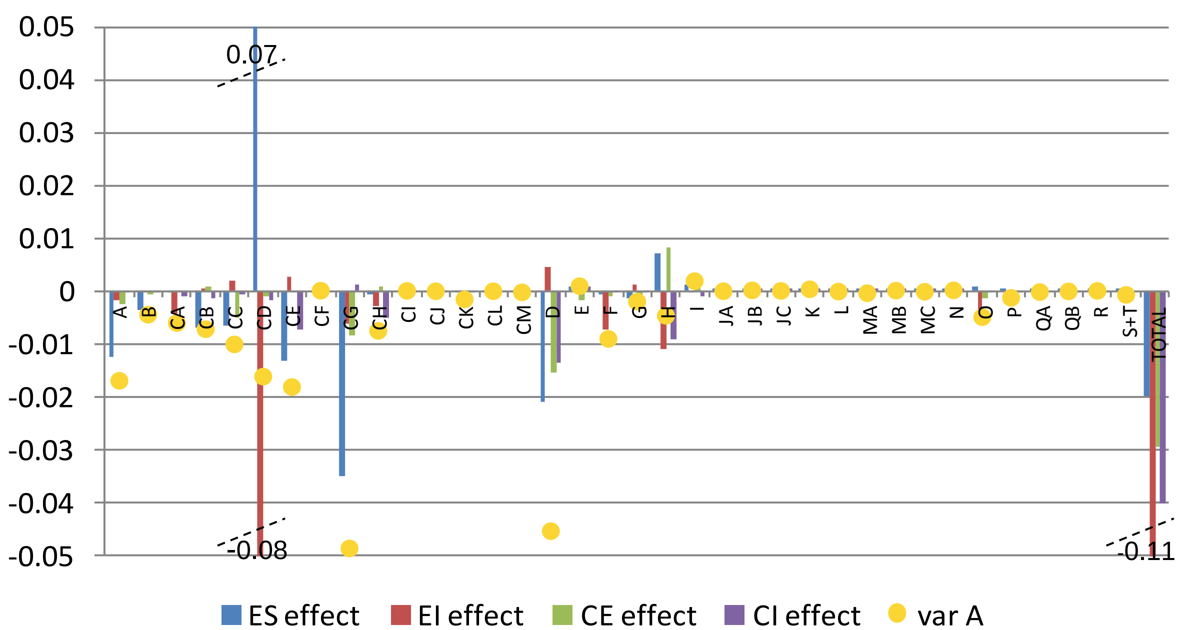
If we look at the effects for the considered period (1996-2009), we can see that the CO_2 emissions intensity (A) diminished significantly (-38.1%, obtained dividing variation of A (Var A) by the initial value of A), that is, the economy is emitting less CO_2 by each unit of goods and services produced. However, there were years in which this intensity raised/increased, such as in 1999, 2002, 2004 and 2005 (see table A2.2 in appendix).

We found that EI effect is the one that has more influence (bigger percentages) in the determination of Var A (see figure A2.1 in appendix). It means that the energy intensity of economic sectors is the most important effect in the determination of the CO_2 emissions intensity.

Regarding the evolution of each effect (see figure A2.2 in appendix), we can infer the following facts: i) CI effect often presents negative values, and its trend is decreasing, but almost constant. It means that the economy is emitting less CO_2, for the same quantity of fossil fuels used, which can reveal that the technologies used are more efficient and less polluting, for the same amount of fuel used, or that there was a substitution between fossil fuels in favour of less polluting ones; ii) CE effect is increasing, despite in some years being positive and in others negative and has registered between 1996 and 2009, a negative variation. That is, in 2009 the economy was using less fossil fuel in relation to total energy consumption, compared to 1996, but this effect had a positive trend. This means that the technologies related to fossil fuels may still have a significant role; iii) EI is the most important effect because its magnitude of values hardly influences positively or negatively the global effect; it has a negative trend and iv) ES effect has a decreasing trend, but this tendency is difficult to interpret given the level of aggregation of data for economic sectors.

The sectors that contributed the most to the reduction of emissions intensity were agriculture, forestry and fishing, electricity, gas, steam and air-conditioning supply, the manufacture of chemicals and chemical product, the manufacture of rubber and plastics products, and other non-metallic mineral products, the manufacture of wood and paper products and printing. In these sectors ES effect was the greater influence, whereas in the manufacture of coke, and refined petroleum products and construction, EI effect was the greater influence (see figure 2.1). That is, the first ones diminished its importance in the economic structure, and the second ones diminished its energy intensity and consequently the emissions intensity.

Figure 2.1 – Effects of decomposition of CO2 emissions intensity change (1996-2009) by sectors



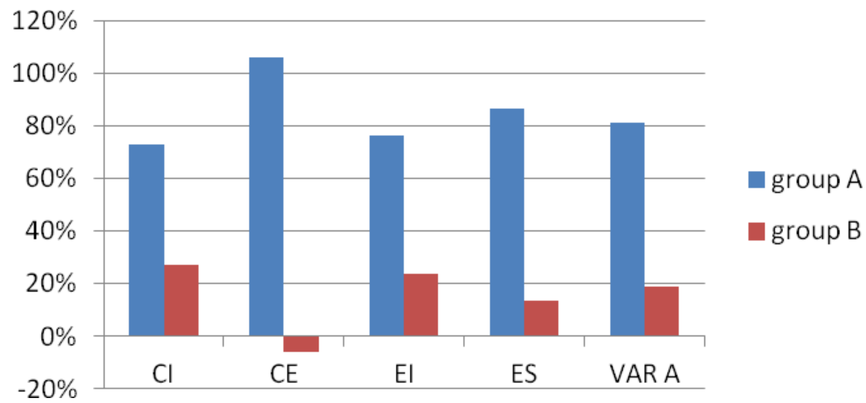
2.3.1.1 Industrial sectors

We calculated the same effects for industry separately, that is, for the 16 sectors with nº2 in A10 classification (see table A2.1 in appendix) which we will call group A sectors. We found very similar results compared to the general effects, that is, the industry is contributing largely to the effects of variation of CO_2 emissions intensity. In table 2.1 and figure 2.2, we can see the magnitude of the effects of industry sectors (group A) and of the other sectors (group B), compared to the general effects (for the 36 sectors), in percentage. The importance of group B in the determination of the general effects is negligible.

Table 2.1 - Weight of effects of industries (group A) and the remaining sectors (group B) in % of the effects of all sectors

	CI effect		CE effect		EI effect		ES effect		Var A	
	A	B	A	B	A	B	A	B	A	B
1996-1997	248%	-148%	118%	-18%	110%	-10%	104%	-4%	**555%**	**-480%**
1997-1998	98%	2%	104%	-4%	102%	-2%	108%	-8%	**136%**	**-36%**
1998-1999	96%	4%	101%	-1%	102%	-2%	52%	48%	**100%**	**0%**
1999-2000	136%	-36%	98%	2%	100%	0%	102%	-2%	**101%**	**-1%**
2000-2001	92%	8%	91%	9%	77%	23%	91%	9%	**90%**	**10%**
2001-2002	100%	0%	98%	2%	108%	-8%	112%	-12%	**144%**	**-44%**
2002-2003	94%	6%	102%	-2%	102%	-2%	191%	-91%	**98%**	**2%**
2003-2004	79%	20%	100%	0%	108%	-8%	11%	89%	**242%**	**-142%**
2004-2005	209%	-109%	100%	0%	102%	-2%	-19%	119%	**161%**	**-61%**
2005-2006	-255%	355%	112%	-12%	91%	9%	97%	3%	**74%**	**26%**
2006-2007	-175%	275%	89%	11%	82%	18%	649%	-548%	**70%**	**30%**
2007-2008	104%	-4%	93%	7%	71%	29%	98%	2%	**76%**	**24%**
2008-2009	71%	29%	106%	-6%	78%	22%	93%	7%	**94%**	**6%**
1996-2009	73%	27%	106%	-6%	76%	24%	87%	13%	**81%**	**19%**

Figure 2.2 - Weight of effects of industries (group A) and the remaining sectors (group B) in % of the effects of all sectors (1996-2009)



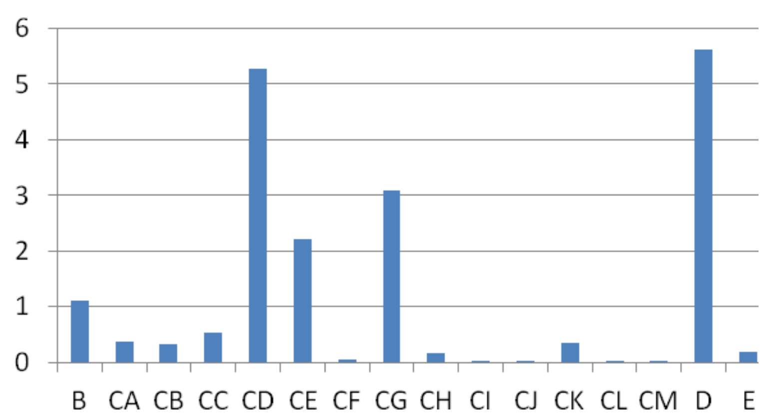
For the industrial sector we can see in table 2.2., that Var A was negative for this period, that is, these sectors are issuing less CO2 per unit of GDP produced (-31%). EI effect is the most significant effect in this reduction, for most years, which reveals an effort to reduce the energy intensity in these activities.

Looking at the emissions intensity of industrial sectors, for the year of 2009 (see figure 2.3), we can see that there are 5 sectors that differ from the others: B (mining and quarrying), CD (the manufacture of coke, and refined petroleum products), CE (the manufacture of chemicals and chemical products), CG (the manufacture of rubber and plastics products, and other non-metallic mineral products) and D (electricity, gas, steam and air-conditioning supply). These are also some of the sectors that most contributed to the variation of emissions intensity in this period, as mentioned above. So we thought it relevant to do a particular analysis of these sectors. From now on we will call this set of sectors group C (and the remaining industrial sectors group D). We have included here, the energy sectors, particularly the sectors of coal, oil, electricity and gas.

Table 2.2 - Complete decomposition of CO2 emissions intensity change (1996-2009) for industrial sectors (Group A)

	CI effect		CE effect		EI effect		ES effect		var A	
1996-1997	0.004	-211%	-0.021	1076%	-0.025	1321%	0.040	-2086%	**-0.002**	**100%**
1997-1998	-0.017	403%	-0.020	477%	0.054	-1301%	-0.022	522%	**-0.004**	**100%**
1998-1999	-0.010	-26%	-0.075	-198%	0.121	318%	0.003	7%	**0.038**	**100%**
1999-2000	0.005	-9%	0.050	-86%	-0.095	163%	-0.018	31%	**-0.058**	**100%**
2000-2001	-0.008	30%	0.006	-22%	-0.003	10%	-0.021	82%	**-0.026**	**100%**
2001-2002	-0.007	-47%	-0.035	-240%	0.064	440%	-0.008	-53%	**0.014**	**100%**
2002-2003	0.004	-9%	0.057	-117%	-0.114	237%	0.005	-10%	**-0.048**	**100%**
2003-2004	-0.002	-139%	-0.039	-2972%	0.041	3183%	0.000	27%	**0.001**	**100%**
2004-2005	0.002	19%	-0.030	-247%	0.039	325%	0.000	3%	**0.012**	**100%**
2005-2006	0.000	1%	0.041	-114%	-0.097	268%	0.020	-55%	**-0.036**	**100%**
2006-2007	0.003	-12%	0.025	-107%	-0.048	208%	-0.003	11%	**-0.023**	**100%**
2007-2008	-0.005	36%	-0.012	87%	-0.009	66%	0.012	-90%	**-0.014**	**100%**
2008-2009	-0.002	11%	0.013	-66%	0.012	-60%	-0.042	215%	**-0.020**	**100%**
1996-2009	-0.029	18%	-0.031	19%	-0.088	53%	-0.017	11%	**-0.166**	**100%**

Figure 2.3 – Portuguese Industry Emissions Intensity in 2009



We can see in figure 2.4, that the effects of this group of industries, represent an importance of nearly 100%, in each year of the period studied, which means that these 5 sectors have a great influence on the determination of the observed intensity of CO2 emissions.

Figure 2.4 - Relevance (in %) of the effects of group C in the effects of industrial sectors

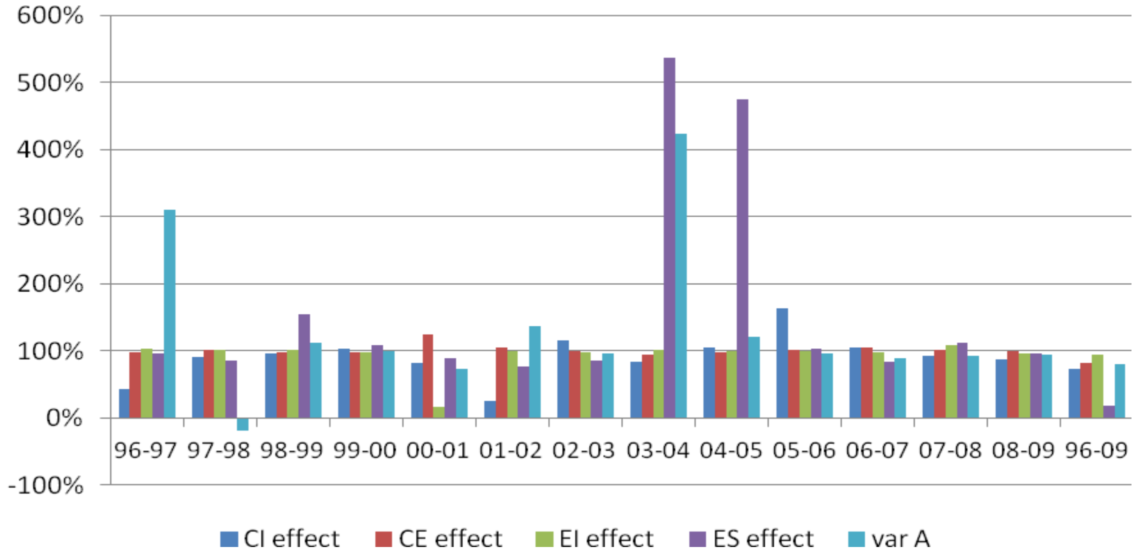
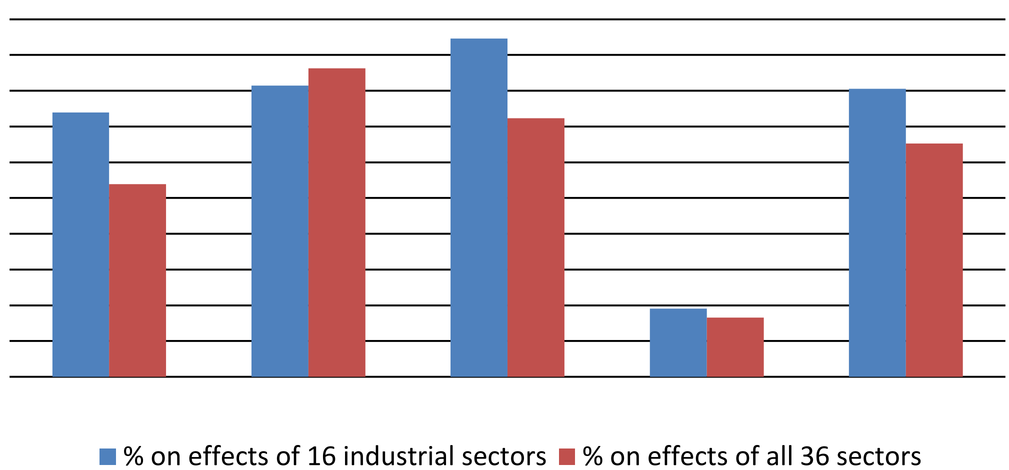


Figure 2.5 confirms the previous idea. The only effect that is not so relevant is the ES effect, which may mean that these sectors are losing importance in the structure of the economy.

We can also observe that these five sectors contribute to 81% and 65% of the total variation of the emissions intensity, of the industry and of the overall economy, respectively.

Figure 2.5 - Relevance (in %) of the effects of group C in the effects of industrial sectors, and in the effects of all 36 sectors, for the period 1996-2009



In Figure 2.6 and in table 2.3, we can see that in group C there is a decrease of Var A for the period considered, and the EI effect reveals to be the most important one in this reduction. Nevertheless, in a few years it is the ES effect that predominates. This means that in the 5 most relevant sectors for determining the emissions intensity in Portugal, the reduction of energy consumption is critical, but it is also critical to reduce the importance of these sectors in the economy (in favour of less polluting sectors). Note that the CE effect, though not predominant as the most important, has a significant relevance, and is opposite to the effect of EI. This makes sense because by definition of each effect, if power consumption decreases, then so should EI decrease and CE increase (for the same level of GDP and fossil fuels).

Figure 2.6 - Complete decomposition of CO2 emissions intensity change (1996-2009) of group C sectors

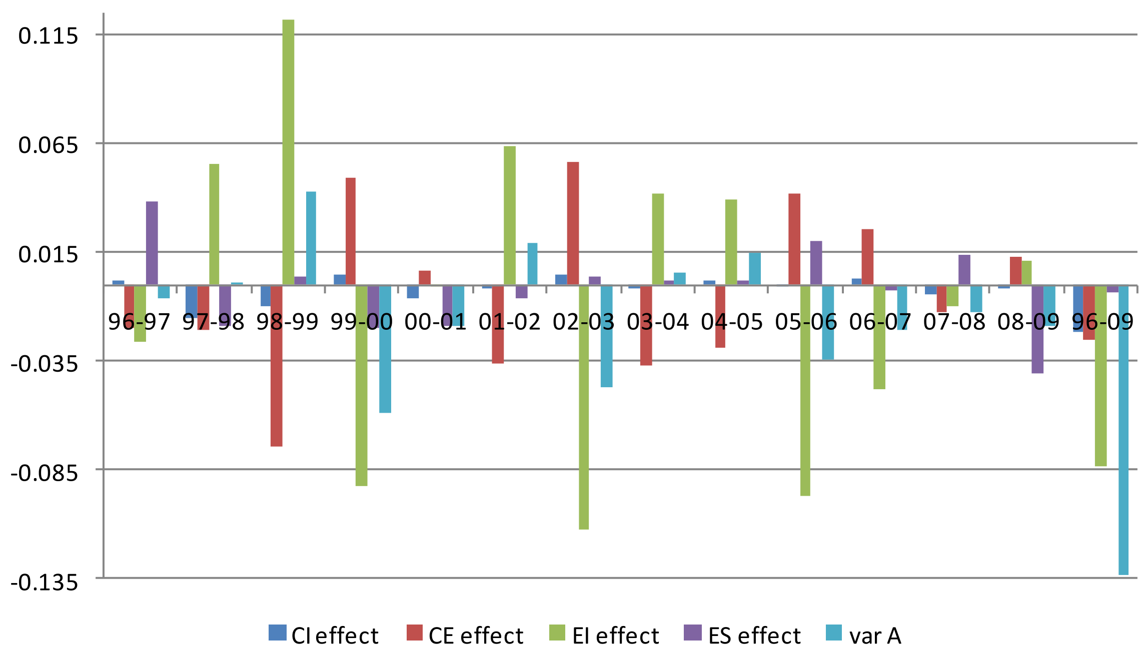


Table 2.3 - Complete decomposition of CO2 emissions intensity change in percentage (%) of Var A of group C and D

	CI effect		CE effect		EI effect		ES effect	
	C	D	C	D	C	D	C	D
1996-1997	-29.4	57.7	337.0	-12.9	439.9	23.7	-647.6	31.4
1997-1998	-1921.8	29.5	-2546.7	-8.9	6917.7	18.8	-2349.2	60.6
1998-1999	-22.6	6.6	-173.5	27.9	287.0	36.0	9.1	29.5
1999-2000	-8.9	-1170.3	-83.8	6311.4	158.7	-13927.4	34.0	8886.3
2000-2001	34.4	19.5	-37.1	19.4	2.3	29.5	100.4	31.6
2001-2002	-8.9	93.8	-183.9	-32.5	322.6	6.9	-29.8	31.9
2002-2003	-11.0	51.7	-120.2	-18.8	240.2	124.1	-9.0	-57.0
2003-2004	-27.5	6.9	-667.2	46.0	760.6	10.7	34.1	36.4
2004-2005	16.3	3.9	-197.6	28.4	268.3	10.4	13.0	57.3
2005-2006	1.7	-15.0	-121.5	59.0	279.2	3.7	-59.4	52.2
2006-2007	-14.3	6.4	-124.5	53.5	228.3	21.9	10.5	18.2
2007-2008	36.0	37.1	95.4	-12.0	78.2	-75.7	-109.6	150.5
2008-2009	10.1	22.9	-68.8	-9.9	-61.3	-44.8	220.1	131.8
1996-2009	16.3	23.7	19.1	18.0	62.1	14.7	2.5	43.5

In relation to energy sectors, the manufacture of coke and refined petroleum products and the electricity, gas, steam and air-conditioning supply sectors (CD and D in figure 2.1 above, respectively), we can see that they are the fifth and the second largest contributors to the reduction of CO2 emissions intensity, respectively, in the whole economy. Nonetheless, CD has the most important EI negative effect, that is, it is the main contributor for the reduction of CO2 emissions intensity, through the reduction of energy intensity. On the other hand, it also has the biggest positive ES effect, which almost eliminates the first effect.

In the electricity, gas, steam and air-conditioning supply sector the ES, CE and CI effects have an important influence in the reduction of emissions intensity, while its EI effect is positive. It means that this sector lost importance in the economy, diminished its emissions and the use of fossil fuels, but even so had a bad result in energy intensity. On the other hand, the manufacture of coke, and refined petroleum products, reduced its emissions intensity by the reduction of energy intensity, but gained importance in economic structure.

Comparing the results with other studies that infer to Portugal, we can say that our conclusions confirm the results of Diakoulaki and Mandaraka [9] regarding the fact that ES effect is negative and that energy intensive sectors are reducing their importance in the economy. The relative importance that fossil fuels still show in the Portuguese economy is in accordance with the “decoupling effect” found by the authors.

Hatzigeorgiou et al. [45], have in common the result that the EI effect is the most important in determining the variation of energy intensity, although in this study its importance is of 16% and ours is 56%. If we consider only the 5 sectors of group C, the percentage is of 62.1%, while for group D it is only 11%. The different results may have to do with the different periods analysed and the sectors considered.

2.3.2 Generalized variance decomposition

Table 2.4 presents the results of the generalized variance decomposition over a ten-year period for group C and group D industry sectors. The variance decomposition explains how much of the predicted error variance of a variable is described by innovations generated from each independent variable in a system, over various time horizons.

Table 2.4 - Variance decomposition of group C and D sectors

	A		CI		CE		EI		ES	
Period	**C**	**D**	**C**	**D**	**C**	**D**	**C**	**D**	**C**	**D**
					Variance Decomposition of A					
1	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	96.51	95.72	0.01	0.11	0.00	1.30	0.43	2.75	3.05	0.12
3	94.95	93.88	0.23	0.11	1.12	1.35	0.94	4.44	2.76	0.22
4	93.92	92.37	0.21	0.32	2.03	1.24	1.08	5.82	2.75	0.25
5	93.03	90.71	0.20	0.74	2.90	1.10	1.21	7.20	2.66	0.26
10	90.16	80.54	0.80	4.05	5.46	1.06	1.17	14.14	2.42	0.22

	A		CI		CE		EI		ES	
Period	**C**	**D**	**C**	**D**	**C**	**D**	**C**	**D**	**C**	**D**
Variance Decomposition of CI										
1	0.06	28.44	99.94	71.56	0.00	0.00	0.00	0.00	0.00	0.00
2	0.53	25.27	94.44	70.52	1.57	3.38	2.49	0.03	0.97	0.80
3	1.87	24.35	92.89	70.85	2.78	3.43	1.78	0.16	0.68	1.20
4	3.26	23.73	89.15	71.19	5.75	3.46	1.30	0.30	0.53	1.31
5	4.54	23.26	86.02	71.55	7.99	3.35	1.03	0.50	0.42	1.34
10	7.47	21.97	76.66	71.58	15.13	3.09	0.54	2.10	0.20	1.27
Variance Decomposition of CE										
1	4.77	0.07	0.16	22.56	95.08	77.38	0.00	0.00	0.00	0.00
2	5.21	0.29	0.37	24.86	89.08	74.09	0.82	0.45	4.51	0.30
3	4.32	0.60	0.71	24.13	89.95	74.38	0.89	0.58	4.13	0.31
4	4.04	1.22	1.18	23.50	89.35	74.02	0.98	0.95	4.45	0.30
5	4.10	1.98	1.52	22.67	88.64	73.73	1.38	1.36	4.36	0.27
10	5.53	6.62	1.97	18.68	85.32	69.63	2.64	4.87	4.53	0.21
Variance Decomposition of EI										
1	97.84	47.00	0.32	8.34	0.21	7.88	1.63	36.77	0.00	0.00
2	92.83	32.39	0.57	6.77	0.15	8.40	2.84	52.44	3.61	0.01
3	91.05	25.94	0.97	6.72	0.74	8.10	3.94	59.23	3.30	0.01
4	90.22	21.61	0.90	6.95	1.22	7.39	4.23	64.04	3.42	0.01
5	89.67	18.29	0.85	7.16	1.61	6.68	4.47	67.86	3.40	0.01
10	88.09	8.90	1.68	7.32	2.38	3.93	4.36	79.84	3.49	0.01
Variance Decomposition of ES										
1	25.06	6.71	1.05	9.39	0.33	0.16	26.54	4.48	47.01	79.26
2	23.58	3.47	2.07	8.45	0.79	0.52	22.76	8.65	50.81	78.91
3	21.02	2.44	3.89	8.77	1.24	0.38	20.03	8.89	53.82	79.52
4	19.28	2.00	5.39	9.60	1.48	0.36	18.08	8.88	55.77	79.16
5	17.69	1.87	6.65	10.40	2.01	0.32	16.45	8.70	57.19	78.72
10	13.55	2.76	9.20	13.13	2.46	0.22	12.36	7.54	62.43	76.35

For group C sectors, the empirical evidence indicates that 90.16 per cent of CO2 emissions intensity is due to its own innovative shocks. The standard deviation shock in CE is the variable that better explains energy pollutants intensity, although with a low percentage (5.46 per cent). A small portion of CO2 emissions intensity is explained by innovative shocks in ES (2.42 per cent), EI (1.17 per cent) and CI (0.8 per cent).

A 15.13 per cent of CI is explained by one standard deviation shock in CE and 76.66 per cent is due to CI effect by its own innovative shocks. A small portion of CI effect is explained by innovative shocks stemming in A (7.46 per cent) and an insignificant portion of CI is explained by EI and ES, i.e., 0.54 and 0.20 per cent respectively.

CE explains itself by 85.32 per cent. A little contribution (5.53 and 4.53 per cent) exists in CE by shocks stemming in A and ES respectively. CI and EI explain CE minimally by 1.97 and 2.64 per cent respectively.

A strong and significant portion of 88.08 per cent of EI is explained by one standard deviation shock in CO2 emissions intensity and a small portion of 4.36 per cent is contributed to innovative shocks in EI.

The contribution of CO2 emissions intensity and EI to ES are 13.55 and 12.36 per cent respectively and the remaining 62.43 per cent is explained by its own standard innovative shocks and by the shocks on CI (9.2 per cent) and CE (2.46 per cent).

Taking 5% as a threshold, we can infer that there is bidirectional causality between CO2 emissions intensity (A) and the share of fossil fuels in total energy consumption (CE). This means that one of the ways to reduce the emissions intensity will be by reducing the consumption of fossil fuels and increasing the use of renewable energy. The opposite will occur if we reduce emissions intensity by making investments in renewable energy, as we should have to monetize these same investments, and therefore reduce the use of fossil fuels.

Considering also the reference of 5%, we can infer that there is unidirectional causality from A to CI, to EI and to ES, from CE to CI, from CI to ES and from EI to ES. This means that the intensity of emissions causes all the factors in which it decomposes... which makes sense by definition. On the other hand, the share of fossil fuels in total energy consumption affects emissions per unit of fossil fuel. In other words, if we reduce the share of fossil fuels, we will also reduce emissions per unit of fossil, because in addition to reducing, there should be a change in the mix of fossil fuels in favour of cleaner fuels. Economic structure is also affected by the emissions by fossil fuels and energy intensity since the efforts made to change technology, to change fossil fuel mix and to reduce energy consumption, influence the importance of each sector in the economy.

The results reported in Table 2.4 for D group sectors, indicate that dioxide emissions intensity is explained by EI (14.14 per cent), 80.54 per cent is contributed by its own innovative shocks, while the contribution of CI, CE and ES is negligible.

For CI the contribution of CO2 emissions intensity is decreasing over time but explains 21.97 per cent of its predicted error variance at period 10. The contribution of the other variables is negligible.

For CE the contribution of CI is decreasing over time and explains 18.68 per cent of its predicted error variance at period 10. The contribution of emissions intensity is of 6.62 per cent and the effects of EI and ES are insignificant. CO2 emissions intensity and CI are the relevant variables explaining EI (8.9 and 7.32 per cent respectively).

A 13.13 per cent of ES is explained by one standard deviation shock in CI and a 76.35 per cent is contributed to ES by its own innovative shocks. EI is also a relevant variable causing ES, with a percentage of 7.54.

In group D industries, considering the percentage of 5%, we found unidirectional causality from A to CI and CE, from CI to CE, CI and to ES, and from EI to ES. This means that a reduction in emissions by fossil fuel implies a decrease of the importance of fossil energy consumption and also of energy intensity.

Bidirectional causality is found between A and EI, which means that a lower emissions intensity causes low energy intensity and vice-versa.

Common to these two groups of industries we highlight the following: emissions intensity influences the emissions per unit of fossil fuel, that is, if A decreases, then CI decreases too, because we use less fossil fuels or the mix of fossil fuels is different. It is the emissions by fossil fuel and energy intensity that cause the structure of the economy. This means that if we reduce CI and EI we will change the mix of fossil fuels used in the economy or we will change the technology, which could adjust the importance of certain sectors in this economy. By changing the energy intensity there may be sectors that contract, including the energy-intensive ones in favour of less energy intensive ones.

2.3.2.1 Impulse Response Functions

With the aim of simulating the behaviour over time of the variables involved in the study, we analysed the IRFs underlying the two groups of industries (C and D). The IRFs indicate how long and to what extent the dependent variable reacts to shock in forcing variables.

For group C sectors, we have the IRFs represented at figure 2.7. We can see that emissions intensity reacts more significantly to shocks in CE, compared to shocks in other variables. This reaction is positive, as well as the reaction to a shock in EI. Nevertheless, the latter ends up disappearing in the long term. The response to a shock in CI is negative until it reaches the 4th time horizon, becoming thereafter positive. The reaction to ES is negative, bigger in the short run, but dissipates in the long run.
The intensity of emissions compared to fossil fuels reacts more sharply to shocks in CE (negatively) and to shocks in A (positively). Concerning shocks in EI and ES, the short run reaction is positive but after the third period it dissipates.

For the weight of fossil energy consumption (CE), shocks that affect it more in the long run (positively) are the shocks in emissions intensity (A) and in the structure of the economy (ES). For ES there is a significant positive reaction in the short term, while for A the short-term reaction is negative, becoming positive in the 3rd period. The reaction of CE to a shock in energy intensity is positive only until the second period. If a shock in CI occurs, then CE has a slightly negative reaction in the short run, becoming positive in the 2nd period and vanishing in the long run.

Energy intensity has a significant and positive reaction to a shock in emissions intensity, with a slightly negative response to shocks in other variables. These responses become positive for shocks in CE and CI in the 2nd period and 5th respectively.

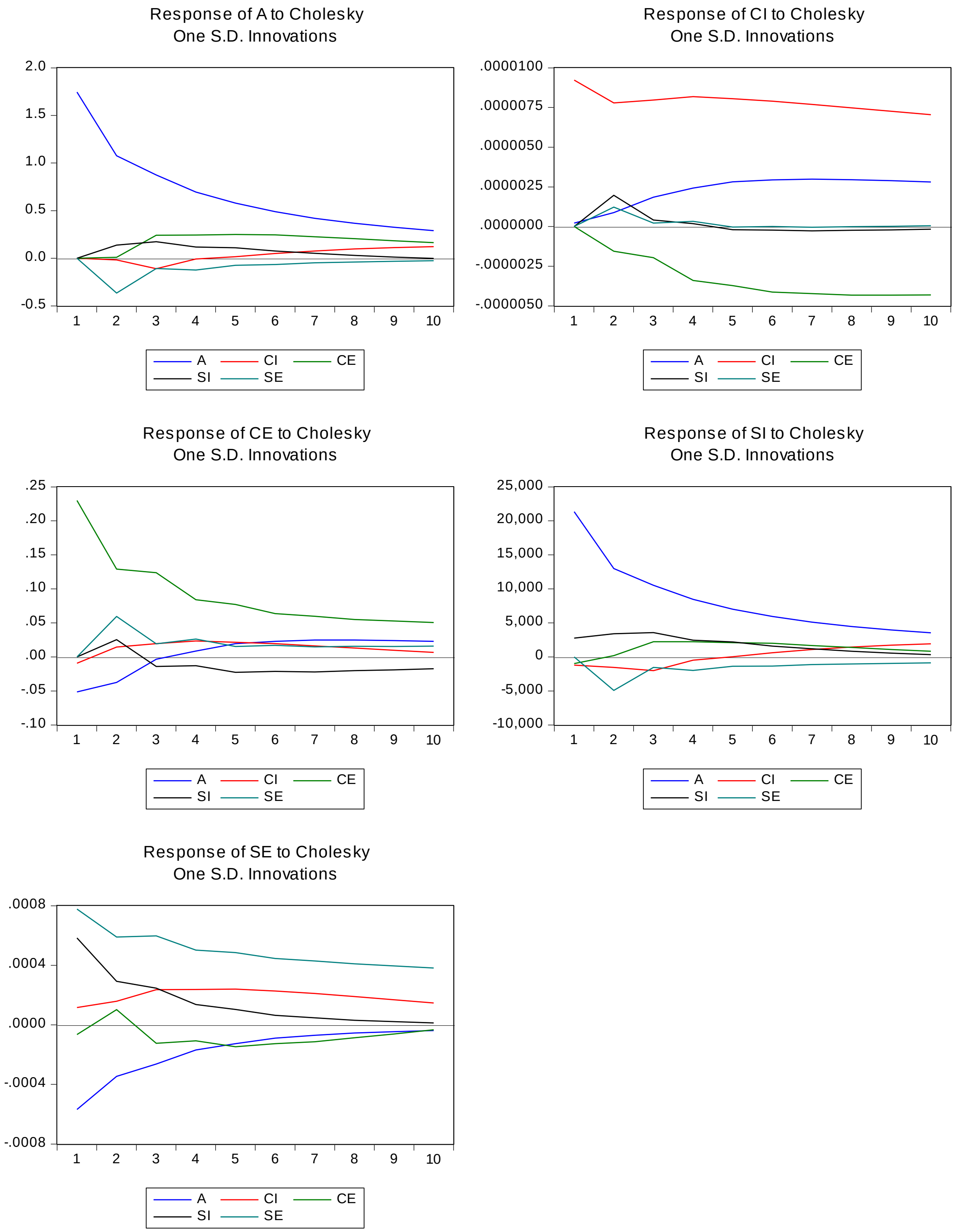
The structure of the economy has a relevant reaction in the short term to a shock in energy intensity and in emissions intensity, being positive for the first variable and negative for the second. But these reactions almost vanish in the long run. ES shows a positive reaction to a shock in CI, which lingers in the long run.

The analysis of IRFs suggests the occurrence of the same causality relationships that were observed in variance decomposition analysis.

The results in figure 8 show reactions of the considered variables for group D industries. We confirm a positive response of CO2 emissions intensity due to one standard deviation shock in energy intensity. However, the response to CI changes from positive to negative after the 2nd time horizon, maintaining its level in the long run.

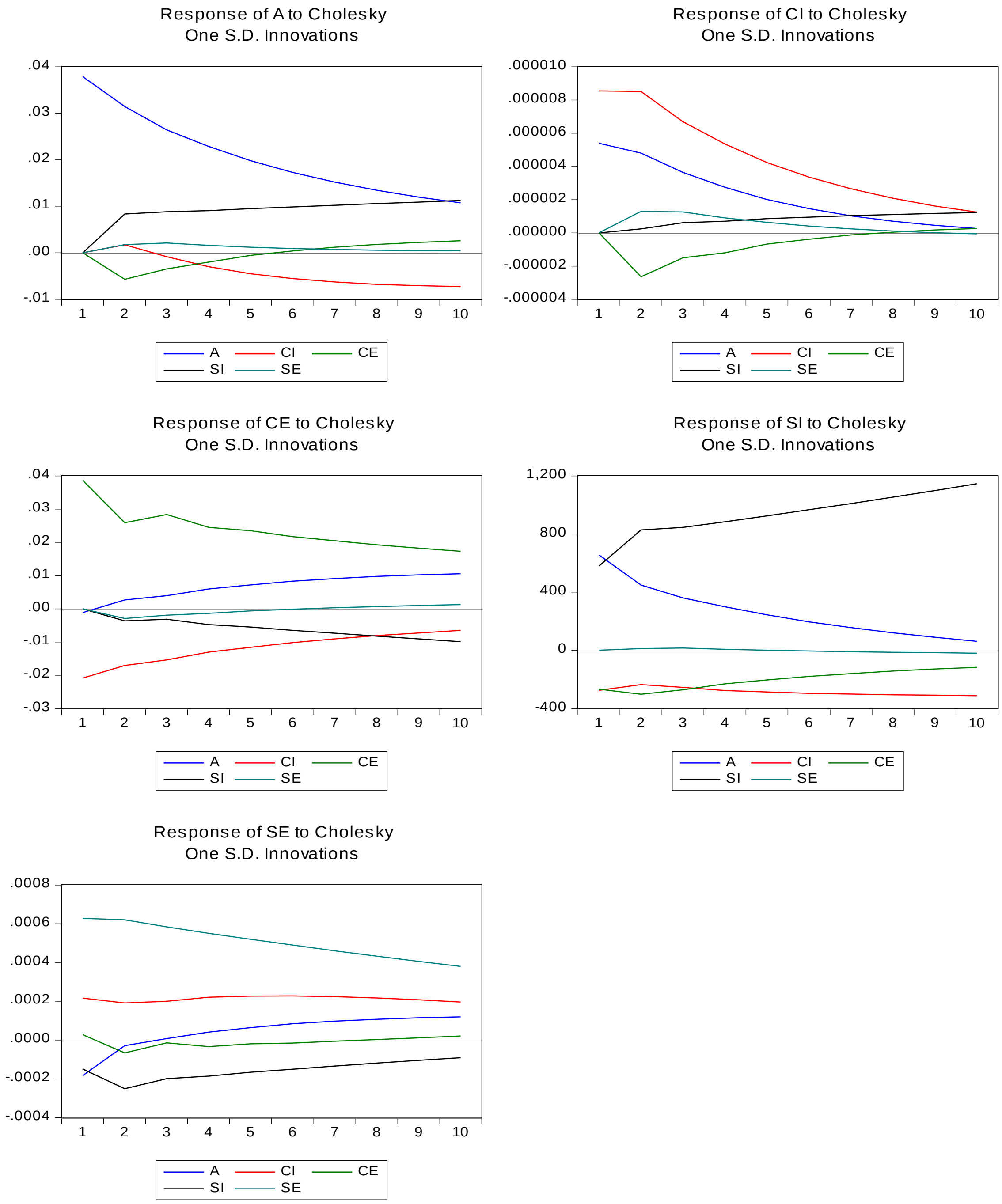
The response of CI to shock in CO2 emissions intensity is positive but is decreasing in all time horizons. CI responds negatively to a shock in CE, which in turn responds positively to shocks in emissions intensity and negatively to shocks in CI and EI. Energy intensity is affected positively by emissions intensity but this effect tends to disappear in the long run. The reaction is negative to shocks in CI and CE. Finally, economic structure is affected positively by CI and negatively by EI. Emissions intensity also affects ES negatively but in the second period the reaction becomes positive.

Figure 2.7 - IRFs for Group C sectors



The analysis of IRFs suggests the occurrence of the same causality relationships that were observed in variance decomposition analysis, with the exception of the bidirectional causality between A and CI and unidirectional causality from CE to EI. Nevertheless, the reaction seen in IRFs is not significant for these different results.

Figure 2.8 - IRFs for Group D sectors



2.4 Conclusions

Is this research, we used the 'complete decomposition' technique to examine CO2 emissions intensity and its components. We considered CO2 intensity for 36 economic sectors as well as its reflecting changes over the 1996-2009 period. In addition, we have implemented the IAA that includes forecast error variance decomposition and IRFs, applied to the factors in that emissions intensity was decomposed.

With this analysis we can draw conclusions about the evolution of the intensity of CO2 emissions in Portugal and what its main determinants were in the past, but also inference about the behaviour of these variables in the future. This allows us to make a more complete approach, since implementing any policy, in particular an energy or environmental policy, it is important to know the past context but also to know in what direction the future will evolve, because it is in this timeframe that the policy will have effects.

After making the decomposition analysis we observed that the emissions intensity decreased, and the effect that contributed more to this was energy intensity. The sectors that have contributed more to reduce the intensity of emissions through the reduction of energy intensity are the manufacture of coke, refined petroleum products and construction. Yet, there are sectors that contributed to reduce energy intensity because of lower production in sectors of the economy such as agriculture, forestry and fishing, electricity, gas, steam and air-conditioning supply, the manufacture of chemicals and chemical product, the manufacture of rubber and plastics products, and other non-metallic mineral products, the manufacture of wood and paper products, and printing.

In 2009 the economy was using less fossil fuel in relation to total energy consumption, compared to 1996, but this effect had a positive trend. This means that the technologies related to fossil fuels may still have a significant role.

For the majority of sectors, since the energy intensity has more weight in determining the intensity of emissions, reducing energy consumption must be a priority in policymaking. This effect has already had a tendency of decreasing. This shows that the technologies used are more efficient and less polluting, for the same amount of fuel used, or that there was a substitution between fossil fuels in favour of less polluting energy.

It has been shown that there are five critical sectors in determining the intensity of CO2 emissions (mining and quarrying, the manufacture of coke, and refined petroleum products, the manufacture of chemicals and chemical products, the manufacture of rubber and plastics products, and other non-metallic mineral products and electricity, gas, steam and air-conditioning supply). The results of the decomposition of the energy intensity for these sectors have an important influence on the results for the economy as a whole.

Looking at these five sectors, results show that the reduction of energy consumption is critical, as well as reducing the importance of these sectors in the economy (in favour of less polluting ones).

Policies aimed at reducing the energy intensity will cause a reduction in fossil fuel consumption and / or a change in the mix of fossil fuels. Such policies have important effects on the sectoral structure of the economy’s GDP, in favour of less energy intensive sectors.

In the future, particularly for industries, it is expected, that emissions intensity will affect and will be affected by the importance of fossil fuels in energy consumption. Any policy that encourages the reduction of the use of fossil fuels in favour of renewable energy will end up decreasing emissions intensity.

The results reveal that a decrease in the use of fossil fuels will reduce emissions per unit of fossil fuel used. This shows that there will be a change in technology or a change in the mix of fossil fuels used. In turn, this will require a change in the structure of the GDP of the economy in favour of less energy-intensive sectors. As it is shown that causality between A and CE and between A and CI is bivariate, this path will take us again to the reduction of energy intensity level.

The present times of recession will help in the reduction of the emissions intensity through the decrease of economic activity. Additionally, other policies may help to follow the right path and make the most of these causal relationships. The European Commission presented in April 2011 a proposal with two main goals: (i) to contribute to growth and employment by shifting taxation from labour to consumption, (ii) to promote energy efficiency and consumption of more environmentally friendly products. Furthermore, the proposal aims to complement the existing European Union Emission Trade System (EU ETS) by applying a CO2 tax on sectors that are out of its present scope (transport, households, agriculture and small industries). If approved, this will result in a sort of hybrid regulation system for CO2 emissions.

On the other hand, a few European Directives were aimed at improving the performance of uncovered sectors, namely the European Energy Performance in Buildings Directive (EPBD), the Ecodesign Directive, the Biofuels Directive and the Energy Services Directive.

However, the sectors mentioned in this study as having greater relevance in determining the emissions intensity and its components are sectors that are already regulated by EUETS.

Future research in this surrounding context can strike a study that decomposes emissions intensity including the population effect (as in Hatzigeorgiou [45]), and on the sectoral analysis the effect of the number of workers per sector could be considered.

Appendix

Table A2.1 - National Accounts Classification by Industry

A10	A38	Description
1	A	Agriculture, forestry and fishing
2	B	Mining and quarrying
2	CA	Manufacture of food products, beverages and tobacco products
2	CB	Manufacture of textiles, wearing apparel and leather products
2	CC	Manufacture of wood and paper products, and printing
2	CD	Manufacture of coke, and refined petroleum products
2	CE	Manufacture of chemicals and chemical products
2	CF	Manufacture of basic pharmaceutical products and pharmaceutical preparations
2	CG	Manufacture of rubber and plastics products, and other non-metallic mineral products
2	CH	Manufacture of basic metals and fabricated metal products, except machinery and equipment
2	CI	Manufacture of computer, electronic and optical products
2	CJ	Manufacture of electrical equipment
2	CK	Manufacture of machinery and equipment n.e.c.
2	CL	Manufacture of transport equipment
2	CM	Manufacture of furniture; other manufacturing; repair and installation of machinery and equipment
2	D	Electricity, gas, steam and air-conditioning supply
2	E	Water, sewerage, waste management and remediation activities
3	F	Construction
4	G	Wholesale and retail trade, repair of motor vehicles and motorcycles
4	H	Transportation and storage
4	I	Accommodation and food service activities
5	JA	Publishing, audio visual and broadcasting activities
5	JB	Telecommunications
5	JC	Computer programming, consultancy and related activities; information service activities
6	K	Financial and insurance activities
7	L	Real estate activities
8	MA	Legal and accounting activities; activities of head offices; management consultancy activities; architecture and engineering activities; technical testing and analysis
8	MB	Scientific research and development
8	MC	Advertising and market research; other professional, scientific and technical activities; veterinary activities
8	N	Administrative and support service activities
9	O	Public administration and defence; compulsory social security
9	P	Education
9	QA	Human health services
9	QB	Social work activities
10	R	Arts, entertainment and recreation
10	S	Other services activities
10	T	Activities of households as employers of domestic personnel and undifferentiated goods and services production of households for own use
10	U	Activities of extra-territorial organizations and bodies

Table A2.2 - Complete decomposition of CO2 emissions intensity change (1996-2009)

	CI effect		CE effect		EI effect		ES effect		Var A	
1996-1997	0.002	-471%	-0.018	5079%	-0.023	6641%	0.039	-11149%	**0**	**100%**
1997-1998	-0.017	559%	-0.019	623%	0.053	-1741%	-0.02	659%	**-0.003**	**100%**
1998-1999	-0.01	-28%	-0.075	-197%	0.118	311%	0.005	13%	**0.038**	**100%**
1999-2000	0.004	-6%	0.051	-89%	-0.095	164%	-0.018	31%	**-0.058**	**100%**
2000-2001	-0.009	30%	0.006	-21%	-0.003	11%	-0.023	81%	**-0.029**	**100%**
2001-2002	-0.007	-68%	-0.035	-353%	0.059	589%	-0.007	-68%	**0.01**	**100%**
2002-2003	0.005	-10%	0.056	-113%	-0.112	228%	0.003	-5%	**-0.049**	**100%**
2003-2004	-0.002	-421%	-0.038	-7148%	0.038	7103%	0.003	567%	**0.001**	**100%**
2004-2005	0.001	15%	-0.03	-398%	0.038	511%	-0.002	-28%	**0.007**	**100%**
2005-2006	0	0%	0.037	-75%	-0.106	217%	0.02	-42%	**-0.049**	**100%**
2006-2007	-0.002	5%	0.028	-84%	-0.059	177%	0	1%	**-0.033**	**100%**
2007-2008	-0.005	27%	-0.013	72%	-0.013	71%	0.013	-70%	**-0.018**	**100%**
2008-2009	-0.003	14%	0.012	-58%	0.015	-73%	-0.045	217%	**-0.021**	**100%**
1996-2009	-0.04	20%	-0.03	15%	-0.115	56%	-0.02	10%	**-0.205**	**100%**

Table A2.3 - Complete decomposition of CO2 emissions intensity change (1996-2009) for groups A and B

	CI effect		CE effect		EI effect		ES effect		Var A	
	A	B	A	B	A	B	A	B	A	B
1996-1997	0.002	0.002	-0.020	-0.001	-0.026	0.001	0.039	0.001	**-0.006**	**0.004**
1997-1998	-0.015	-0.002	-0.020	0.000	0.055	-0.001	-0.019	-0.003	**0.001**	**-0.005**
1998-1999	-0.010	0.000	-0.074	-0.001	0.123	-0.002	0.004	-0.001	**0.043**	**-0.005**
1999-2000	0.005	0.000	0.049	0.001	-0.093	-0.002	-0.020	0.002	**-0.058**	**0.000**
2000-2001	-0.007	-0.001	0.007	-0.001	0.000	-0.002	-0.019	-0.002	**-0.019**	**-0.007**
2001-2002	-0.002	-0.005	-0.036	0.002	0.064	0.000	-0.006	-0.002	**0.020**	**-0.005**
2002-2003	0.005	-0.001	0.056	0.000	-0.113	-0.002	0.004	0.001	**-0.047**	**-0.001**
2003-2004	-0.002	0.000	-0.037	-0.002	0.042	-0.001	0.002	-0.002	**0.006**	**-0.004**
2004-2005	0.002	0.000	-0.029	-0.001	0.040	0.000	0.002	-0.002	**0.015**	**-0.003**
2005-2006	-0.001	0.000	0.042	-0.001	-0.097	0.000	0.021	-0.001	**-0.035**	**-0.002**
2006-2007	0.003	0.000	0.026	-0.001	-0.048	-0.001	-0.002	0.000	**-0.021**	**-0.002**
2007-2008	-0.005	0.000	-0.012	0.000	-0.010	0.001	0.014	-0.002	**-0.013**	**-0.001**
2008-2009	-0.002	0.000	0.013	0.000	0.011	0.001	-0.041	-0.001	**-0.019**	**-0.001**
1996-2009	-0.022	-0.008	-0.026	-0.006	-0.083	-0.005	-0.003	-0.014	**-0.134**	**-0.032**

Figure A2.1 - Complete decomposition of CO2 emissions intensity change in percentage of var A

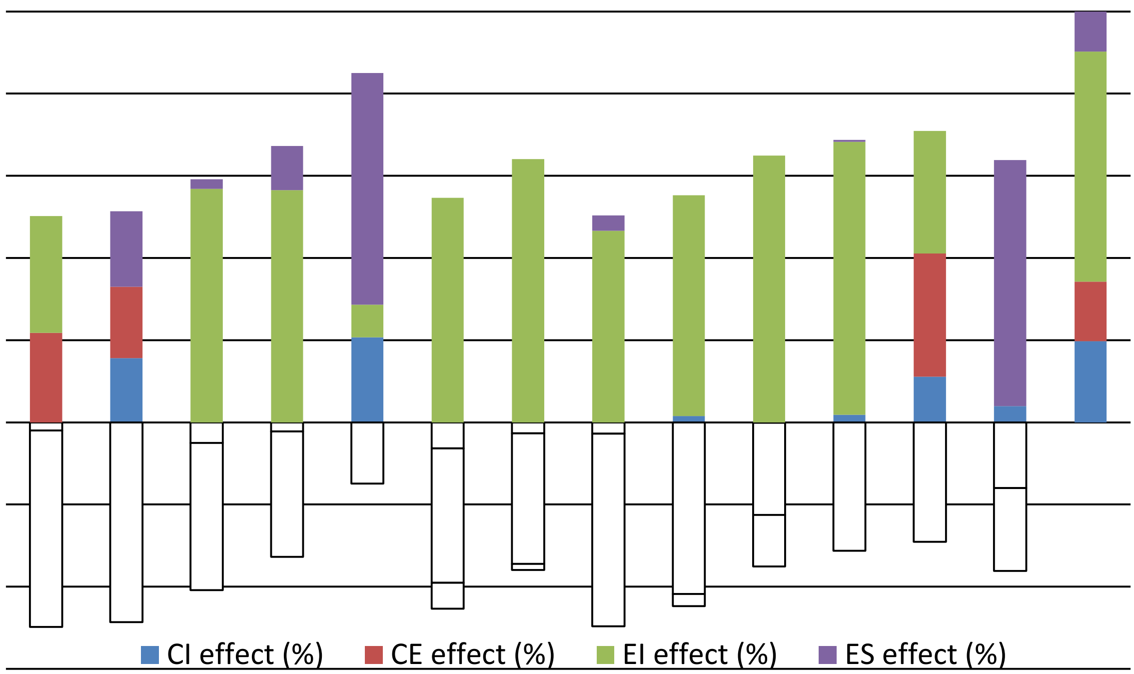
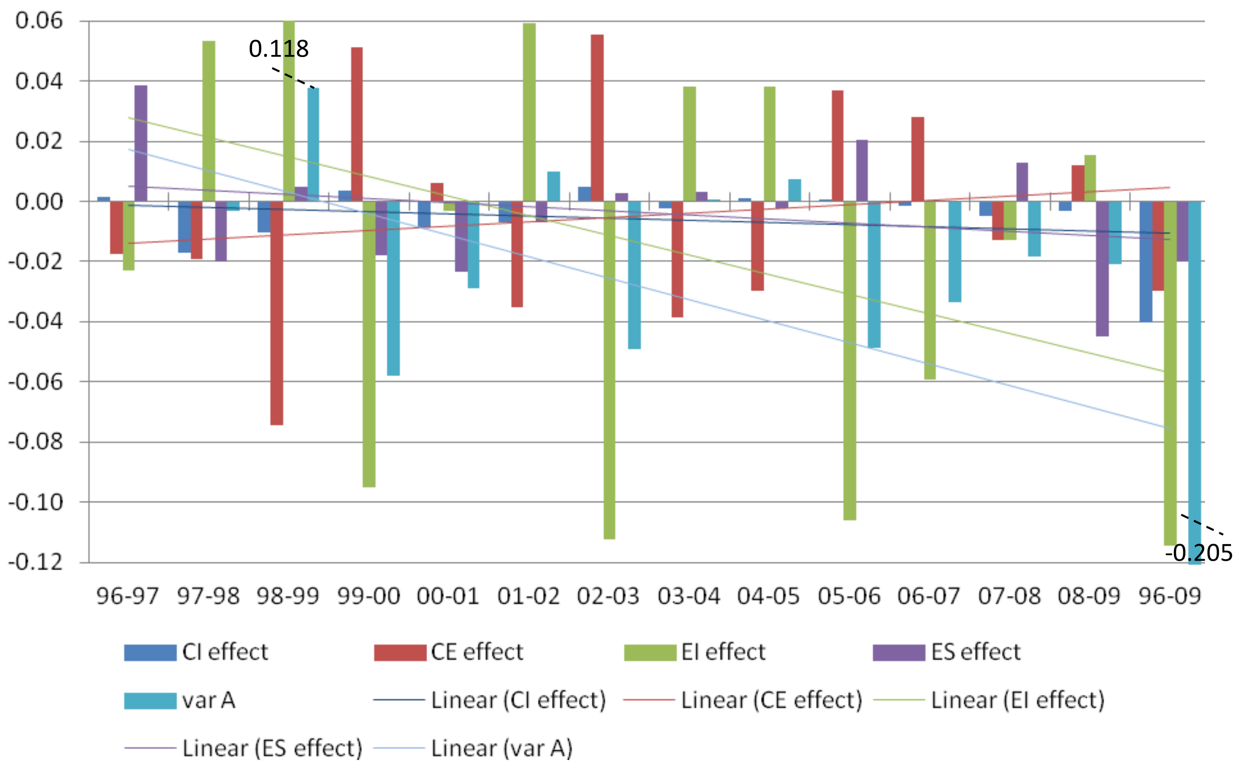


Figure A2.2 - Complete decomposition of CO2 emissions intensity change (1996-2009)



Acknowledgments

The authors gratefully acknowledge Jorge Mota from University of Aveiro for his collaboration in the econometric methodology.

References

[1] Alcantara V, Duro JA. Inequality of energy intensities across OECD countries: A note. Energy Policy. 2004;32(11):1257-60.

[2] Duro JA, Alcántara V, Padilla E. International inequality in energy intensity levels and the role of production composition and energy efficiency: An analysis of OECD countries. Ecological Economics. 2010;69(12):2468-74.

[3] Sun JW. The decrease in the difference of energy intensities between OECD countries from 1971 to 1998. Energy Policy. 2002;30(8):631-5.

[4] Mendiluce M, Pérez-Arriaga I, Ocaña C. Comparison of the evolution of energy intensity in Spain and in the EU15. Why is Spain different? Energy Policy. 2010;38(1):639-45.

[5] Douglas S, Nishioka S. International differences in emissions intensity and emissions content of global trade. Journal of Development Economics. 2012;99(2):415-27.

[6] Greening LA, Davis WB, Schipper L. Decomposition of aggregate carbon intensity for the manufacturing sector: Comparison of declining trends from 10 OECD countries for the period 1971-1991. Energy Economics. 1998;20(1):43-65.

[7] Fan Y, Liu LC, Wu G, Tsai HT, Wei YM. Changes in carbon intensity in China: Empirical findings from 1980-2003. Ecological Economics. 2007;62(3-4):683-91.

[8] Agência Portuguesa do Ambiente. Portuguese National Inventory Report on Greenhouse Gases 1990-2009. In: Protocol SutUNFCoCCatK, editor. 2011.

[9] Diakoulaki D, Mandaraka M. Decomposition analysis for assessing the progress in decoupling industrial growth from CO2 emissions in the EU manufacturing sector. Energy Economics. 2007;29(4):636-64.

[10] Sun JW. Changes in energy consumption and energy intensity: A complete decomposition model. Energy Economics. 1998;20(1):85-100.

[11] Zhang M, Mu H, Ning Y, Song Y. Decomposition of energy-related CO2 emission over 1991-2006 in China. Ecological Economics. 2009;68(7):2122-8.

[12] Ang BW, Pandiyan G. Decomposition of energy-induced CO2 emissions in manufacturing. Energy Economics. 1997;19(3):363-74.

[13] Sun JW. Accounting for energy use in China, 1980-94. Energy. 1998;23(10):835-49.

[14] Ang BW, Zhang FQ. A survey of index decomposition analysis in energy and environmental studies. Energy. 2000;25(12):1149-76.

[15] Choi KH, Ang BW. A time-series analysis of energy-related carbon emissions in Korea. Energy Policy. 2001;29(13):1155-61.

[16] Choi KH, Ang BW. Measuring thermal efficiency improvement in power generation: the Divisia decomposition approach. Energy. 2002;27(5):447-55.

[17] Paul S, Bhattacharya RN. CO2 emission from energy use in India: A decomposition analysis. Energy Policy. 2004;32(5):585-93.

[18] Lu IJ, Lin SJ, Lewis C. Decomposition and decoupling effects of carbon dioxide emission from highway transportation in Taiwan, Germany, Japan and South Korea. Energy Policy. 2007;35(6):3226-35.

[19] Wang WC, Mu HL, Kang XD, Song RC, Ning YD. Changes in industrial electricity consumption in china from 1998 to 2007. Energy Policy. 2010;38(7):3684-90.

[20] Oh I, Wehrmeyer W, Mulugetta Y. Decomposition analysis and mitigation strategies of CO2 emissions from energy consumption in South Korea. Energy Policy. 2010;38(1):364-77.

[21] Akbostanci E, Tunc GI, Turut-Asik S. CO2 emissions of Turkish manufacturing industry: A decomposition analysis. Applied Energy. 2011;88(6):2273-8.

[22] Sheinbaum-Pardo C, Mora-Perez S, Robles-Morales G. Decomposition of energy consumption and CO2 emissions in Mexican manufacturing industries: Trends between 1990 and 2008. Energy for Sustainable Development. 2012;16(1):57-67.

[23] Hoekstra R, van der Bergh JJCJM. Comparing structural and index decomposition analysis. Energy Economics. 2003;25(1):39-64.

[24] Rose A, Casler S. Input-output structural decomposition analysis: a critical appraisal. Economic Systems Research. 1996;8(1):33-62.

[25] Ang BW, Zhang FQ. Inter-regional comparisons of energy-related CO2 emissions using the decomposition technique. Energy. 1999;24(4):297-305.

[26] Wang C, Chen J, Zou J. Decomposition of energy-related CO2 emission in China: 1957-2000. Energy. 2005;30(1):73-83.

[27] Wu L, Kaneko S, Matsuoka S. Driving forces behind the stagnancy of China's energy-related CO2 emissions from 1996 to 1999: The relative importance of structural change, intensity change and scale change. Energy Policy. 2005;33(3):319-35.

[28] Lee K, Oh W. Analysis of CO2 emissions in APEC countries: A time-series and a cross-sectional decomposition using the log mean Divisia method. Energy Policy. 2006;34(17):2779-87.

[29] Lise W. Decomposition of CO2 emissions over 1980-2003 in Turkey. Energy Policy. 2006;34(14):1841-52.

[30] Liu LC, Fan Y, Wu G, Wei YM. Using LMDI method to analyze the change of China's industrial CO 2 emissions from final fuel use: An empirical analysis. Energy Policy. 2007;35(11):5892-900.

[31] Ma C, Stern DI. China's changing energy intensity trend: A decomposition analysis. Energy Economics. 2008;30(3):1037-53.

[32] Zhang FQ, Ang BW. Methodological issues in cross-country/region decomposition of energy and environment indicators. Energy Economics. 2001;23(2):179-90.

[33] Liaskas K, Mavrotas G, Mandaraka M, Diakoulaki D. Decomposition of industrial CO2 emissions: The case of European Union. Energy Economics. 2000;22(4):383-94.

[34] Sun JW. Is CO2 emission intensity comparable? Energy Policy. 2000;28(15):1081-4.

[35] Sun JW. Energy demand in the fifteen European Union countries by 2010 - A forecasting model based on the decomposition approach. Energy. 2001;26(6):549-60.

[36] Bhattacharyya SC, Matsumura W. Changes in the GHG emission intensity in EU-15: Lessons from a decomposition analysis. Energy. 2010;35(8):3315-22.

[37] O' Mahony T, Zhou P, Sweeney J. The driving forces of change in energy-related CO 2 emissions in Ireland: A multi-sectoral decomposition from 1990 to 2007. Energy Policy. 2012;44:256-67.

[38] Huang JP. Industry Energy Use and Structural-Change - a Case-Study of the Peoples-Republic-of-China. Energy Economics. 1993;15(2):131-6.

[39] Sinton JE, Levine MD. Changing Energy Intensity in Chinese Industry - the Relative Importance of Structural Shift and Intensity Change. Energy Policy. 1994;22(3):239-55.

[40] Miketa A. Analysis of energy intensity developments in manufacturing sectors in industrialized and developing countries. Energy Policy. 2001;29(10):769-75.

[41] Hamilton C, Turton H. Determinants of emissions growth in OECD countries. Energy Policy. 2002;30(1):63-71.

[42] Zhang ZX. Why did the energy intensity fall in China's industrial sector in the 1990s? The relative importance of structural change and intensity change. Energy Economics. 2003;25(6):625-38.

[43] Liao H, Fan Y, Wei YM. What induced China's energy intensity to fluctuate: 1997-2006? Energy Policy. 2007;35(9):4640-9.

[44] Zhao M, Tan LR, Zhang WG, Ji MH, Liu YA, Yu LZ. Decomposing the influencing factors of industrial carbon emissions in Shanghai using the LMDI method. Energy. 2010;35(6):2505-10.

[45] Hatzigeorgiou E, Polatidis H, Haralambopoulos D. Energy CO2 Emissions for 1990–2020: A Decomposition Analysis for EU-25 and Greece. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2010;32(20):1908-17.

[46] Zhang XP, Cheng XM. Energy consumption, carbon emissions, and economic growth in China. Ecological Economics. 2009;68(10):2706-12.

[47] Lee CC, Chien MS. Dynamic modelling of energy consumption, capital stock, and real income in G-7 countries. Energy Economics. 2010;32(3):564-81.

[48] Menyah K, Wolde-Rufael Y. CO2 emissions, nuclear energy, renewable energy and economic growth in the US. Energy Policy. 2010;38(6):2911-5.

[49] Alam MJ, Begum IA, Buysse J, Rahman S, Van Huylenbroeck G. Dynamic modeling of causal relationship between energy consumption, CO2 emissions and economic growth in India. Renewable and Sustainable Energy Reviews. 2011;15(6):3243-51.

[50] Lee CC, Chiu YB. Nuclear energy consumption, oil prices, and economic growth: Evidence from highly industrialized countries. Energy Economics. 2011;33(2):236-48.

Chapter 3

Carbon Dioxide Emissions Intensity of Portuguese Manufacturing Industry: A Convergence Analysis and Econometric Approach

3.1 Introduction

3.1.1 Background and Motivation

The energy-related Carbon Dioxide (CO_2) emissions, in the European Union (EU)-15, produced by the manufacturing sector, changed between 1990- 2010 from 37% to 30%. The direct effect (fuel driven) and the indirect effect (due to industrial electricity consumption) both contribute towards these emissions. At worldwide level, the industrial (manufacturing) sector accounted for 26% of global energy use and 18.5% of global CO_2 emissions in 2010 [1].

Portugal managed to meet Kyoto Target for the period 2008-2012. In 2011 it showed a level of emissions 16% higher than the 1990 level (its limit was 27%) [2]. However, the goals of reducing emissions are not restricted to this period. In 2009 a new package of environmental measures was adopted at the EU level, known as the 20-20-20 targets: by 2020 there should be a 20% reduction of Greenhouse Gases (GHG) emissions compared with 1990, 20% share of renewable energy in EU energy consumption, and energy improvement by 20%.

To meet these goals, it is important to realize which variables affect GHG emissions, particularly the intensity of emissions (emissions by unit of output). It is important to understand the evolution and influence between emissions intensity, energy intensity, and the share of fossil fuels in total energy consumption.

The main gas emitted in Portugal is CO_2, representing approximately 74% of total GHGs emissions expressed as global warming potential (GWP) weighted emissions [2]. The energetic and industrial sectors are the major emitters of CO_2 (68.2%), despite its weight declined in favour of the services and transport sectors (figure A3.1 in appendix).

Indeed, the emissions intensity and the energy intensity of the industrial and energy sectors are well above the average of the economy (figure A3.2 and A3.3 in appendix), which highlights the importance of looking to these sectors as paramount in achieving environmental goals.

The question becomes even more relevant if we observe that most of the energy used comes from fossil fuels (coal, oil and natural gas), and that this percentage is much higher in the manufacture and energy sectors than the average for the Portuguese economy (figure A3.4 in appendix). This explains the relative high value of intensity of emissions in these sectors. In 2009, this percentage was of 95,3% for the manufacture and energy sectors compared with 82,4% of the average of the economy. However, this path is changing with a progressive enhancement of renewable energy, in particular, the expansion of windmills [1].

Given the need to reduce the CO_2 emissions coming from the manufacturing sector, it is important, for planning purposes, to know which manufacturing sub-sectors have the greatest potential for reducing energy use. CO_2 emissions intensity is largely converging towards two distinct groups of that industry: one group with relatively high CO_2 energy intensity (mainly energy sectors) and another with relatively low CO_2 emissions intensity. Robaina-Alves and Moutinho [3] refer that in Portugal there are 5 manufacturing sectors that can be distinguished from the others by their emissions intensity: mining and quarrying, the manufacture of coke and refined petroleum products, the manufacture of chemicals and chemical products, the manufacture of rubber and plastic products, and other non-metallic mineral products and electricity, gas, steam and air-conditioning supply. Different energy drivers still are related and a priori, both spatial and temporal effects are expected between CO_2 emissions intensity and their drivers. On the one hand, there is a wide range of cross dependence of industrial sub-sectors and, on the other, the CO_2 emissions intensity is expected to be mitigated over time.

Although, the European Carbon Market imposes different caps to the various sectors (see Robaina-Alves, et. al. [4], for a sectoral analysis of the effects of this market in Portugal), they are exposed to a common commitment, and to the uniformity of public policies, for example, among others, the policy of reducing fossil fuel intensity and promoting renewable energy sources supporting the mitigation of CO_2 emissions intensity. Therefore, it is important to: (i) know if there is a common pattern of emissions intensity, fuel intensity and energy intensity, between industries (convergence), to know if it justifies a more specific application of energy policies between sectors; (ii) study the long term effects of those specific variables on the mitigation of CO_2 emissions. These two approaches can give relevant information for the policy making with regard to the timing of policy interventions and to the choice of policy instruments.

Given all these specific objectives, we believe that the use of the convergence analysis, together with the use of the PCSEs econometric approach, allows us to evaluate, in the long-term, the existence of differences between the CO_2 emission intensities and their main drivers in the Portuguese industrial sector and subsectors; and also allows to reach some conclusive evidence on the frequency in the changes of these differences of the intensities of emissions and their drivers.

3.1.2 Literature Review

In this research, we focused not only on CO_2 emissions drivers, but also on the CO_2 emissions' intensity drivers. In the latter, there are many studies that decompose CO_2 emissions intensity of manufacturing industries into several factors or effects. See for instance Huang [5], Sinton and Levine [6], Hamilton and Turton [7], Paul and Bhattacharya [8], Liao et al. [9], Ma and Stern [10], Zhang et al. [11], Zhao et al. [12], Oh et al. [13], Akbostanci et al. [14], Sheinbaum-Pardo et al. [15], O`Mahony et al. [16] and

Miketa [17] for studies of energy intensity or CO2 emissions intensity decomposition in industrial sectors. For Portugal, the following studies are known: Diakoulaki and Mandaraka [18], Hatzigeourgiou et al. [19] and Robaina-Alves and Moutinho [3], where the 'complete decomposition' technique to examine CO2 emissions intensity and its components is used. These studies are useful for understanding the methods of decomposition of energy–related CO2 emissions and for identifying the factors that have influenced the changes in the level of energy–related CO2 emissions. The most common are the output effect, the energy mix effect, the energy intensity effect and the structural effect. Hatzigeougiou et al. [19] also use the population effect and Diakoulaki and Mandaraka [18] the utility mix effect.

To see if there is a common pattern in the pollution path or in the energy consumption path of different countries or sectors, there are works that analyse energy intensity or emissions intensity convergence. For instance, Robinson [20] uses the concepts of Beta convergence and stochastic convergence to study the ambition to create a single European Electricity Market. Newman et al. [21], assess Beta convergence of natural gas prices in European markets. Blot and Serranito [22], use the concepts of Sigma-convergence, to justify the unit-root test analysis for the sectorial breaks in the fiscal policies in European Monetary Union (EMU).

Especially in sectorial industrial studies, among others, Strazicich and List [23], examined the period 1960-1997 of carbon dioxide emissions in twenty-one industrial countries and tested the convergence for stochastic and conditional convergence. Using both panel unit root tests and cross-section regressions, they found significant evidence that CO2 emissions converged. Liddle [24], analysed the aggregate and sectoral convergence in the electricity intensity and energy intensity in IEA/OECD countries, and concluded that there is convergence, since the countries with the highest intensities exhibit downward trends, and many of the other countries show slight increasing trends. Aggregate electricity intensity has converged among countries, but less dramatically than aggregate energy intensity. The three analysed sectors (residential, industry and commercial) have converged at different rates. Commercial electricity intensity has a distribution that is most characterized by a bell-shape while industry and residential electricity intensity have more bimodal distributions. Camarero et al. [25] using Phillips and Sul [26] methodology, test the convergence of CO2 emissions intensity and their determinants among OECD countries over the period 1960-2008, and they find that differences in emissions intensity convergence are more determined by differences in convergence of the carbonisation index rather than differences in the energy intensity.

To study the influence of determinant variables on pollution we can refer to Hettige et al. [27], who used the panel OLS (fixed effects and random effects) for industrial water pollution, or Stern [28], who applied a panel data set for sulphur emissions using a econometric decomposition approach to estimate the Environmental Kuznets Curve (EKC) model. Cole et al. [29], used econometric panel estimation OLS with fixed effects and random effects to study the variables that influence pollution intensity.

Others studied the influence of some variables on energy intensity, like Miketa [17], which conducted the panel analysis for ten manufacturing industries of 39 countries over 1971-1996. The results of this study show that capital formation has the effect of increasing energy intensity and this effect is stronger where sectorial output is larger.

The purpose of this paper is to study: (i) the existence of convergence of some relevant ratios as CO2 emissions intensity, CO2 emissions by fossil fuel consumption, fossil fuel intensity, energy intensity and economic structure, between manufacturing sectors in Portugal, and (ii) the influence that the consumption of fossil fuels, the consumption of aggregate energy and GDP have on CO2 emissions, and the influence that the ratios in which CO2 emissions intensity decomposes can affect that variable, using an econometric approach. As usual, decomposition analysis leaves a residual term, which is the unexplained portion of the change in an aggregate variable, and the decomposition analysis is a series expansion, truncated after the first order terms. For that limitation, we used the Panel Corrected Standard Errors (PCSE) estimator. In two different and complementary methodologies, we conducted the analysis for the 16 aggregated manufacturing sectors (Group A) and for the group of the 5 most polluting manufacturing sectors (concerning emissions intensity), composed mainly by energy sectors (Group B). This methodology allows one, on the one hand, to observe whether there is a common behaviour among the variables determining the emissions for the two groups of industries. If so, then it is useful to study the influence in terms of elasticity of these same variables on emissions. This allows us to evaluate the effect that energy policies affecting the variables studied will have on emissions, and if common policies will have the same effect on the behaviour of the variables for the various industries.

The remainder of this paper is organised as follows. Section 2 describes the data and methodology. The main results are reported in Section 3 and Section 4 concludes.

3.2 Data and Methodology

We obtained the data from the INE (National Accounts), with an aggregation of 16 Portuguese industrial sectors (group A) and a sub group of 5 industries (group B). We present a table in appendix with the sectors included in these groups. We considered the period 1996 – 2009, because it was the most recent period for which we had common data for all variables.

We considered data of CO2 emissions from fossil origin, in 10^3 tons. To obtain fossil fuels consumption, we added INE data of natural gas, coal and lignite, petroleum coke, fuel oil, diesel oil, motor gasoline, LPG and other petroleum products, in GJ. We used consumption of energy data (emissions relevant), in GJ, and Gross Domestic Product from the production side at market and constant prices, in 10^6 Euros.

3.2.1 Convergence

The convergence analysis intends to see if stochastic differences in the long-term, between industrial sectors, means that accumulated random differences in the short-term constitute an explanation to see if the shocks on those series persist over time.

The convergence was calculated for five ratios, in the two groups of industries in Portugal. The ratios are: (i) CO_2 emissions/GDP (emissions intensity) (ii) CO_2 emissions/fossil fuels consumption (denoted by CI), (iii) fossil fuels consumption/total energy consumption (denoted by CE), (iv) energy/GDP (denoted by energy intensity or EI) and (v) sector GDP/ GDP (denoted by economic structure or ES).

Two measures of convergence where calculated (following Boyle and McCarthy [30]): sigma convergence and gamma convergence. Sigma convergence tracks the inter-temporal change. For instance for the ratio CE it is calculated as:

$$\sigma = \left(\frac{\mathrm{var}\ (CE_{ti})/\mathrm{mean}(CE_{ti}\ )}{\mathrm{var}\ (CE_{t0})/\mathrm{mean}(CE_{t0})}\right)$$

Where *ti* is the current year and *t0* is the first year (1996). If we observe a fall in this measure it means that there is sigma convergence.

Gamma convergence is useful to analyse if the most polluting sectors occupy the same position at the beginning and at the end of the considered period, and if the importance of the emissions intensity drivers remains the same throughout this period. For instance for the ratio CE it is calculated as:

$$\gamma = \left(\frac{\mathrm{var}\ (RCE_{ti} + RCE_{t0})}{\mathrm{var}\ (RCE_{t0} * 2)}\right)$$

Gamma ranges from zero to unity. If it is close to zero it means that there was mobility in the position of the sectors. RCE is the rank of the sector in current year *ti* or in the first year *t0*, for the ratio CE.

3.2.2 Econometric approach

With this methodology we intend to analyse the influence on CO2 emissions (dependent variable) of variables such as the consumption of fossil fuels, energy consumption and production. On the other hand, taking as dependent variable the intensity of CO2 emissions, we analyse the influence of the ratios previously defined as CI, CE, EI and ES. The study is made for the two groups of Portuguese industries.

The econometric methodology follows Marques and Fuinhas [31]. We employed the following steps: (i) analysis of the presence of heteroskedasticity, panel autocorrelation and contemporaneous correlation, (ii) the PCSE estimator is applied (iii) we confirm the robustness of results applying the Random effect estimator (REE), and the Fixed effect estimator (FEE).

For group wise heteroskedasticity, following Baum [32, 33], and as reported in Marques and Fuinhas [31], a modified Wald statistic was provided in the residuals of a fixed effect regression model. For analyzing the presence of serial correlation, we employed the Wooldridge test for autocorrelation in panel data. The null hypothesis of no first-order autocorrelation is rejected. The existence of cross section independence was tested by applying the parametric test proposed by Pesaran [34] and the semi-parametric test proposed by Frees [35, 36], either to Fixed effect estimator or Random effect estimator.

We proposed two models, based on a panel regression analysis of drives of energy related CO2 emissions, and CO2 emissions intensity, in Portuguese industrial sectors. The first regression model with two versions (linear and no linear regression) is developed as follows:

Model 1: $LnCO_{2it} = \alpha_{1t} + \beta_{1i} LnF.Fuel_{it} + \beta_{2i} LnECons_{ct} + \beta_{3i} LnGDP_{it} + d_{1i} + d_{1t} + \mu_{it}$

where the dependent variable, CO_2 refers to CO2 emissions, and the explanatory variables are, FFuel that refers to Fossil Fuel consumption, ECons that refers to Energy consumption and GDP that refers to the sector production. We expect all variables to have positive impact on the dependent variable. i refers to the industry sector and t to the year. The error term is $\mu_{it} = \rho_{it}\mu_{it-1} + \eta_{it}$, where η_{it} is serially uncorrelated, but correlated over sectors.

In the second regression model we studied the influence on CO2 emissions intensity (dependent variable) of the factors in which it can be decomposed (explanatory variables). The equation developed as follows:

Model 2:

$$\ln\left(\frac{CO_2}{GDP_{it}}\right) = \alpha_{it} + \beta_{1i}\ln\left(\frac{CO_2}{FFuel_{it}}\right) + \beta_{2i}\ln\left(\frac{FFuel_{it}}{ECons_{it}}\right) + \beta_{3i}\ln\left(\frac{ECons_{it}}{GDP_{it}}\right) + \beta_{4i}\ln\left(\frac{GDP_{it}}{GDP}\right) + d_{2i} + d_{2t} + \mu_{it}$$

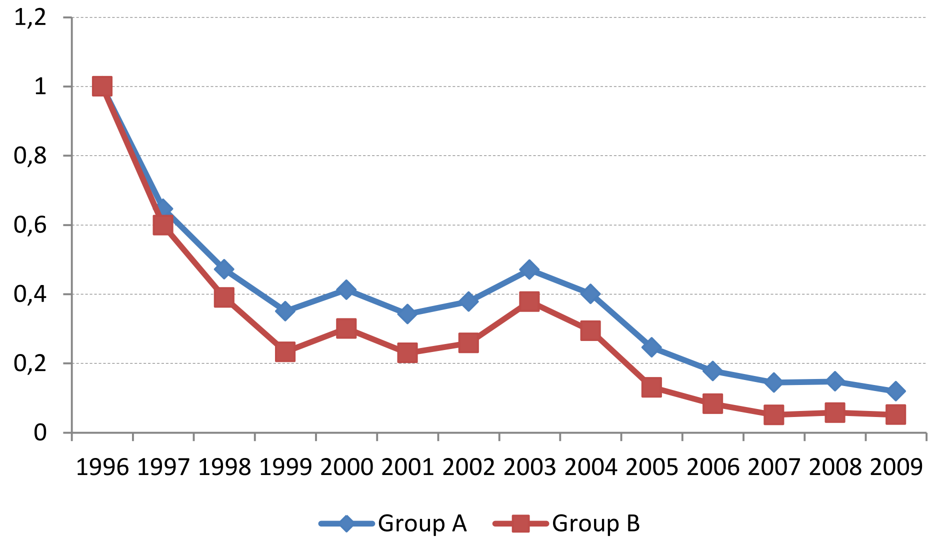
Each factor or driver in this regression can be interpreted as follows: the dependent variable CO_2 / GDP_{it}, namely emissions intensity can be influenced by the explanatory variables as the ratio $CO_2 / F.Fuel_{it}$ namely the CO_2 emissions by unit of fossil fuel, the ratio $F.Fuel / ECons_{it}$ namely the fossil fuel-intensity effect, indicates the proportion of total energy consumption from fossil sources, the ratio $ECons_{it} / GDP_{it}$, namely energy-intensity effect of economic output, reflecting efficiency of energy use in the industrial sector and the ratio $GDPit/GDP$ that reflects the relevance of the sector on the whole industry, that is, the economic structure of industry.

3.3 Results

3.3.1 Convergence

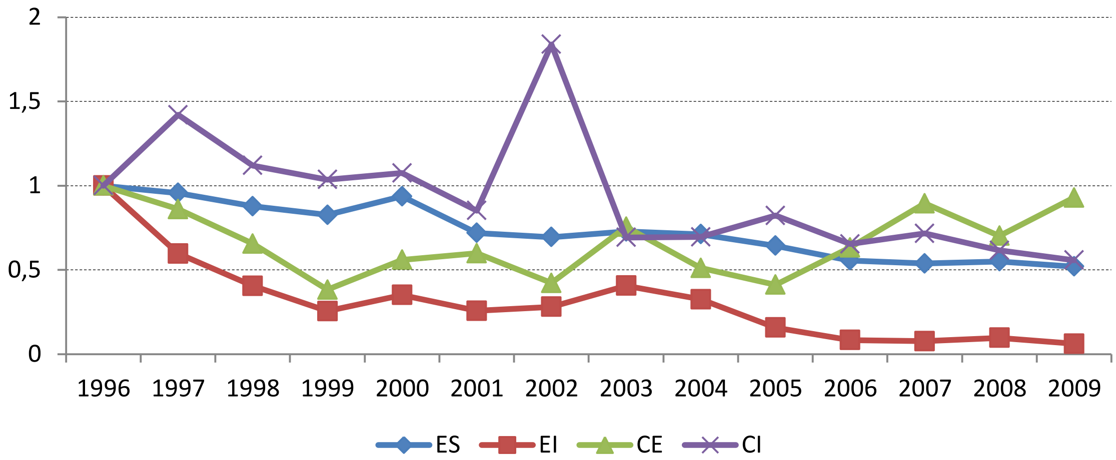
Observing the sigma convergence of CO2 emissions intensity for the 2 groups of industries (figure 3.1), we can see that there is convergence, which was most marked between 1996 and 1999 and between 2003 and 2006. The convergence is more evident for group B.

Figure 3.1 - Sigma Convergence of CO2 emissions intensity



Analyzing sigma convergence for the various factors on which intensity of emissions decomposes (figure 3.2), we can see that in group A, the highest degree of convergence is presented by EI factor, which means, in what concerns energy intensity, those sectors tend to have a similar behaviour. The value for this factor in 2009 is very close to zero (0.062).

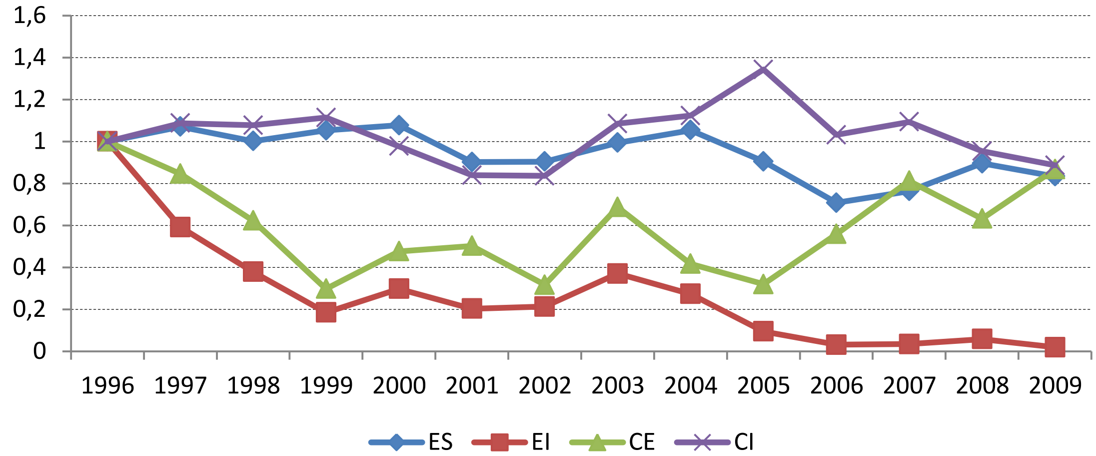
Figure 3.2 - Sigma Convergence for group A



ES factor also presents convergence for group A, although not as pronounced. On the other hand, CE and CI factors are irregular in their pattern of convergence. CE tends to converge until 2002, but thereafter diverge and CI offers a wide divergence in 2001 and is back to converge in 2002. This shows that in terms of the mix of fossil fuels used and in terms of the share of fossil fuels in total energy consumption, industrial sectors are not yet harmonized.

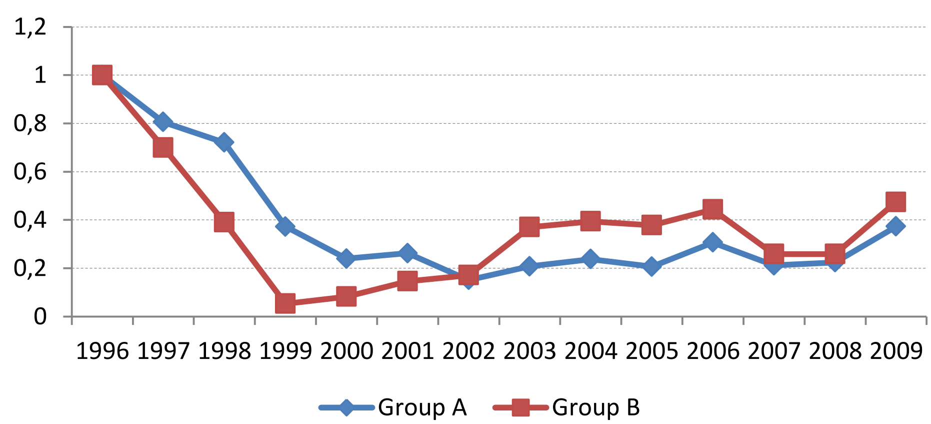
As for sigma convergence in group B (figure 3.3), we can see that CI and ES have among themselves a similar trajectory, until 2004. CI has two periods of convergence (2000-02 and 2005-09) and two periods of divergence (1996-99 and 2002-05). ES shows a slight trend of convergence in the period studied. The ratios EI and CE have an irregular route although similar until 2005 and from then CE clearly diverges and EI converges, approaching this indicator to zero. This last ratio is the one with a greater tendency of convergence.

Figure 3.3 - Sigma Convergence for group B



Regarding gamma convergence, for the intensity of CO_2 emissions (figure 3.4), there was a clear convergence of industries in group A until 2002 and from then there was a slight tendency to diverge. There is a strong convergence in industries group B between 1996-99 and in 2006, and in other years there is a slight divergence. In the overall period the trend in the two groups is for convergence, which is more pronounced in group A.

Figure 3.4 - Gamma Convergence of CO2 emissions intensity



For group A all ratios have a tendency to converge (figure 3.5). EI appears more unstable with divergence in 2002-03 and 2004-09. CE introduces a period of divergence from 2004. In figure 3.6 it can be seen that for group B the ratios ES and EI have a slight downward trend (convergence) and in some years have values very close to zero (1999 to EI and 2006 to ES). CE and CI present instability with a growing trend (divergence), especially CI. Nevertheless, in some years this indicator is close to zero (1998 and 2000 for CE and 2004 for CI).

Figure 3.5 - Gamma Convergence for group A

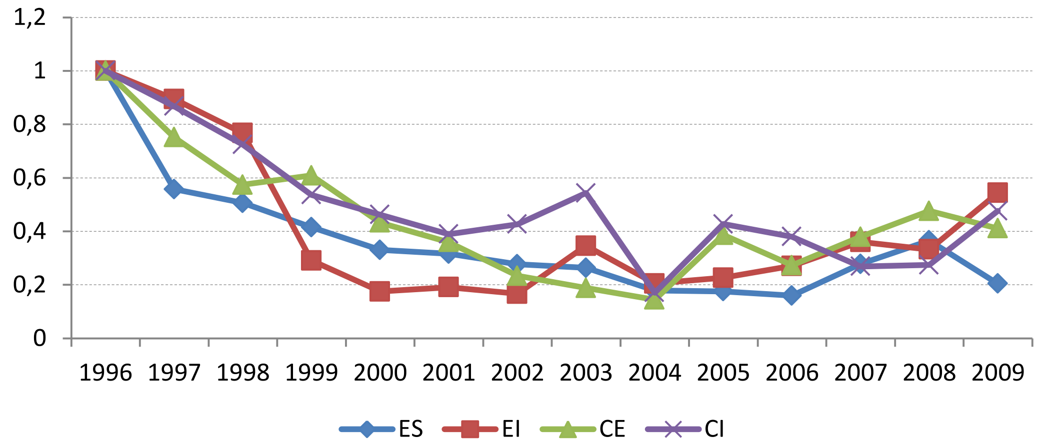
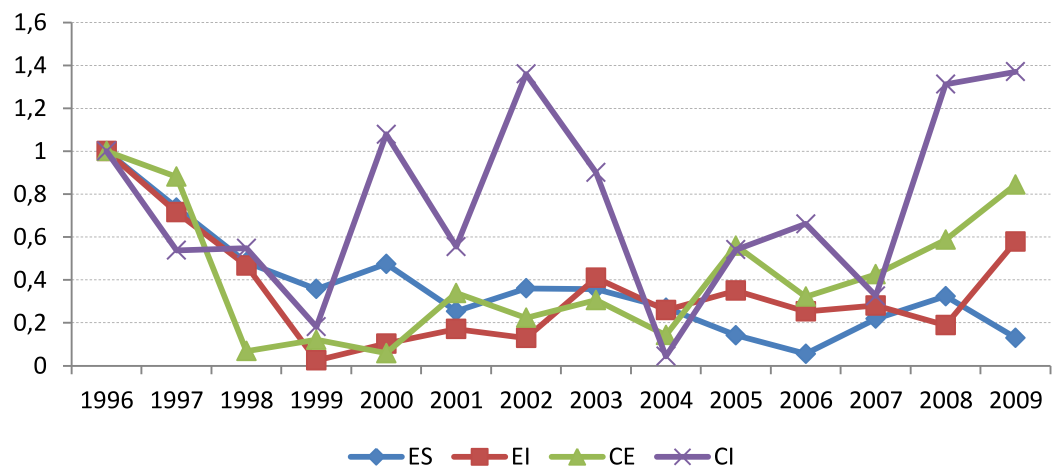


Figure 3.6 - Gamma Convergence for group B



Comparing the gamma convergence for the two groups we can see that the trajectory of ES and EI is very similar. The CE ratio between the period 1997-2001 is much lower in group B due to a sudden drop of this indicator from 1997 to 1998. After 2001 the trajectory of convergence is very similar for the two groups of industries. The CI ratio in group A has a more stable trajectory of convergence than in group B, in which there are periods of great divergence.

3.3.2 Econometric approach

Initial results of specifications tests are reported in table 3.1. The existence of serial correlation was tested and the Wooldridge test for autocorrelation was performed; the results rejected, at the 1% level, the null hypothesis of no first-order autocorrelation for group A and group B. Analysing for possible heteroskedasticity, a modified Wald statistic for group wise heteroskedasticity was used for two industrial group sectors and the result is significant at the 1% level.

Table 3.1 - Specification tests

Model 1 – Group A : 16 Industries

	Pooled	**Random effects**	**Fixed Effects**
Modified Wald test (χ2)			57372***
Pesaran's test		8.940***	4.040***
Frees' test		2,518***	2,624***
Wooldridge test F(N(0,1))		409.10***	

Model 2 – Group A : 16 Industries

	Pooled	**Random effects**	**Fixed Effects**
Modified Wald test (χ2)			1.3e+08***
Pesaran's test		-1.538	3.254***
Frees' test		2,834***	3,462***
Wooldridge test F(N(0,1))	725.58***		

Model 1 – Group B : 5 Industries

	Pooled	**Random effects**	**Fixed Effects**
Modified Wald test (χ2)			608***
Pesaran's test		3.556***	1.311
Frees' test		0.239	-0.224
Wooldridge test F(N(0,1)) 43.28***			

Model 2 – Group B : 5 Industries			
	Pooled	Random effects	Fixed Effects
Modified Wald test (χ2)			4.2e+05***
Pesaran's test		0.287	-2.088
Frees' test		0.074	0.538***
Wooldridge test F(N(0,1))	49.55***		

Notes: The Wooldridge test is normally distributed N(0,1) and tests the null hypothesis of no serial correlation; ***, ** and *, denote 1,5 and 10% significance level, respectively; The Modified Wald Test has x2 distribution and tests the null hypothesis; Pesaran test the null hypothesis of cross section, independence.

The existence of cross section independence was tested applying the Pesaran [34] and Frees [36] procedure either to the fixed effect or the random effect models. We reject the null hypothesis of no cross-sectional dependence, for the 2 groups of industries and for the two models. Globally, the results suggest the evidence of contemporaneous correlation across all the industrial sectors and reveal (through fixed and random effect model), at 1% significance level, the rejection of the null hypothesis of cross sectional independence.

For each model 1 and 2, we estimated four submodels using PCSE estimator, to evaluate the robustness of the estimations. While presenting the results of the four submodels (in tables 3.2 and 3.3), we only analyse the submodel (III) by considering the most appropriate given the specification test results.

Model 1 reveals for group A and for group B that explanatory variables have, jointly, a great significance explaining CO_2 emissions. From table 3.2 we can see that a 1% increase on fossil fuel consumption (natural gas, coal and lignite, petroleum, coke, fuel oil, diesel oil, motor gasoline, LPG and other petroleum products) induces an increase around 92% on CO_2 emissions for all panel group A (16 industries), while a 1% increase in energy consumption induces an increase on CO_2 emissions, around 12%, ceteris paribus. For group B, these impacts are of 58% and 60% respectively.

Table 3.2 - Results of Parsimonious

Model 1 – Group A

Dependent variable $LnCO2_{i,t}$

	PCSE			
Independent variables	(I) Corr(AR1)	(II) Corr(psAR1)	(III) Corr(AR1) hetonly	(Iv) Corr(linear)
Ln F.Fuel	0.91924 (0,000)***	0.96330 (0,000)***	0.91924 (0,000)***	0.97954 (0,000)***
Ln ECons	0.12099 (0,000)***	0.12998 (0,000)***	0.12099 (0,000)***	0.13650 (0,000)***
Ln GDPi	0,03567 (0,187)	- 0,01411 (0,630)	0,03567 (0,182)	- 0,10854 (0,000)***
Constant	- 10,2873 (0,000)***	- 10,709 (0,000)***	- 10,287 (0,000)***	- 10,429 (0,000)***
Observations	240	240	240	240
R^2 / Pseudo R^2	0,9568	0,9806	0,9568	0,9844
Wald (χ2)	2523 (0,000)***	9619 (0,000)***	2745 (0,000)***	588757 (0,000)***

Model 1 – Group B

Dependent variable $LnCO2_{i,t}$

	PCSE			
Independent variables	(I) Corr(AR1)	(II) Corr(psAR1)	(III) Corr(AR1) hetonly	(Iv) Corr(linear)
Ln F.Fuel	0.581885 (0,000)***	0.579763 (0,000)***	0.581885 (0,000)***	0.468375 (0,000)***
Ln ECons	0.600654 (0,000)***	0.481002 (0,000)***	0.600654 (0,000)***	0.82296 (0,000)***
Ln GDPi	0,012630 (0,436)	0,01366 (0,249)	0,012630 (0,506)	- 0,01585 (0,848)
Constant	- 12.4141 (0,000)***	- 10,235 (0,000)***	- 12.4141 (0,000)***	- 14,241 (0,000)***
Observations	75	75	75	75
R^2 / Pseudo R^2	0,989	0,998	0,989	0,990
Wald (χ2)	1694 (0,000)***	3386 (0,000)***	1360 (0,000)***	8121 (0,000)***

Notes: The Wald test has χ2 distribution and tests the null hypothesis of non- significance of all coefficients of explanatory variables; panel corrected standard errors are reported in brackets. ***, **, *, denote significance at 1, 5 and 10% significance levels, respectively; Corr (AR1) - first-order autoregressive error, Corr (psAR1) – correlation over sectors and autocorrelation sector; Corr (AR1) hetonly – heteroskedastic over sectors and common first order autoregressive error AR(1); Corr (linear) – correlation over sectors and no autocorrelation.

Table 3.3 - Results of Parsimonious

Model 2 –Group A				
Dependent variable $CO2/GDP_{i,t}$				
Independent variables	PCSE			
	(I) Corr(AR1)	(II) Corr(psAR1)	(III) Corr(AR1) hetonly	(Iv) Corr(linear)
Ln CO2 /F.Fuel	1.12524 (0,000)***	1.11370 (0,000)***	1.12524 (0,000)***	1.2881 (0,000)***
Ln F.Fuell/EC	0.970624 (0,000)***	0,984384 (0,000)***	0.970624 (0,000)***	0.98232 (0,000)***
Ln EC/GDPi	0.958276 (0,000)***	0.962707 (0,000)***	0.958276 (0,000)***	0.95807 (0,000)***
Ln GDPi/GDP	0.984449 (0,000)***	0.962261 (0,000)***	0.984449 (0,000)***	0.88676 (0,000)***
Constant	1.361855 (0,028)**	1.187062 (0,000)***	1.361855 (0,022)**	2.5969 (0,000)***
Observations	240	240	240	240
R^2 / Pseudo R^2	0,9237	0,9801	0,9237	0,9764
Wald (χ2)	27370 (0,000)***	33856 (0,000)***	28951 (0,000)***	1.01e+06 (0,000)***

Model 2 – Group B				
Dependent variable $CO2/GDP_{i,t}$				
Independent variables	PCSE			
	(I) Corr(AR1)	(II) Corr(psAR1)	(III) Corr(AR1) hetonly	(Iv) Corr(linear)
Ln CO2 /F.Fuel	1.22921 (0,000)***	1.17247 (0,000)***	1.22921 (0,000)***	1.7279 (0,000)***
Ln F.Fuell/EC	1.05798 (0,000)***	1,04377 (0,000)***	1.05798 (0,000)***	1.07328 (0,000)***
Ln EC/GDPi	1.03328 (0,000)***	0.997317 (0,000)***	1.03328 (0,000)***	1.00882 (0,000)***
Ln GDPi/GDP	1.0442 (0,000)***	1.03893 (0,000)***	1.0442 (0,000)***	1.0026 (0,000)***
Constant	1.85526 (0,183)	1.70022 (0,071)*	1.85526 (0,176)	1.46921 (0,082)*
Observations	75	75	75	75
R^2 / Pseudo R^2	0,881	0,979	0,881	0,972
Wald (χ2)	15372 (0,000)***	33856 (0,000)***	9361 (0,000)***	154287 (0,000)***

Notes: The Wald test has χ2 distribution and tests the null hypothesis of non-significance of all coefficients of explanatory variables; panel corrected standard errors are reported in brackets. ***, **, *, denote significance at 1, 5 and 10% significance levels, respectively; Corr (AR1) - first-order autoregressive error, Corr (psAR1) – correlation over sectors and autocorrelation sector; Corr (AR1) hetonly – heteroskedastic over sectors and common first order autoregressive error AR(1); Corr (linear) – correlation over sectors and no autocorrelation.

In the PCSE model 2 (table 3.3.) we have a good jointly significance of explanatory variables towards CO2 emissions intensity. The model for group A shows that a 1%

increase of the ratio CO2 emissions by fossil fuel consumption induces an increase of 113% on CO2 emissions intensity, a 1% increase in the ratio fossil fuel consumption by energy consumption induces an increase of 97% on CO2 emissions intensity, a 1% increase in the energy intensity ratio induces an increase of 96% on CO2 emissions intensity and the impact of a 1% change in the economic structure (given by the ratio sectorial GDP/GDP) induces a change of 98% on the dependent variable, ceteris paribus. For group B the magnitude of the impacts is bigger. The values are of 123%, 106%, 103% and 104% for the impacts of explanatory variables mentioned above.

To check the robustness of the results, confirming a possible inefficiency in the estimation of coefficients and bias in the estimation of errors, one should compare the similarity with the estimators obtained through the panel with random effects and fixed effects. If the results are different from the PCSE estimators, the PCSE results are more robust (minimum variance). The results of the estimates for both FEE and REE lead to the erroneous rejection of the power to explain some explanatory variables, such as the ratio Fossil Fuel / Energy Consumption and the ratio CO2 / Fossil Fuel. The comparison of both FEE and REE is made regarding the inefficiency in coefficients estimation in three options: Conventional Standard Errors (CSE), Robust Standard Errors (RSE) and First-order Autoregressive Errors (AR (1)).

In fact, those estimators are not well suited to dealing simultaneously with both serial and contemporaneous correlations, for which we found statistical evidence with the PCSE estimator. Therefore, with both results of FEE and REE presented in next table 3.4, we can see the parameters revealing similar significances into both estimators, and the results of the Wald tests revealing statistical significance at 1% level, rejecting the null hypothesis of non-significance, as a whole of the parameters of the ratio explanatory variables. On the other hand, LM test statistically and strongly reject the null hypothesis of the existence of industrial sectors specific effects. In fact, the results do not invalidate the poor quality and inefficiency for both estimators FEE and REE, while the PCSE estimator is highly efficient; in general the variance of the PCSE estimators is smaller than FEE or REE.

Table 3.4 - Results from usual panel data estimators

Model 1- Group A

Dependent variable Ln $CO2_{i,t}$						
	Random effects	Fixed effects	Random effects	Fixed effects	Random effects	Fixed effects
Independent variables	CSE		RSE		AR(1)	
Ln F.Fuel	0.84454 (0,000)***	0.61941 (0,000)***	0.84454 (0,000)***	0.69412 (0,044)**	0.92291 (0,000)***	0.81502 (0,000)***
Ln ECons	0.24544 (0,000)***	0,29538 (0,000)***	0,24544 (0,159)	0,29538 (0,195)	0.12664 (0,001)***	0.12240 (0,002)***
Ln GDPi	-0.073898 (0,060)*	-0.04977 (0,227)	-0.07389 (0,327)	-0,04977 (0,506)	0.023200 (0.499)	0.06852 (0.085)*
Constant	-10.387 (0,000)***	-7,96367 (0,000)***	-10.387 (0,000)***	-7.9636 (0,020)**	-10.3424 (0,000)***	-9.02897 (0.000)***
Observations	240	240	240	240	240	240
Ftest		88.50 (0,000)***		10.15 (0,000)***		147.81 (0,000)***
Wald (χ2)	1164.20 (0,000)***		469.40 (0,000)***		1699.09 (0,000)***	
Hausman (χ2)		14.70 (0,002)***				

Model 1- Group B

Dependent variable Ln $CO2_{i,t}$						
	Random effects	Fixed effects	Random effects	Fixed effects	Random effects	Fixed effects
Independent variables	CSE		RSE		AR(1)	
Ln F.Fuel	0.4637 (0,000)***	0.65898 (0,000)***	0.4637 (0,000)***	0.65898 (0,007)***	0.92291 (0,000)***	0.81502 (0,000)***
Ln ECons	0,82296 (0,000)***	0,16469 (0,055)*	0,82296 (0,000)***	0,16469 (0,280)	0.12664 (0,001)***	0.12240 (0,002)***
Ln GDPi	-0.00158 (0,937)	0.00045 (0,983)	-0.00158 (0,918)	0.00045 (0,954)	0.023200 (0.499)	0.06852 (0.085)*
Constant	-14.241 (0,000)***	-6.0433 (0,000)***	-14.241 (0,000)***	-6.0433 (0,000)***	-10.3424 (0,000)***	-9.02897 (0.000)***
Observations	75	75	75	75	240	240
Ftest		65.42 (0,000)***		39.91 (0,002)***		147.81 (0,000)***
Wald (χ2)	7193 (0,000)***		12371 (0,000)***	0.65898 (0,007)***	1699.09 (0,000)***	
Hausman (χ2)		51.83 (0,000)***				

Model 2 -Group A						
Dependent variable CO_2 / $GDP_{i,t}$						
	Random effects	Fixed effects	Random effects	Fixed effects	Random effects	Fixed effects
Independent variables	CSE		RSE		AR(1)	
Ln CO2 /F.Fuel	1.03767 (0,000)***	1.02676 (0,000)***	1.03767 (0,000)***	1.02676 (0,000)***	1.07412 (0,000)***	0.98498 (0,000)***
Ln F.Fuel / EC	1.00231 (0,000)***	1.05227 (0,000)***	1.00231 (0,000)***	1.05227 (0,000)***	0.98608 (0,000)***	0.971396 (0,000)***
Ln EC / GDPi	0.99476 (0,000)***	1.04636 (0,000)***	0,99476 (0,000)***	1.04637 (0,000)***	0.96809 (0,000)***	0.938048 (0,000)***
Ln GDPi/ GDP	0.96688 (0,000)***	1.02978 (0,000)***	0,96688 (0,000)***	1.02978 (0,000)***	0.965222 (0,000)***	1.05280 (0,000)***
Constant	0.19731 (0.809)	-0.13274 (0,878)	0,1973 (0,557)	-0.13274 (0,680)	0.75658 (0.493)	0.42663 (0.405)
Observations	240	240	240	240	240	240
Ftest		116.51 (0,000)***		798.84 (0,000)***		55.90 (0,000)***
Wald (χ2)	1025 (0,000)***		18856 (0,000)***		1098 (0,000)***	
Hausman (χ2)		1.99 (0,737)				

Model 2 -Group B						
Dependent variable CO_2 / $GDP_{i,t}$						
	Random effects	Fixed effects	Random effects	Fixed effects	Random effects	Fixed effects
Independent variables	CSE		RSE		AR(1)	
Ln CO2 /F.Fuel	1.17279 (0,000)***	1.05519 (0,009)***	1.17279 (0,000)***	1.05519 (0,000)***	1.20824 (0,000)***	0.92992 (0,055)*
Ln F.Fuel / EC	1.07328 (0,000)***	1.24416 (0,002)***	1.07328 (0,000)***	1.24416 (0,006)***	1.06474 (0,000)***	0.80196 (0,085)*
Ln EC / GDPi	1,00882 (0,000)***	1.084523 (0,000)***	1,00882 (0,000)***	1.084523 (0,000)***	1.0767 (0,000)***	0.87071 (0,004)***
Ln GDPi/ GDP	1,00262 (0,000)***	1.12903 (0,000)***	1,00262 (0,000)***	1.12903 (0,000)***	1.0346 (0,000)***	0.98885 (0,004)***
Constant	1,46921 (0,563)	0.04450 (0,991)	1,46921 (0,259)	0.04450 (0,951)	1.67607 (0.526)	0.62248 (0.796)
Observations	75	75	75	75	75	75
Ftest		8.43 (0,000)***		159.45 (0,000)***		3.65 (0,009)***
Wald (χ2)	2513 (0,000)***		265897 (0,000)***		819 (0,000)***	
Hausman (χ2)		0.88 (0,927)				

Notes: The F-test tests the null hypothesis of non-significance as a whole of the estimated parameters; The Wald test has χ2 distribution and tests the null hypothesis of non-significance of all coefficients of explanatory variables; P>l z l and P>l t l are reported in brackets. ***, **, *, denote significance at 1, 5 and 10% significance levels, respectively; CSE - Conventional Standard Errors; RSE - Robust Standard Errors; Corr(AR1) - first-order autoregressive error; the regressions were performed in Stata 12.

3.4 Conclusions and policy implications

The purpose of this paper is to study: (i) the existence of convergence of some relevant ratios as CO_2 emissions intensity, CO_2 emissions by fossil fuel consumption, fossil fuel intensity, energy intensity and economic structure, between manufacturing sectors in Portugal, and (ii) the influence that the consumption of fossil fuels, the consumption of aggregate energy and GDP have on CO_2 emissions, and the influence that the ratios in which CO_2 emissions intensity decomposes can affect that variable, using an econometric approach. We conducted the analysis for aggregated manufacturing of 16 sectors (Group A) and for the group of 5 most polluting manufacturing sectors (concerning emissions intensity), composed mainly by energy sectors (Group B).

From this analysis we can highlight two set of conclusions. The first one is related with convergence. In what concerns sigma convergence, emissions and energy intensity, sectors tend to have similar behaviour, even these similarities are bigger for industries in group B. There is also convergence in the economic structure, higher for group A. In fact, in 1999 there were more discrepancies between sectoral GDP than in 2009. Sectors with much importance in 1999, as CB, CC and CG decreased its importance significantly (see graph in appendix). Particularly in group B, the sectors CG, EC and D lost relative importance in consideration of the CD sector. In terms of the mix of fossil fuels used, industrial sectors are not yet harmonized, that is, there is not a common behaviour between sectors. CI factor is also irregular in its pattern of convergence for the two groups but the trend is to converge, more evident for group A. Therefore, for the intensity of emissions and for energy intensity, there is a trend towards harmonization of sectors for the whole period, most evident in group B. For emissions by fossil fuel and the structure of the economy there is more harmonization in group A.

Regarding gamma convergence, in the overall period the trend in the two groups is for convergence for all ratios, which means that the sectors decreased their discrepancies in terms of its rank position, that is, the most polluting sectors decreased their importance in relation to the various ratios studied. An exception is the ratio CI and CE for group B, where sectors did not change their rank position. This reveals difficulties in the change of fossil fuel mix, and in the substitution of fossil fuels by renewable energy, in the most polluting sectors, which does not happen for all industries included in group A.

In the Portuguese manufacturing industry, the CO2 emissions intensity and their energy-related drivers were converging towards two distinct industrial groups: one of relatively high CO2 emissions intensity and the whole group of manufacturing industries. Indeed, when the manufacturing industry is disaggregated this way, the convergence is more evident in emissions intensity, energy intensity and the percentage of fossil fuels in the total energy consumption, for group B. It means this group of high emissions intensity has similar energy intensity and energy consumption mix, and that it is well connected in the energy trade and technology transfer systems in the manufacturing industry and other sectors, and that it has common Government commitment for reducing the CO2 emissions intensity and improving efficiency in the use of energy or shifting toward less fossil fuel consumption.

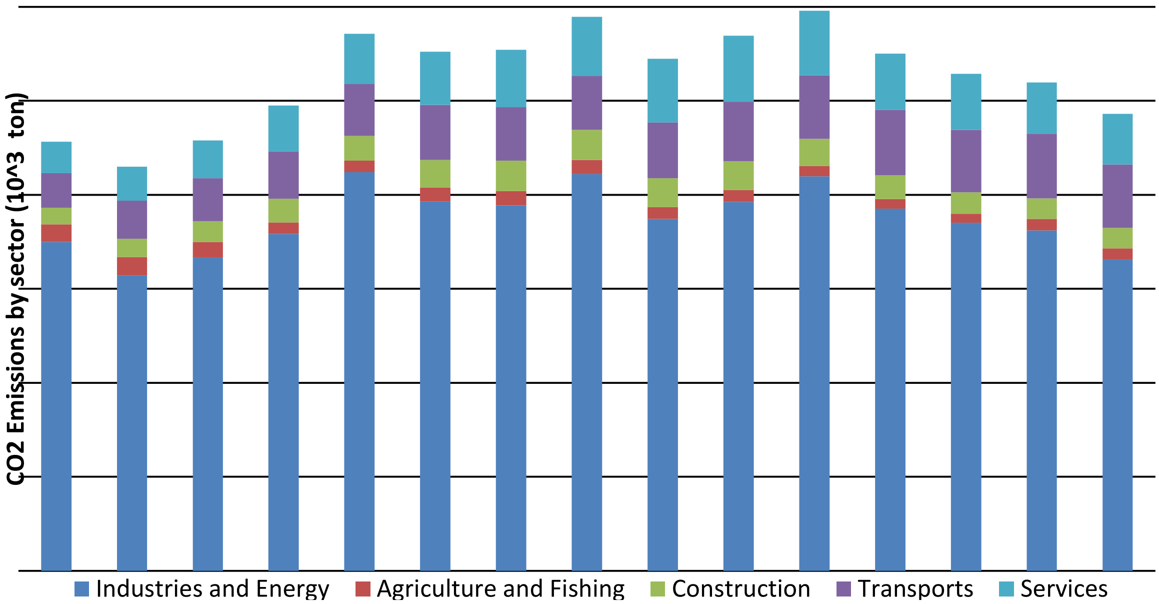
In the convergence analysis stochastic differences, in the long-term, between industrial sectors, means that accumulated random differences in the short-term constitute an explanation to see if the shocks on those series persist over time. This same evidence is of interest to energy policy makers because, evidence of a random shock can reverse the direction wanted to those variables, among others, those that promote productive efficiency in these sectors with the use of new cleaner technologies. This is important to understand, specifically for Portugal, concerning the progressive increase of regulatory incentives in the industrial sectors of energy, particularly in terms of incentives and public policies that promote such investments to producers operating in those industries. On the other hand if there is evidence for differences in the long term of being deterministic, this means that the deterministic random components of the series, over time, are diluted. In this case, policy makers do not need to intervene in certain moment of time, since the same series follows the desired evolution.

The second set of conclusions is related with the econometric approach. For Model 1 we saw that the variables have a significant importance in explaining CO2 emissions, including the use of fossil fuels and energy consumption. Group B presents a smaller impact in the case of fossil fuels, but larger compared with total energy consumption. For model 2 we have a good jointly significance of explanatory variables towards CO2 emissions intensity. The ratio CO2 emissions by fossil fuel consumption, the ratio fossil fuel consumption by energy consumption, the energy intensity and the economic structure, present elasticities of 113%, 97%, 96% and 98% respectively on the dependent variable, ceteris paribus. For group B the magnitude of the impacts is greater. The values are of 123%, 106%, 103% and 104%. This can reinforce the idea that these five sectors included in group B contributed more to the variations on CO2 emissions intensity in the considered period.

These results show that these ratios are crucial to reducing the CO2 intensity of Portuguese sectors, especially in the industries listed in Group B, particularly in what concerns increasing energy efficiency and the use of renewable energy, both points focused on European policy (2009/28/CE directive) [37]. European policies are focused on market-based instruments (mainly taxes, subsidies and the CO2 emissions market), but also in the development of energy technologies (especially technologies dedicated to energy efficiency and renewable energy, or technologies for low-carbon) and the EU financial instruments supporting the achievement of political goals. If the European CO2 emissions market gives a different treatment for the different sectors, at the level of licenses assigned, in other policies there is little or no discrimination between sectors, and what this study shows is that for some variables or particular set of sectors, observed behaviour and the effects obtained are not homogeneous.

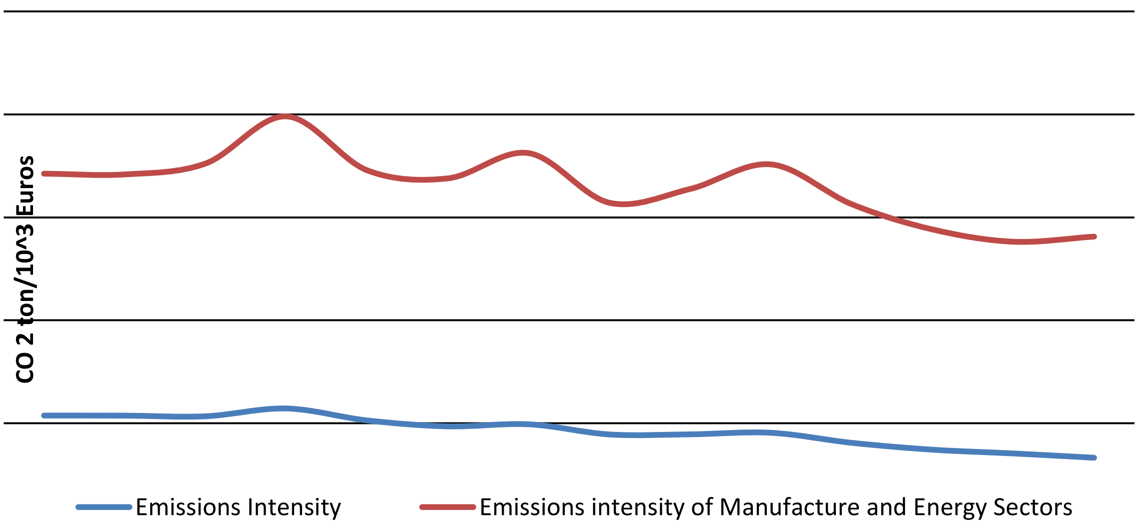
Appendix

Figure A3.1 - Evolution of CO2 emissions in Portugal by sectors in 1995-2009



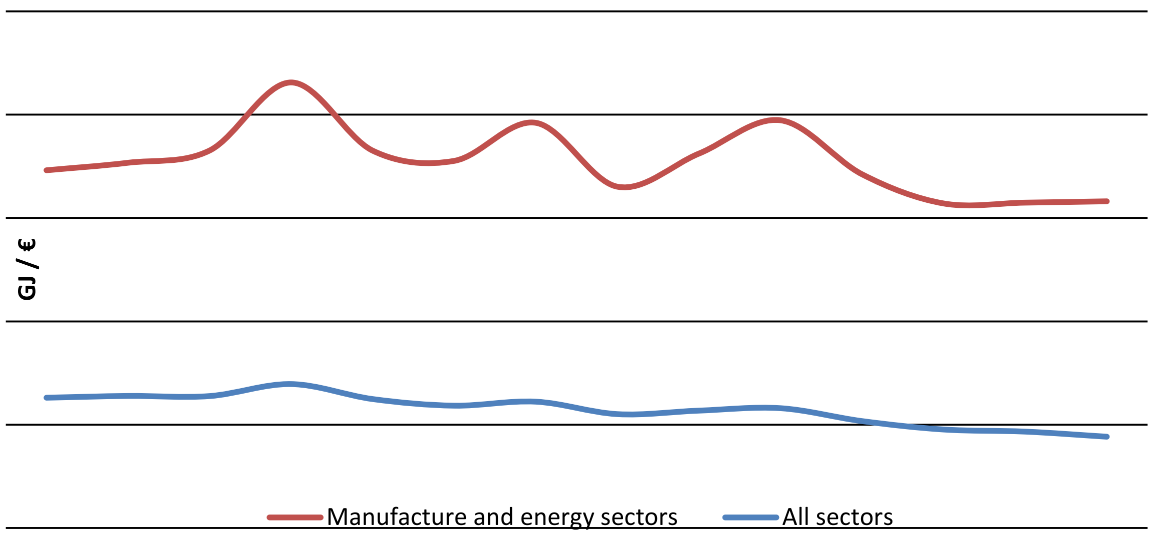
Source: Own elaboration using data from INE. Statistics Portugal. National Accounts

Figure A3.2 - Evolution of Portuguese emissions intensity 1996-2009



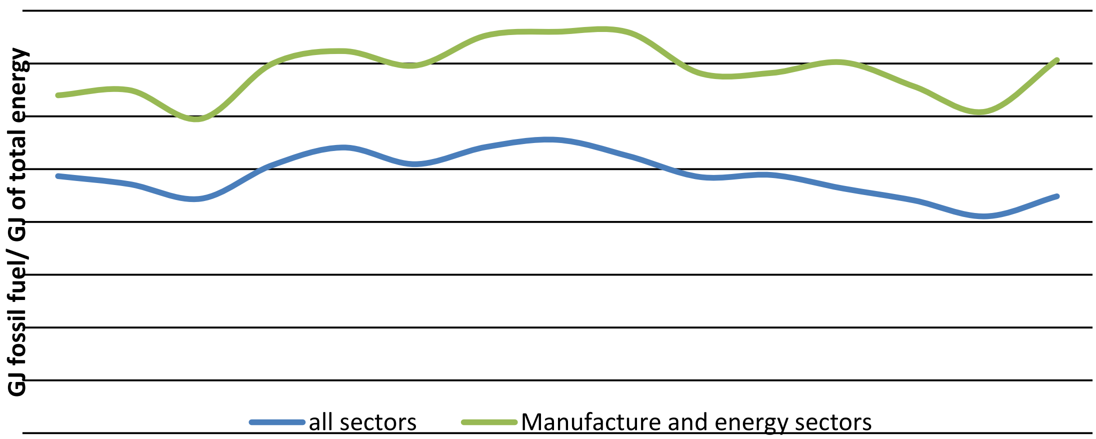
Source: Own elaboration using data from INE. Statistics Portugal. National Accounts

Figure A3.3 - Evolution of Portuguese energy intensity 1996-2009



Source: Own elaboration using data from INE. Statistics Portugal. National Accounts

Figure A3.4 - Weight of fossil fuels in total energy consumption 1995-2009



Source: Own elaboration using data from INE. Statistics Portugal. National Accounts

Table A3.1 - National Accounts Classification by Industry

Group A

A10	A38	Description
2	B	Mining and quarrying
2	CA	Manufacture of food products, beverages and tobacco products
2	CB	Manufacture of textiles, wearing apparel and leather products
2	CC	Manufacture of wood and paper products, and printing
2	CD	Manufacture of coke, and refined petroleum products
2	CE	Manufacture of chemicals and chemical products
2	CF	Manufacture of basic pharmaceutical products and pharmaceutical preparations
2	CG	Manufacture of rubber and plastics products, and other non-metallic mineral products
2	CH	Manufacture of basic metals and fabricated metal products, except machinery and equipment
2	CI	Manufacture of computer, electronic and optical products
2	CJ	Manufacture of electrical equipment
2	CK	Manufacture of machinery and equipment n.e.c.
2	CL	Manufacture of transport equipment
2	CM	Manufacture of furniture; other manufacturing; repair and installation of machinery and equipment
2	D	Electricity, gas, steam and air-conditioning supply
2	E	Water, sewerage, waste management and remediation activities

Group B

A10	A38	Description
2	B	Mining and quarrying
2	CD	Manufacture of coke, and refined petroleum products
2	CE	Manufacture of chemicals and chemical products
2	CG	Manufacture of rubber and plastics products, and other non-metallic mineral products
2	D	Electricity, gas, steam and air-conditioning supply

References

[1] European Environmental Agency. Approximated EU GHG inventory: A Early estimates for 2011. EEA Technical report No 13/2012.

[2] Portuguese Environmental Agency. Portuguese National Invert Report on Greenhouse Gases 1990-2011. Submitted under the United Nations Framework convention on Climate change and the Kyoto; 2013.

[3] Robaina-Alves M, Moutinho V. Decomposition analysis and Innovative Accounting Approach for energy-related CO2 emissions intensity over 1996-2009 in Portugal. Energy. 2013, (in press).

[4] Robaina-Alves M, Rodríguez M, Roseta-Palma C. Sectoral and regional impacts of the European carbon market in Portugal. Energy Policy. 2011;39(5):2528-41.

[5] Huang JP. Industry Energy Use and Structural-Change - a Case-Study of the Peoples-Republic-of-China. Energy Economics. 1993;15(2):131-6.

[6] Sinton JE, Levine MD. Changing Energy Intensity in Chinese Industry - the Relative Importance of Structural Shift and Intensity Change. Energy Policy. 1994;22(3):239-55.

[7] Hamilton C, Turton H. Determinants of emissions growth in OECD countries. Energy Policy. 2002;30(1):63-71.

[8] Paul S, Bhattacharya RN. CO2 emission from energy use in India: A decomposition analysis. Energy Policy. 2004;32(5):585-93.

[9] Liao H, Fan Y, Wei YM. What induced China's energy intensity to fluctuate: 1997-2006? Energy Policy. 2007;35(9):4640-9.

[10] Ma C, Stern DI. China's changing energy intensity trend: A decomposition analysis. Energy Economics. 2008;30(3):1037-53.

[11] Zhang M, Mu H, Ning Y, Song Y. Decomposition of energy-related CO2 emission over 1991-2006 in China. Ecological Economics. 2009;68(7):2122-8.

[12] Zhao M, Tan LR, Zhang WG, Ji MH, Liu YA, Yu LZ. Decomposing the influencing factors of industrial carbon emissions in Shanghai using the LMDI method. Energy. 2010;35(6):2505-10.

[13] Oh I, Wehrmeyer W, Mulugetta Y. Decomposition analysis and mitigation strategies of CO2 emissions from energy consumption in South Korea. Energy Policy. 2010;38(1):364-77.

[14] Akbostanci E, Tunc GI, Turut-Asik S. CO2 emissions of Turkish manufacturing industry: A decomposition analysis. Applied Energy. 2011;88(6):2273-8.

[15] Sheinbaum-Pardo C, Mora-Perez S, Robles-Morales G. Decomposition of energy consumption and CO2 emissions in Mexican manufacturing industries: Trends between 1990 and 2008. Energy for Sustainable Development. 2012;16(1):57-67.

[16] O' Mahony T, Zhou P, Sweeney J. The driving forces of change in energy-related CO 2 emissions in Ireland: A multi-sectoral decomposition from 1990 to 2007. Energy Policy. 2012;44:256-67.

[17] Miketa A. Analysis of energy intensity developments in manufacturing sectors in industrialized and developing countries. Energy Policy. 2001;29(10):769-75.

[18] Diakoulaki D, Mandaraka M. Decomposition analysis for assessing the progress in decoupling industrial growth from CO2 emissions in the EU manufacturing sector. Energy Economics. 2007;29(4):636-64.

[19] Hatzigeorgiou E, Polatidis H, Haralambopoulos D. Energy CO2 Emissions for 1990–2020: A Decomposition Analysis for EU-25 and Greece. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2010;32(20):1908-17.

[20] Robinson T. The convergence of electricity prices in Europe. Applied Economic Letters. 2007;14:473–6.

[21] Neumann A, Siliverstovs B, von Hirschhausen C. Convergence of European spot market prices for natural gas? A real-time analysis of market integration using the Kalman Filter. Applied Economic Letters. 2006;13:727–3.

[22] Blot C, Serranito F. Convergence of fiscal policies in EMU: a unit-root tests analysis with structural break. Applied Economic Letters. 2006;13:211–6.

[23] Strazicich M, List J. Are CO 2 Emission Levels Converging Among Industrial Countries? Environmental & Resource Economics, European Association of Environmental and Resource Economists. 2003;24(3):263-71.

[24] Liddle B. Electricity intensity convergence in IEA/ OECD countries: Aggregated and sectorial analysis. Energy Policy. 2009;27:1470-78.

[25] Camarero M, Tadeo AJP, Tamarit C. Are the determinants of CO2 emissions converging among OECD countries. Economic Letters. 2013;118(1):159-62.

[26] Phillips PC, Sul D. Transition Modeling and Econometric Convergence Tests. Econometrica. 2007;75(6):1771-855.

[27] Hettige H, Mani M, Wheeler D. Industrial pollution in economic development: the environmental Kuznets curve revisited. Journal of Development Economics. 2000;629:445-76.

[28] Stern DI. Explaining changes in global sulfur emissions: an econometric decomposition approach. Ecological Economics. 2002;429:201-20.

[29] Cole MA, Elliott RJR, Shimamoto K. Industrial characteristics, environmental regulations and air pollution: an analysis of the UK manufacturing sector2. Journal of Environment Economics and Management. 2005;50:121-43.

[30] Boyle GE, McCarthy TG. A simple measure of beta-convergence. Oxford Bulletin of Economics and Statistics. 1997;59(2):257-64.

[31] Marques AC, Fuinhas JA. Are public policies towards renewables successful? Evidence from European countries. Renewable Energy 2012;44:109-18.

[32] Baum CF. Residual diagnostics for cross-section time series regression models. Stata Journal. 2001;1:101-4.

[33] Baum CF. A review of Stata 8.1 and its time series capabilities. International Journal of Forecasting. 2004;20(1):151-61.

[34] Pesaran MH. General diagnostic tests for cross dependence in panels. Cambridge Working Papers in Economics: Faculty of Economics, University of Cambridge 0435; 2004.

[35] Frees E. Assessing cross-sectional correlation in panel data. Journal of Econometrics. 1995;69:393-414.

[36] Frees E. Longitudinal and panel data: analysis and Applications in the Social Sciences. Cambridge: University Press; 2004.

[37] EU. Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing directives 2001/77/EC and 2003/30/EC; 2009.

Chapter 4

Is there convergence and causality between the drivers of energy-related carbon dioxide emissions among the Portuguese Tourism Industry?

4.1 Introduction

The reduction of Carbon Dioxide (CO2) emissions and other atmospheric pollutants constitutes a foremost objective at a global scale. The tourism industry, linked with several sectors like trade, transport, accommodation, dining and attractions, contributes to climate change namely by producing greenhouse gases (GHG) emissions. The rapid growth of tourism activities has caused a rise in tourism-related emissions, posing a great challenge to this industry (Scott et al, [1]).

Several studies suggest that it is possible to make significant reductions in pollution provoked by these sectors. Specifically for the travel industry, the Inter-governmental Panel on Climate Change (IPCC) estimates that about 15% to 20% of emissions can be reduced cost-effectively by 2020 and an additional 10% emissions reduction (around 6 MtCO2) would require around $430 million investment (at an average abatement cost of $75 per ton of CO2). For the accommodation sector, Chiesa and Gautam [2] say that it's possible to reduce carbon emissions specially by using existing mature technologies in lighting, heating and cooling that significantly improve hotel energy efficiency.

Portugal is a country with a high potential for tourism, rich in landscapes, culture and history, with very favourable natural and climatic conditions. The Portuguese strategic plan for tourism for 2007-2015 has proposed to increase the tourism contribution to the Portuguese economy. One of the challenges is the reduction of the tourism energy consumption and CO2 emissions. On the other hand, Portugal has integrated European Union (EU) Directives and Decisions related to mitigation (2008/101/EC and 406/2009/EC) into national law. Furthermore, there is national financial support and incentive systems for investments in energy efficiency and renewable energies, and more sustainable tourism practices are expected, to face the emerging tourist demand (OECD [3]).

The various sub-sectors related to tourism have different impacts on the level of emissions but also different factors that contribute to these emissions. Most of these emissions are produced by the transport of tourists and, in particular, air travel. However, energy consumption is largely related to road transport and it increased in the 90s due to steady growth of vehicle fleets and road travel volumes, reflecting GDP (Gross Domestic Product) growth, higher family incomes and strong investments in road infrastructure (Chiesa and Gautam [2]). Accommodation is pointed as the second most polluting tourism subsector accounting for about one quarter of emissions (Scott et al. [1]). It is not expected that this importance will decline, since the accommodation capacity is likely to increase, and in addition, there is an increasing substitution of private homes and guesthouses for luxury hotels and resorts which are more energy intensive.

Other sub-sectors related to tourism, such as trade, telecommunications and recreational services have a more indirect impact on emissions. For instance, emissions from electricity usage in travel agency offices, amusement parks, shops or museums.

This study has two main objectives. The first is to analyse whether the various subsectors of tourism behaved similarly in the period 1996-2009 in relation to the intensity of CO2 emissions and for their determinant ratios, such as the carbon intensity, the share of fossil fuels on the total energy consumption, energy intensity and the importance of the sector in the economy in terms of GDP. This question is studied through the convergence analysis, dividing tourism subsectors between their direct and indirect impact on tourism industry.

If the sectors or groups of sectors behave differently in view of these ratios they should be subject to different energy or environmental policies, or at least these differences should be taken into consideration when formulating those policies.

The second objective has to do with the prediction of the interaction between the intensity of emissions and its determinant ratios in the future. Their relationships and mutual influences must be included and considered in environmental and energy policies and strategies to be implemented in the tourism sector. This prediction is useful, given the lack of data on the second phase of the Kyoto Protocol and on the post Kyoto period. This question is studied through a forecast error variance decomposition and impulse response function among the variation of CO_2 emissions intensity, and their drivers or effects.

The article is designed as follows: the introductory section 1 describes the research context, objectives and study motivation. In section 2, we researched important literature that examines the energy-related CO_2 emissions, in the tourism industry. Section 3 introduces the investigation methodology. The results about convergence and forecast causality from 1996-2009 are presented in section 4. Finally, section 5 presents the conclusions drawn from the research findings.

4.2 Literature review

The existence of studies in the revised literature applied to the tourism industry is scarce and it is important to identify factors that influence global changes in CO_2 emissions intensity.

In the tourism literature reviewed, there are some studies about energy consumption in tourism activities and its implications on CO_2 emissions and global warming, for instance, Bode et al. [4], Ceron and Dubois [5] and [6], Stern [7], Scott et al [1], Scott [8], Weaver [9] and Gossling et al. [10], among others. In specific sectors associated to tourism industry, there are studies with significant policy contribution and practice changes in air travel and transport emissions reductions, and about sustainability of tourism in what concerns climate change, for example, Hoyer [11], Becken et al. [12], Gossling [13], Black [14], Lee et al. [15], Bows et al. [16], Martin-Cejas and Sanchez [17], Liu et al. [18], Wang et al. [19], Pu and Peihua [20], Lee and Brahmasrene [21], Dwyer et al. [22], Andreoni and Galmarini [23], O'Mahony et al. [24], among others. Other studies focus on accommodation and food services, with respect to the sources of energy used as well as the amount of energy consumed in those sectors, such as

Deng and Burnett [25] and [26], Bohdanowicz [27], Bohdanowicz et al. [28], Kasim [29] and [30], Mihalič et al. [31], Gossling et al. [10] and Kasim and Ismail [32].

Some recent literature reports that tourism makes a significant contribution to environmental degradation with negative social and cultural impacts and habitat fragmentation, for example: Tovar and Lockwood [33], Peeters and Dubois [34], Dolnicar [35], Dolnicar and Leisch [36], Dolnicar et al. [37], Bramwell [38], Bramwell and Lane [39]; while other link of literature explain that climate change and environmental perceptions are likely to alter destination choice and influence tourism demand, for instance, Becken and Hay [40], Gossling et al. [41], [10] and Gossling [42] and [43]).

From our knowledge there are no studies for energy related CO2 emissions in Tourism industry, which use the Converge analysis or decomposition variance and generalized impulse response techniques to examine this environmental problem.

In this context, it is important to mention some recent studies, which applied the convergence analysis. Liddle [44] analysed the aggregated and sectoral convergence in the electricity intensity and energy intensity in IEA/OECD countries, Camarero et al. [45] studied the convergence of CO2 emissions intensity and their determinants among OECD countries over the period 1960-2008. More recently, Robaina-Alves and Moutinho [46] joined the decomposition analysis and Innovative Accounting Approach (IAA), that is, variance decomposition and impulse function response, to examine CO2 emissions intensity and its effects for 36 economic sectors.

4.3 Data and Methodology

4.3.1 Data

All data was collected from INE (National Accounts). The most important economic activities for the tourism industry were considered, identified into six categories: Wholesale and retail trade, repair of motor vehicles and motorcycles (category G), transportation and storage (category H), Accommodation and food service activities (category I), telecommunications (category JB), arts, entertainment and recreation (category R) and others services (categories S+T), over 1996 – 2009 period. This was the most recent period for which we had common data for all variables considered in this study.

These activities were chosen because Statistics of Portugal in National Accounts classifies them as tourism characteristic industries. Furthermore, studies that focus on tourism activities such as Lui et al. [18] and Scott et al. [1] regard these sectors as comprising directly or indirectly to tourism. Sectors which include hotels, restaurants and transports, or trade in general, affect the tourism activity directly, whereas activities that provide goods and services to tourism enterprises such as telecommunications, arts, entertainment, handicraft, certain local and domestic activities, affect tourism indirectly. Therefore, apart from the inclusion of these sectors, we also opted to apply the methodology used by dividing the subsectors of tourism in two groups (B and C), one considering the activities with direct influence (G, H and I) and another considering the activities with a more indirect influence on tourism (R, JB, S + T).

<table>
<tr><th colspan="2">Considered Groups</th><th>A38
Classification by Statistics Portugal</th><th>Description</th></tr>
<tr><td rowspan="6">Group A</td><td rowspan="3">Group B</td><td>G</td><td>Wholesale and retail trade, repair of motor vehicles and motorcycles</td></tr>
<tr><td>H</td><td>Transportation and storage</td></tr>
<tr><td>I</td><td>Accommodation and food service activities</td></tr>
<tr><td rowspan="3">Group C</td><td>JB</td><td>Telecommunications</td></tr>
<tr><td>R</td><td>Arts, entertainment and recreation</td></tr>
<tr><td>S + T</td><td>Other services activities + Activities of households as employers of domestic personnel and undifferentiated goods and services production of households for own use</td></tr>
</table>

We considered the driving forces (effects) resulting from the decomposition analysis developed by Robaina-Alves and Moutinho [46]. The authors decomposed the variation of CO2 emissions intensity in the following effects: (i) the changes in the CO2 emissions compared to the fossil fuels consumption (denoted by CI effect), (ii) the changes in the fossil fuels consumption compared to total energy consumption (denoted by CE effect), (iii) the change in energy intensity effect (denoted by EI effect) and (iv) changes in the economic structure effect (denoted by ES effect).

These effects can be used to evaluate various points related to energy consumption and the impact of tourism sectors on the environment, through the level of CO2 emissions. For example, we can evaluate the quality of fossil fuels and the replacement that can be done between them (through the effect CI), the ability to adopt abatement technologies and replace fossil fuels with renewable energy (through the effect CE), the energy intensity (through the effect EI) and the relative position of each tourism subsector in the overall economic activity (ES effect).

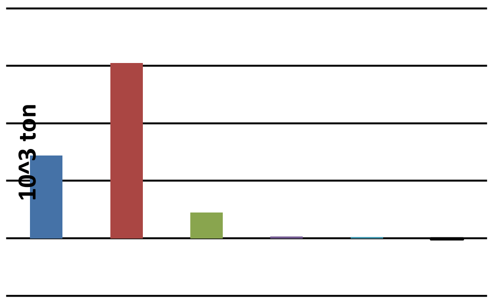
4.3.1.1 Data about energy-related CO2 emissions in the Portuguese Tourism Industry

Looking at CO2 emissions in absolute terms (figure 4.1) we see that the subsector in which they increased the most were sectors H (3 million tons), G (1.4 million tons) and I (448,000 tons), with relative increases of 227%, 115% and 83% respectively.

Considering the variables in relative terms, i.e. the emissions due to production and their respective determinants we can make the following analysis.

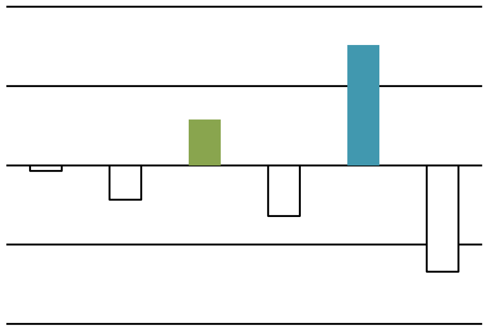
Regarding the intensity of CO2 emissions (figure 4.2) we can see that in G, H, R and S + T, this variable decreased, with the most significant reductions in these last two sectors, with the variation of - 32% and -67% respectively.

Figure 4.1 – Variation of CO_2 emissions Tourism subsectors 1996-2009



Source: own elaboration based on data from INE (National Accounts)

Figure 4.2 – Variation (%) of emissions intensity in Tourism subsectors



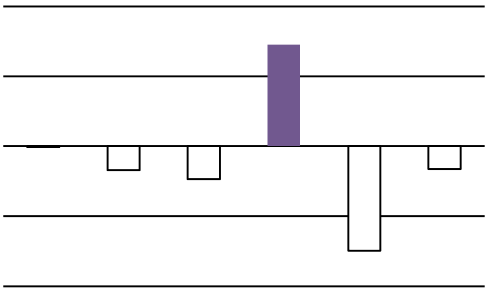
Source: own elaboration based on data from INE (National Accounts)

The sectors I and JB showed a significant increase of 29% and 76% respectively. Note that these sectors represent accommodation and food services, and telecommunications, the first one being a very important activity with direct impact on the tourism industry.

One effect that may influence the change in emission intensity has been the carbon intensity, that is, emissions per unit of fossil fuels, which can be an indicator of the type of fossil fuel used (more or less clean). In this aspect, tourist activities, except subsector R (Arts, entertainment and recreation), have decreased this carbon intensity, which may indicate that they have replaced more polluting fuels such as coal with less polluting ones, such as natural gas (figure 4.3). Note that the sector JB has the greatest positive variation in the intensity of emissions and has the biggest reduction on carbon intensity, therefore the increase in emissions will have to be justified on other effects.

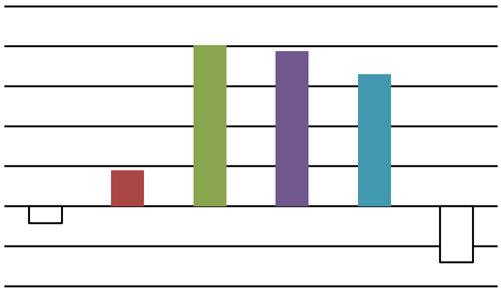
Most sectors (with the exception of G and S + T), show an increase in the ratio of fossil fuels per total energy consumption (figure 4.4), which means that with the exception of trade and other services, the remaining sectors are not, in a general way, replacing fossil fuels with renewable energy. The accommodation and food sectors, telecommunication and arts, entertainment and recreation show increases of 81%, 77% and 66% respectively in the importance of fossil fuels in total energy consumption.

Figure 4.3 - Variation (%) of carbon intensity (CO2 Emissions/Fossil fuels consumption) in Tourism subsectors



Source: own elaboration based on data from INE (National Accounts)

Figure 4.4 - Variation (%) of fossil fuels consumption by total energy consumption in Tourism subsectors

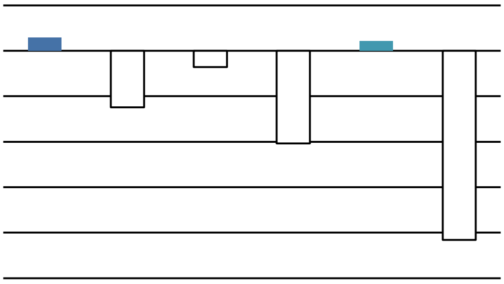


Source: own elaboration based on data from INE (National Accounts)

Energy intensity shows better results, since only G and JB show slight increases. The sectors H, JB and S + T show significant reductions of 25%, 41% and 83% respectively, in the amount of energy used per unit of value produced (figure 4.5).

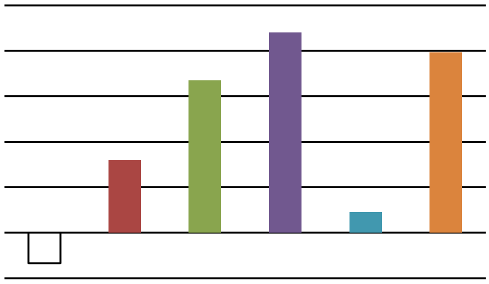
The contribution of these sectors to the country's total emissions can also be changed if the current importance of these in national production varies. Analysing the variation of the ratio of the sector GDP on total GDP (figure 4.6), we can see that, with the exception of sector G, all other sub-sectors of tourism gained importance in the Portuguese economy, specially the sectors R, S +T and I, with increases of 44 %, 40% and 33% respectively. The increasing importance of these sectors in the Portuguese economy reinforces the significance of the analysis of the respective emissions and their contribution to the total emissions of the country, in particular what is behind (the drivers of) the emissions in these subsectors of tourism.

Figure 4.5 - Variation (%) of energy intensity in Tourism subsectors



Source: own elaboration based on data from INE (National Accounts)

Figure 4.6 - Variation (%) of economic structure (sector GDP/total GDP) in Tourism subsectors



Source: own elaboration based on data from INE (National Accounts)

4.3.2 Convergence analysis

The convergence analysis aims to see if there are stochastic differences in the long-term between driving forces related to CO_2 emissions intensity in Tourism Industry (6 subsectors). The convergence was calculated for the variation of the emissions intensity and for the four effects referred above.

As in Boyle and McCarthy [47] we calculated two measures of convergence: sigma convergence and gamma convergence. Sigma convergence tracks the inter-temporal change. For each variable *X* it is calculated as:

$$\sigma = \left(\frac{\mathrm{var}\ (X_{ti})/\mathrm{mean}(X_{ti}\ )}{\mathrm{var}\ (X_{t0})/\mathrm{mean}(X_{t0})}\right)$$

Where *ti* is the current year and *t0* is the first year (1996). If we observe a fall in this measure it means that there is sigma convergence, that is, the dispersion was reduced.

Gamma convergence has to do with the rank of the effect. For each variable *X* it is calculated as:

$$\gamma = \left(\frac{\mathrm{var}\ (RX_{ti} + RX_{t0})}{\mathrm{var}\ (RX_{t0} * 2)}\right)$$

If the value is equal to one it means that the variance is the same. If the value is far from 1, there is evidence of sector mobility and reduced dispersion for the analysed effect. In this case, the importance of the emissions intensity drivers is not the same throughout the studied period. RX is the rank of the sector in the current year *ti* or in the first year *t0*, for the variable X.

4.3.3 Innovative Accounting Approach for Granger Causality

We employ the IAA to investigate the dynamic causality relationship among the variation of CO2 emissions intensity, and their drivers or effects. This approach includes a forecast error variance decomposition and impulse response function[1].

The forecast error variance decomposition explains the proportion of movements in the data series due to its own shocks as well as to shocks stemming in other variables in the study and uses a Vector Autoregressive Regression (VAR) system to test the strength of causal relationships between the variables.

For instance, if CI effect explains more of the forecast error variance of CO2 emissions intensity variation, then we deduce that there is unidirectional causality from CI effect to emissions intensity variation. The bidirectional causality exists if shocks in CO2 emissions intensity variation also affect CI effect in a significant way. If shocks occurring in both series do not have any impact on the changes in CO2 emissions intensity variation and in CI effect then there is no causality between the variables.

Impulse Response Functions (IRFs) helps us to trace the time path of shock impacts on variables in the Vector Autoregressive Regression (VAR). One can determine how much the CI, CE, EI and ES effects vary due to its shocks or to a shock in CO2 emissions intensity variation. For example we support the hypothesis that CI effect causes CO2 emissions intensity variation if the impulse response function indicates a significant response of CO2 emissions intensity variation to shocks in CI effect.

4.4 Results

4.4.1 Convergence analysis

For variation of the intensity of CO2 emissions (figure 4.7), there is a general sigma convergence. However there is a period of divergence between 2003 and 2006 when

[1] See Robaina-Alves and Moutinho (2013) to a similar methodology applied to Portuguese industrial sectors, using the CO2 emissions intensity and its determinant ratios.

sectors of group B clearly contributed, while group C sectors continued their process of convergence during this period.
The gamma convergence analysis for the variation of intensity of emissions shows that for groups A and C there is some mobility of sectors, over the ranking they had at the beginning of the period. For Group B there is instability in the path of convergence, and this indicator has a value very close to 1 in 2009, which means that these sectors continue to have the same relative importance in the intensity of emissions.

For all subsectors of Tourism (group A), according figures 4.8a and 4.8b, there is some sigma convergence between the conditioning effects of the intensity of emissions, although the path of convergence has a lot of instability. The effect in which there is the greatest convergence in the total period is the CI effect, although this presents a period of divergence between 1998 and 2002, thereafter it converged significantly. This group of industries has some homogeneity in the behaviour of the effects in this period as a whole (with some periods of divergence), particularly in the replacement of fossil fuels with each other, which changes the ratio of emissions from consumption of fossil fuels.

But if we analyse the sigma convergence for the other two groups (group B a and C), the evolution of this indicator is different. For group B (figures 4.8c and 4.8d) the trajectory of convergence of the effects is much more stable, being rare the years in which the variables diverge. The exception to this is the CI effect, which has large periods of divergence, although in the total period it converges. For this group, CE effect presents a very significant degree of convergence, as this value in 2009 is close to zero (0.152), which means that these sectors have had a similar behaviour in respect to the weight of fossil fuels in the total energy used.

For group C (figures 4.8e and 4.8f) there is some convergence between effects, but EI and CI are those with greater convergence, despite having a period of divergence in 2003-2007 and 1996-1998 respectively.

Regarding gamma convergence, we can see that in group A all ratios have a tendency to converge in the period as a whole. However, in certain periods divergence occurs, particularly for CI in 1997-1998, for EI in 2004-2006 and for CE in

2004-2008. The convergence is quite pronounced for ES and CI, the value being very close to zero in 2009. This means that for this group there was mobility and reduction of dispersion for these effects.

In group B there is a big divergence in the CI effect with a peak in 2003 with a value of 15.25. The CE effect also diverges in the period as a whole and in 2009 the value is of 2.78. ES and EI effects follow a marked pattern of convergence in this period.

For group C, the convergence is relevant for all effects, and only CI effect diverged significantly between 1996 and 1998, thereafter converging sharply.

Figure 4.7- Sigma and Gamma Convergence of CO2 emissions intensity

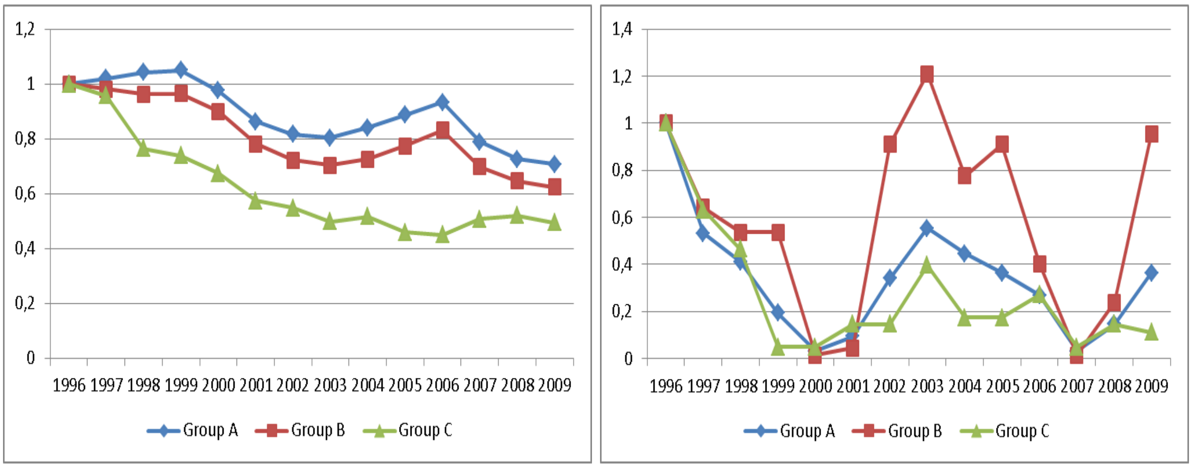


Figure 4.8a -Sigma convergence for group A

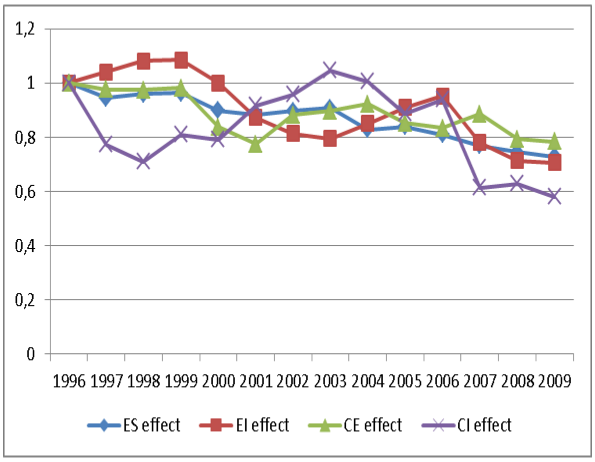


Figure 4.8b -Gamma Convergence for group A

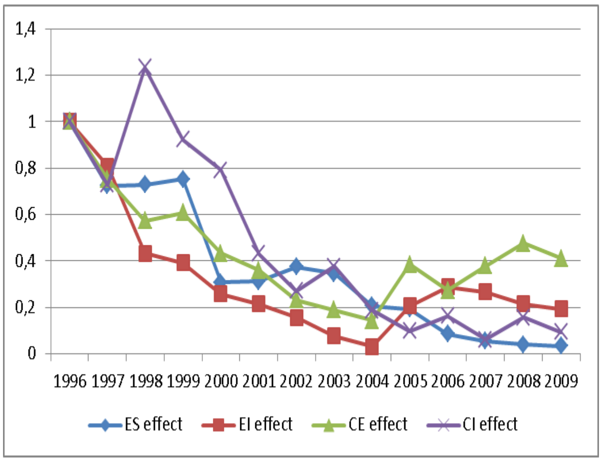


Figure 4.8c- Sigma convergence for group B

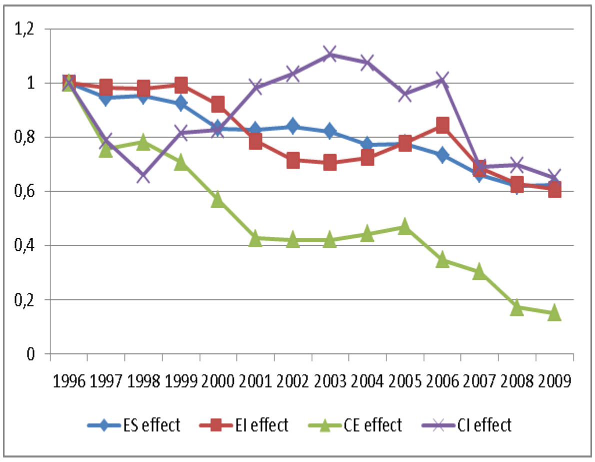


Figure 4.8d- Sigma Convergence for group C

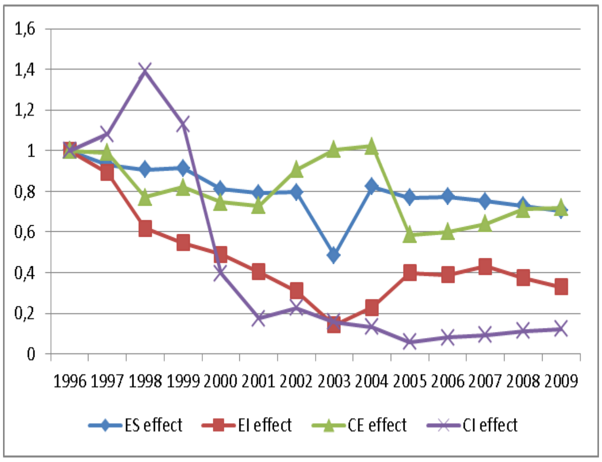


Figure 4.8e- Gamma convergence for group B

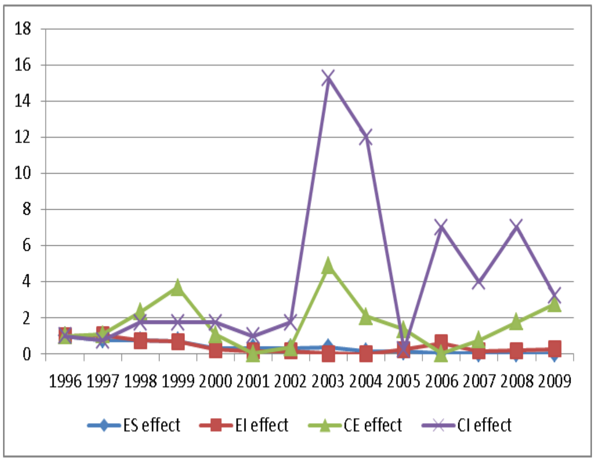


Figure 4.8f- Gamma Convergence for group C

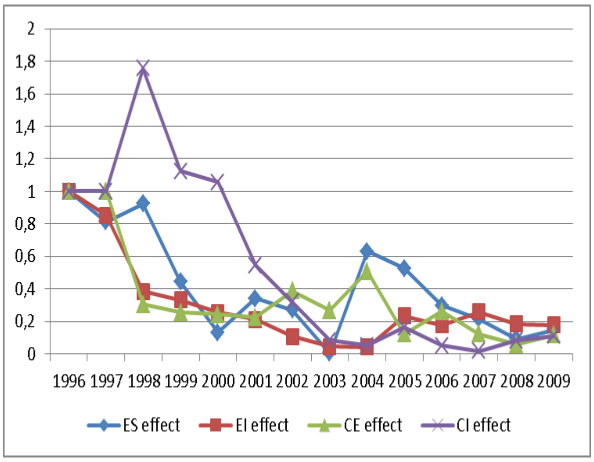


Table 4.1 presents the results for the generalized variance decomposition over a ten-year period for group B and group C.

Table 4.1 - Variance decomposition of group B and group C of Tourism activities

	CO2 emissions intensity		*CI*		*CE*		*EI*		*ES*	
Period	***GroupB***	***GroupC***	***GroupB***	***GroupC***	***GroupB***	***GroupC***	***GroupB***	***GroupC***	***GroupB***	***GroupC***
				Variance Decomposition of CO2 emissions intensity						
1	*100.00*	*100.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
2	*88.33*	*92.92*	*0.11*	*0.00*	*2.03*	*0.33*	*9.52*	*5.69*	*0.00*	*1.05*
3	*78.64*	*75.29*	*1.83*	*10.47*	*5.29*	*1.09*	*14.24*	*4.20*	*0.00*	*8.95*
4	*75.82*	*65.15*	*2.83*	*16.70*	*6.98*	*0.96*	*14.33*	*5.17*	*0.00*	*12.02*
5	*74.94*	*50.92*	*3.41*	*19.34*	*7.24*	*1.07*	*14.37*	*5.39*	*0.04*	*14.27*
10	*71.87*	*48.61*	*7.20*	*14.33*	*5.14*	*3.86*	*15.58*	*12.14*	*0.21*	*21.06*

					Variance Decomposition of CI					
1	*29.75*	*9.49*	*70.25*	*90.51*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
2	*36.33*	*5.62*	*57.93*	*89.57*	*0.029*	*0.00*	*0.01*	*2.57*	*5.69*	*2.23*
3	*39.17*	*6.67*	*54.62*	*80.35*	*0.18*	*0.06*	*0.51*	*2.51*	*5.51*	*10.40*
4	*42.54*	*8.67*	*51.52*	*72.79*	*0.20*	*0.31*	*0.83*	*2.44*	*4.92*	*15.80*
5	*45.90*	*9.12*	*48.31*	*67.97*	*0.17*	*2.68*	*1.33*	*2.33*	*4.28*	*17.89*
10	*55.35*	*7.73*	*38.19*	*56.12*	*0.31*	*12.33*	*3.63*	*3.36*	*2.52*	*20.46*
					Variance Decomposition of CE					
1	*1.01*	*16.44*	*53.73*	*20.47*	*45.26*	*63.07*	*0.00*	*0.00*	*0.00*	*0.00*
2	*1.53*	*14.34*	*35.47*	*21.64*	*47.48*	*58.93*	*0.18*	*0.97*	*15.53*	*4.38*
3	*1.78*	*15.63*	*29.78*	*17.84*	*45.18*	*50.25*	*1.87*	*1.78*	*21.38*	*14.30*
4	*2.43*	*15.86*	*24.89*	*16.82*	*42.15*	*42.29*	*7.32*	*3.54*	*23.19*	*21.48*
5	*2.87*	*16.59*	*22.36*	*16.32*	*39.39*	*36.88*	*11.94*	*4.70*	*23.43*	*25.52*
10	*5.54*	*24.34*	*19.29*	*9.85*	*32.43*	*23.61*	*16.44*	*12.55*	*26.29*	*29.65*
					Variance Decomposition of EI					
1	*98.76*	*40.16*	*0.00*	*5.14*	*0.19*	*41.52*	*1.05*	*13.18*	*0.00*	*0.00*
2	*91.10*	*34.10*	*0.00*	*6.21*	*1.40*	*47.55*	*7.42*	*11.18*	*0.06*	*0.95*
3	*81.35*	*25.68*	*1.56*	*15.60*	*4.73*	*42.49*	*12.23*	*15.19*	*0.13*	*1.04*
4	*78.09*	*23.05*	*2.53*	*20.30*	*6.76*	*40.49*	*12.31*	*15.22*	*0.31*	*0.94*
5	*77.08*	*22.01*	*3.03*	*22.91*	*7.22*	*38.36*	*12.28*	*15.80*	*0.38*	*0.92*
10	*73.20*	*24.93*	*6.75*	*24.93*	*5.14*	*31.27*	*14.06*	*13.55*	*0.85*	*4.17*
					Variance Decomposition of ES					
1	*7.57*	*6.06*	*1.24*	*27.99*	*3.24*	*0.97*	*20.37*	*1.83*	*67.59*	*63.16*
2	*5.12*	*15.26*	*1.98*	*22.64*	*1.87*	*0.59*	*12.83*	*7.15*	*78.19*	*54.35*
3	*3.63*	*20.11*	*1.71*	*17.97*	*1.29*	*3.63*	*10.18*	*8.89*	*83.18*	*49.40*
4	*2.85*	*23.19*	*1.79*	*13.89*	*1.01*	*6.54*	*9.34*	*11.27*	*85.00*	*45.11*
5	*2.50*	*25.35*	*2.02*	*11.17*	*0.93*	*8.28*	*8.56*	*13.05*	*85.99*	*42.14*
10	*2.35*	*28.59*	*2.75*	*638*	*1.08*	*10.47*	*5.96*	*19.05*	*87.86*	*35.50*

The empirical evidence indicates that 71.87 and 48.61 per cent of CO2 emissions intensity are due to their own innovative shocks respectively for group B and C. The standard deviation shock in EI and CI are the two effects that better explain CO2 emissions intensity in group B, with a percentage of 15.58 and 7.2 respectively. For group C the most important effects are ES (21.06%) and CI (14.33%).

In group B, a 38.2 per cent of CI is explained by its own innovative shocks and 55.4 percent is explained by one standard deviation shock in emissions intensity, while in group C, the most important influences on CI come from their own variations (56.12%), from the variations in ES (20.46%) and variations in CE (12.33%).

Variations of CE in group B are mainly justified by changes in the variable itself (32.4%), by variations in ES (26.3%), in CI (19.3%) and in EI (16.4%). In group C, CE changes are mainly explained by variations in ES (29.7%), in emissions intensity (24.3%), in CE (23.6%), and in EI (12.3%).

Changes in EI are strongly determined by variations in the intensity of emissions (73.2%) and in EI (14.1%) in group B. In group C the influence on EI is distributed primarily by CE (31.3%), by the intensity of emissions (24.3%) and by CI (24.3%).

Finally ES is influenced primarily by its own variations in group B (87.9%) and in group C (35.5%). In the latter, variations in emissions intensity (28.6%) and in EI (19.1%) are shown to be significant.
From this analysis we can identify some patterns of causality between variables. These patterns appear to be different for the two groups. For example in group B we found bidirectional causality between the intensity of emissions and EI and between the intensity of emissions and CI. In group C the bidirectional causality exists between the intensity of emissions and ES and between EI and CE.

Regarding unidirectional causality, it exists in group B from ES, CI and EI to EC. In group C we found stronger relationships of causality between variables, namely from CI to the emissions intensity, from ES and CE to CI, from ES and emissions intensity to CE, from emissions intensity to EI and from EI to ES.

4.4.2 Impulse Response Functions

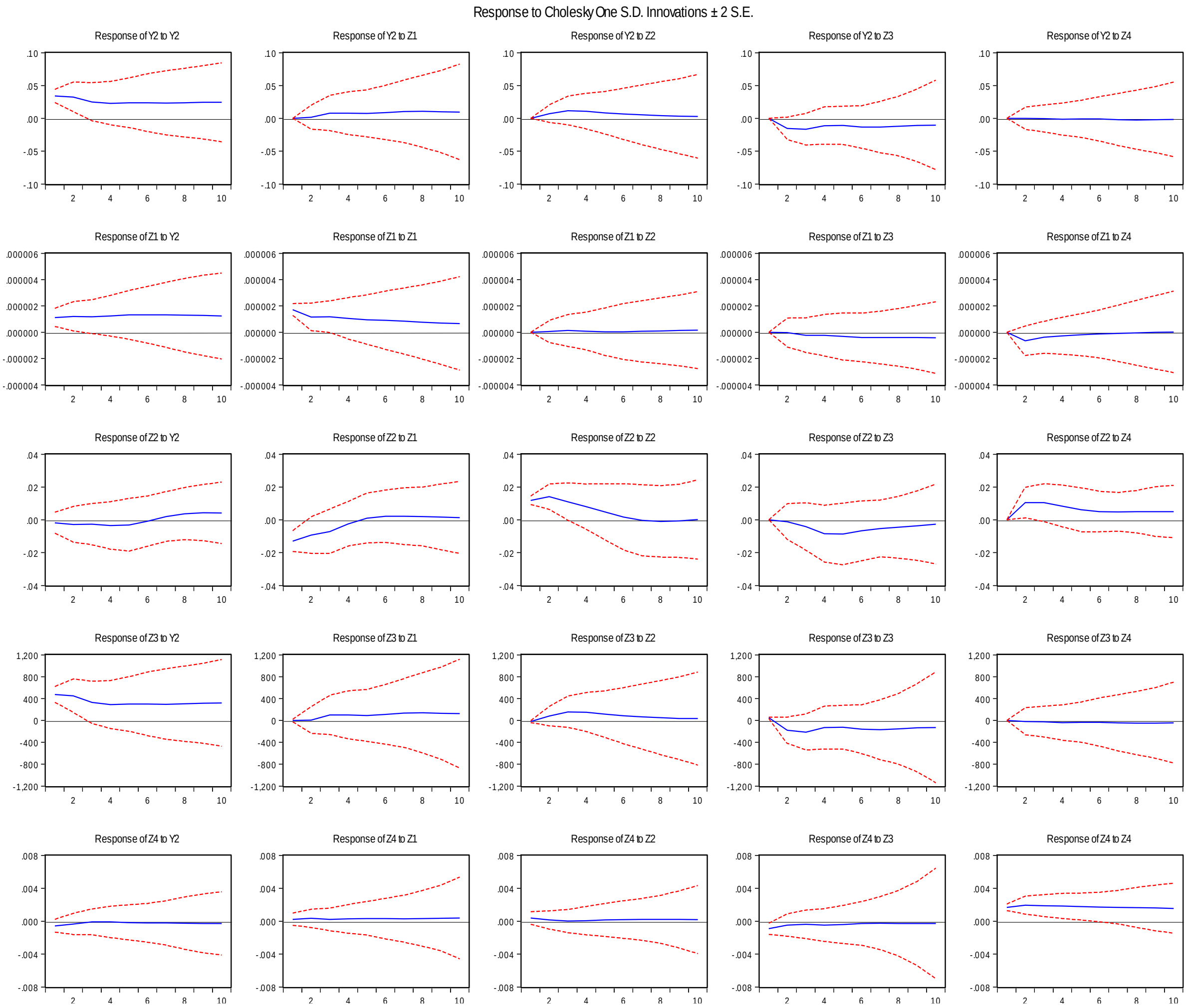
For group B we have the IRFs presented in figure 4.5. We can see that emissions intensity reacts positively to shocks in CI and CE, and negatively to shocks in EI. The response to a shock in CE increases until the third time horizon, then becoming linear and decreasing. The reaction to ES is linear and constant.

CI effect reacts positively to shocks in emissions intensity (A) and negatively to shocks in EI. Concerning shocks in ES, the short run reaction is negative but after the second period it dissipates until the seventh time horizon becoming constant and approximately zero.

The reaction of CE to a shock in emissions intensity is negative and turns positive after the sixth period. When a shock in CI occurs, CE has a slightly negative reaction in the short run, turning into positive in the fifth period. CE reacts negatively to EI and positively to ES.

EI reacts positively to shocks in the intensity of emissions, in EI and in CE, but in the latter case the reaction dissipates in the long run. EI has a negative but very soft reaction to shocks in ES.

Figure 4.9a - IRFs functions of Group B in Tourism Industry



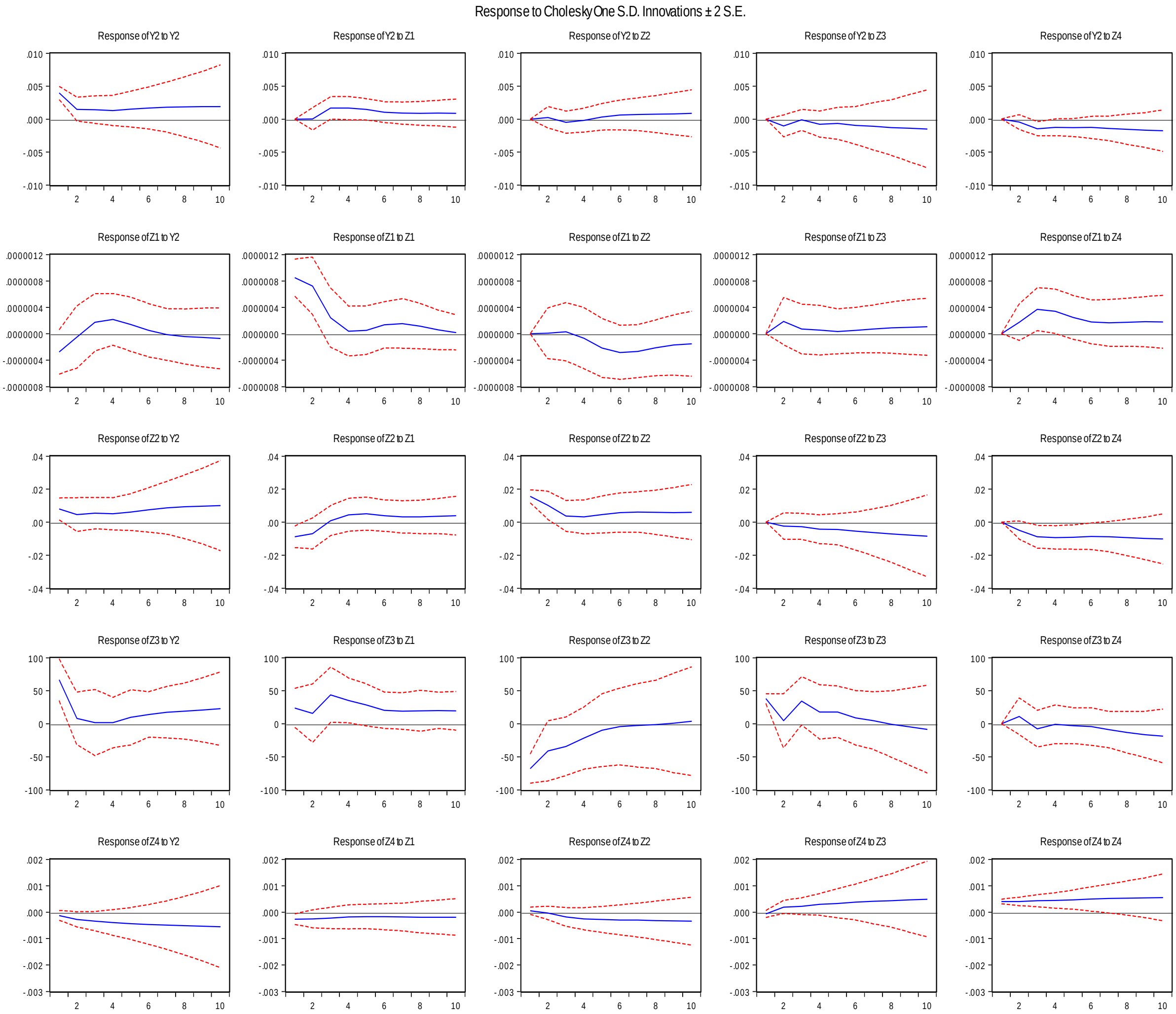
Note : Y2 is equivalent to ratio A, z1 to ratio CI, z2 to ratio CE , z3 to ratio EI and z4 to ratio ES

ES reacts very discreetly to shocks in the other variables. Its reaction is negative with respect to EI and to intensity of emissions, and positive with CI and CE.

The results in figure 4.6 show the reactions of the considered variables for the group B tourism activities.

We confirm a positive response of emissions intensity due to one standard deviation shock in CI. The response to CE, changes from increase to decrease after the second time horizon, and maintains its level in the long run. The reaction to shocks in EI and ES is negative.

Figure 4.9b - IRFs functions of Group C in Tourism Industry



Note : Y2 is equivalent to ratio A, z1 to ratio CI, z2 to ratio CE , z3 to ratio EI and z4 to ratio ES

CI reacts negatively to shocks in the intensity of emissions in the short term. In the second period it becomes positive, and then negative in 7th period. CI almost does not react in the short-term to variations in CE, but after the 3rd period the effect is negative. The reaction of CI to shocks in EI and in ES is positive.

The response of CE to shocks in emissions intensity is positive and to shocks in EI and ES is negative. CE reacts negatively to shocks in CI but the effect becomes positive in the second period.

The reaction of EI to a shock in CE is negative but becomes positive at the seventh time horizon. For a shock in CI, in emissions intensity and in ES, the reaction is positive, but for the latter the effect becomes negative after the third period. ES reacts negatively to all other variables except to EI.

4.5 Conclusions and policy recommendations

The purpose of this paper is to study: (i) whether the various subsectors of tourism in Portugal behaved similarly in the period 1996-2009 in relation to the intensity of CO2 emissions and to their determinant ratios. This question is studied through the convergence analysis, dividing tourism subsectors between their direct and indirect impact on tourism industry; and (ii) the prediction of the interaction between the intensity of emissions and its determinant ratios in the future. This question is studied through a forecast error variance decomposition and impulse response function among the variation of CO2 emissions intensity, and their drivers or effects.

Therefore, two sets of conclusions can be drawn: (i) on the convergence sigma and gamma; (ii) on the generalized variance decomposition and the IRFs.

In general it can be said that there was convergence between the sectors regarding the emission intensity. This reflects a slowdown or reduction in the most polluting sectors and an increase in the less polluting ones. However for group B (sectors with more direct influence on tourism) there was some divergence between 2003 and 2006. We also saw that in groups A and C there was mobility between sectors, that is, the most polluting sectors decreased their rank on the intensity of emissions, and less polluting sectors rose in rank. In group B we didn’t find this mobility, or rather, sectors occupy substantially the same relative importance they had in the beginning of the period.

Concerning the effects of the determinants of emissions intensity in group A, although there appears to be a general convergence of all effects, the carbon intensity (emissions/consumption of fossil fuels) is the effect that converges more. This means that sectors became more similar in terms of the mix of fossil fuels used. In group B the convergence effect is even more stable, which means that in these sectors that directly affect tourism, the evolution of the determinants of emissions are very similar across sectors. This may require more specific and targeted policies for these subsectors included in group B (trade, transportation, accommodation and food service activities). The exception is on carbon intensity, which contrary to what happened in the group A, group B presents periods of great divergence (despite checking the global convergence in the period). This means that the sectors in this group have a different behaviour in relation to the mix of fossil fuels used, which is related to the most appropriate fuel type in the different economic activities.

In group C (activities affecting tourism in a more indirect way) there is convergence in general for all the effects, but most clearly in energy intensity and carbon intensity.

Regarding the rank of sectors on the effects of emissions, there is convergence in group A, that is, there was mobility between sectors. The convergence is quite pronounced for economic structure and carbon intensity. This means that for this group there was reduction of mobility and dispersion for these effects. In group B there is a great divergence in the carbon intensity effect and in the effect of fossil fuels by energy consumed. This means that differences between sectors persist in relation to the fossil fuels used and to the percentage of fossil fuels and renewable energy used. For group C, the convergence is relevant for all effects, and only CI effect diverged significantly between 1996 and 1998, thereafter converging sharply.

To summarize, sectors tend to have similar behaviour, even these similarities are greater for Tourism Industry in trade, transportation, accommodation and food services activities. The lower divergences in tourism activities would facilitate the implementation of measures on how to mitigate CO_2 emissions at tourism industry and as a result commit to Kyoto protocol targets in the first phase.

When linking the conclusions about the generalized variance decomposition and the IRFs, one can notice for the group, B that there is bidirectional causality between the intensity of emissions and energy intensity. The effect of intensity of emissions is positive on energy intensity, and the effect of energy intensity on emissions intensity is negative. This may show that the sectors are using more energy per unit of output, but are replacing fossil fuels by renewable energy.

In group C energy intensity causes a negative effect on the percentage of fossil fuels in total energy consumption, which reflects that sectors that consume more energy became aware of change to renewable energy in the future. The percentage of fossil fuels in total energy consumption also has a negative effect on energy intensity, that is, sectors in where the percentage of fossil fuels increase, try to reduce the consumption of energy by unit produced. But in the long run this effect becomes positive with a negligible value. Intensity of emissions and economic structure have a negative relation of causality. This means that the most polluting sectors tend to reduce its economic importance and that sectors that improve their economic importance can reduce their intensity of emissions.

It was also found that in the group B sectors, the percentage of fossil fuels used, reacts positively to the economic structure and to carbon intensity, in other words, when a sector gains economic importance, it tends to use more fossil fuels, and when it raises its carbon intensity, in the future the use of fossil fuels may rise. On the other hand, a positive shock on energy intensity tends to reduce the percentage of fossil fuels used.

In group C, if carbon intensity raises it leads to an increment of emissions intensity. In addition, carbon intensity rises when sectors improve their economic importance. In these sectors, a positive shock in economic structure diminishes the use of fossil fuels, but the increase of emissions intensity leads to an increase in the use of fossil fuels. Emissions intensity causes a positive effect on energy intensity, and this effect in turn causes a reduction on the economic structure.

The similarity of behaviour between tourism subsectors towards emissions intensity and their determinant effects (particularly between sectors including hotels, restaurants and transports, or trade in general, that affect the tourism activity directly), could imply equal treatment, although specific to each activity, in relation to energy and environmental policies. Recapitulating section 3.1.1, although in trade and transportation sectors emissions intensity has decreased, in accommodation and food services this variable increased in the studied period.

Of all the tourism activities, only recently was the aviation sector included in the European Union Emissions Trade System (EU ETS). All other activities were excluded from this market. The aviation sector was brought into the EU ETS on 1 January 2012 through Directive 2008/101/EC. For 2012 the cap on aviation allowances was set at a level equivalent to 97% of aviation emissions in the 2004-2006 reference period and 85% of allowances were given to aircraft operators for free.

The European Commission is taking the first steps to reduce the GHG emissions from the maritime transport industry. The proposed legislation (only for 2018) will oblige owners of large ships using EU ports to monitor and report the ships' annual CO2 emissions, as well as to provide information about the ships' energy efficiency.

An agreement between the European Parliament, Council and European Commission on a further reduction in CO2 emissions from cars is expected to reduce average CO2 emissions from new cars to 95g per kilometre from 2020 (European Commission, 2012). This represents a 40% reduction from the mandatory 2015 target of 130g/km. The target is an average for each manufacturer's new car fleet; some models will emit less than the average and some will emit more.

As already mencioned, in accommodation and food services CO2 emissions intensity rose between 1996-2009. Since 2009-2010, implemented measures have been adopted under the Ecodesign and Energy Labelling Directives on energy related products. These measures reduce the energy demand of industrial and household products, and have been adopted for a number of electronic appliances, including domestic dishwashers, refrigerators, washing machines, televisions and well as tyres and industrial products such as motors, fans and pumps. The estimated impact of the adopted ecodesign and labelling measures are energy savings in the range of 90 Mtoe in 2020 (European Commission [48]).

On the other hand, dealing with the energy consumed in the building field, in particular for heating and cooling purposes, the EU adopted a revised Energy Performance of Buildings Directive (EPBD) in 2010. The Member States have to apply minimum energy performance requirements for new and existing buildings, and to ensure that by 2021 all new buildings are "nearly zero-energy buildings." (European Commission [48]).

At the national level, green taxation has shown as an important instrument in the Portuguese tax system. The government implemented in 2010 a set of green tax measures, including the strengthening of environmental aspects in automobile tax, a tax on energy efficient light bulbs, and tax deductions for the use of renewable instruments. The Stability and Growth Programme foresees strengthening environmentally related fiscal measures from 2010 onwards. Proposed measures include tax rebates for electric vehicles and higher energy taxes (European Union, [49]). All these instruments affect tourism activities directly and can be justified by the causal relations and future predictions pointed above, particularly for transport and accommodation activities.

Future research could be to apply the study of Robaina Alves and Moutinho [46] to the tourism sector in Portugal and / or in other countries. The objective would be to complement and confront the results of the present study with another methodology, which identifies the effects in which the intensity of CO_2 emissions in tourism can be broken down and analysed, as well as their evolution and which of them has more importance in determining the intensity of emissions. This future study, through the calculation of these effects over time, could also allow us to evaluate aspects such as the substitution between fossil fuels, the substitution of fossil fuels for renewable energy sources, the energy efficiency of tourism activities as well as technology choices, investments for energy saving, and also give us signals about the diversification of tourist products among the various subsectors analysed and the preferences of the consumer.

References

[1] Scott, D., Peeters, P. & Gössiling, S., 2013, Can tourism deliver its "aspirational" greenhouse gas emissions reduction targets? Journal of Sustainable Tourism, 18(3), 393-408.

[2] Chiesa, T and Gautam, A., 2009, Towards a Low Carbon Travel & Tourism Sector report by the World Economic Forum, within the framework of the Aviation, Travel & Tourism Partnership Programme

.[3] OECD (2011) Climate Change and Tourism Policy in OECD countries, in OECD ISBN 978-92-64-11959-8 (online), accessed in 25/08/2013.

[4] Bode, S., Hapke, J. & Zisler, S., 2003, Need and options for a regenerative energy supply in holiday facilities. Tourism Management, 24 (3), 257-266.

[5] Ceron, J.P. Dubois,G., 2003, Changes in leisure/tourism mobility patterns facing the stake of global warning: The case of France. Presentation given a Global Change and Human Mobility., International Geographical Union Commission, Palma de Mallorca, Spain, 3-5 April

[6] Ceron, J.P., Dubois, G., 2007. Limits to tourism? A backcasting scenario for sustainable tourism mobility in 2050. Tourism and Hospitality Planning, Development 4 (3), 191–209.

[7] Stern, N., 2006, The economics of climate change: The Stern review: Cambridge University Press.

[8] Scott, D., 2011, Why sustainable tourism must address climate change. Journal of Sustainable Tourism, 19 (1), 17-34.

[9] Weaver, D., 2011, Can sustainable tourism survive climate change? Journal of sustainable Tourism, 19(1), 5-15.

[10] Gössling, S., Garrod, B., Aall, C., Hille, J., & Peeters, P., 2011, Food management in tourism: Reducing tourism's carbon "foodprint". Tourism Management, 32, 534–543.

[11] Hoyer, K., 2000, Sustainable tourism or sustainable mobility? The Norwegian case. Journal of Sustainable Tourism, 8(2), 147-159.

[12] Becken, S. Frampton C, Simmons D, 2001, Energy consumption patterns in the accommodation sector: The New Zeland case, Ecological Econ., 39 (3), 371-386.

[13] Gössling, S., 2002, Global environmental consequences of tourism. Global Environmental Change, 12 (4), 283-302

[14] Black, W.R. ,2004, Sustainable mobility and its implication for tourism. In L.Lumsdon & S.Page (Eds), Tourism and transport: Issues and agenda for the new millennium (pp,57-68), London, UK: Elsevier

[15] Lee, D.S., Fahey, D.W.., Forster, P.M., Newton, P.J., Wit, R.C.N., Lim, l.l., 2009, Aviation and global climate change in the 21st century. Atmospheric Environment, 43, 3520-3537.

[16] Bows, A., Anderson, B. & Peters, P.M., 2009, Air transport, climate change and tourism. Tourism and Hospitality: Planing & Development, 6 (1), 7-20.

[17] Martin-Cejas, R. & Sánchez, P.P.R., 2010, Ecological footprint analysis of road transport related to tourism activity: the case for Lanzarote Island. Tourism Management, 31(1), 98-103.

[18] Liu, J., Feng, T. & Yang, X., 2011, The energy requirements and carbon dioxide emissions of tourism industry of Western China: A case of Chengdu city. Renewable and Sustainable Energy Reviews, (15) 2887-2894.

[19] Wang, W.W., Zhang, M. & Zhou, M., 2011, Using LMDI method to analyze transport sector CO2 emissions in China. Energy, 36(10), 5909-5915.

[20] Pu W. & Peihua, S., 2011, An estimation of energy consumption and CO2 emissions in tourism sector of China. Journal of Geographical Sciences, 21 (4), 733-745.

[21] Lee, J.W. & Brahmasrene, T., 2013, Investigating the influence of tourism on economic growth and carbon emissions: Evidence from panel analysis of the European Union. Tourism Management, 38, 69-76.

[22] Dwyer, L., Forsyth, P., Spurr, R., & Hoque, S., 2010, Estimating the carbon footprint of Australian tourism. Journal of Sustainable tourism, 18,355-376.

[23] Andreoni, V. & Galmarini, S., 2012, European CO2 emission trends: A decomposition analysis for water and aviation transport sectors. Energy, 45, 595-602.

[24] O'Mahony, T., Zhou, P. & Sweeney, J., 2012, The driving forces of change in energy-related CO2 emissions in Ireland: A multi-sectoral decomposition from 1990 to 2007. Energy Policy, 44, 256-267.

[25] Deng, S.M. and Burnett, J., 2000, A study of energy performance of hotel buildings in Hong Kong. Energy Buildings 31, 7-12.

[26] Deng, S.M. and Burnett, J., 2002, Energy use and management in Hotels in Hong Kong. Hospitality Management, 21, 371-380

[27] Bohdanowicz, P., 2005, European hoteliers´environmental attitudes: Greening the business. Cornell Hotel and Restaurants Administration Quarterly, 46, 188-204.

[28] Bohdanowicz, P., Zientara, P. & Novotna, E., 2011, International hotel chains and environmental protection: An analysis of Hilton's we care! programme (Europe, 2006–2008). Journal of Sustainable Tourism, 19(7), 797–816.

[29] Kasim, A., 2007, Towards a wider adoption of environmental responsibility in the hotel sector. International Journal of hospitality & Tourism Administration, 8(2), 25–49.

[30] Kasim, A., 2009, Managerial attitudes towards environmental management among small and medium hotels in Kuala Lumpur. Journal of Sustainable Tourism, 17(6), 709–725.

[31] Mihalič, T., Žabkar, V. & Knežević Cvelbar, L., 2012, A hotel sustainability business model: evidence from Slovenia, Journal of Sustainable Tourism, 20:5,701-719

[32] Kasim, A., & Ismail, A., 2012, Environmental friendly practices among restaurants: Drivers and barriers to change. Journal of Sustainable Tourism, 20 (4), 551-570.

[33] Tovar, C. and Lockwood, M., 2008, Social impacts of tourism: An Australian Regional Case Study. International Journal of Tourism Research, 10, 365-378.

[34] Peeters, P. M. & Dubois, G., 2009, Exploring tourism travel under climate change mitigation constraints. Journal of Transport Geography 18 (2010) 447–457.

[35] Dolnicar S., F., 2006, Nature conversing tourists: The need for a broader perspective. Anatoia, 17(2) 235-256.

[36] Dolnicar, S. & Leisch, F., 2008, Selective marketing for environmentally sustainable tourism. Tourism Management, 29(4), 672–680.

[37] Dolnicar S., Laesser C. & Matus K., 2009, Short-haul city travel is truly environmentally sustainable. Tourism Management, 1–8.

[38] Bramwell, B., 2011, Governance, the state and sustainable tourism: A political economy approach. Journal of Sustainable Tourism, 19(4–5), 459–477.

[39] Bramwell, B. and Lane, B., 2011, Critical research in the Governance of tourism and sustainability. Journal of Sustainable Tourism, 19, 4-5, 411-421

[40] Becken, S. & Hay, J., 2007, Tourism and Climate change: Risks and opportunities. Clevedon: Channel View Publications.

[41] Gössling S., Hall, C.M., Lane, B. &Weaver, D., 2008, The Helsingborg statement on sustainable tourism. Journal of Sustainable Tourism, 16 (1) ,122-124.

[42] Gössling, S., 2009, Carbon neutral destination: A conceptual analysis. Journal of Sustainable Tourism, 17(1), 17–37.

[43] Gössling, S., Hall, C.M., Peeters, P., & Scott, D., 2010, The future of tourism: Can tourism growth and climate policy be reconciled? A mitigation perspective. Tourism Recreation Research, 35(2), 119–130.

[44] Liddle B., 2009, Electricity intensity convergence in IEA/ OECD countries: Aggregated and sectorial analysis. Energy Policy: 27:1470-78.

[45] Camarero M, Tadeo AJP, Tamarit C., 2013, Are the determinants of CO2 emissions converging among OECD countries. Economic Letters. 118(1):159-62.

[46] Robaina-Alves, M. & Moutinho, V., 2013, Decomposition analysis and Innovative Accounting Approach for energy-related CO2 emissions intensity over 1996-2009 in Portugal. Energy, 57(1), 775-787.

[47] Boyle, G.E. & McCarthy, T.G., 1997, A simple measure of beta-convergence. Oxford Bulletin of Economics and Statistics; 59(2):257-64.

[48] European Commission, 2013, Green Paper - a 2030 framework for climate and energy policies, COM 2013/169 final, Brussels.

[49] European Commission, 2012, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the regions – Cars 2020: Action Plan for a competitive and sustainable automotive industry in Europe, COM 2012/636 final, Brussels

Chapter 5

Decomposition of energy-related GHG emissions in Agriculture over 1995-2008 for European Countries

5.1 Introduction

It is widely accepted that the role of agriculture cannot be underestimated in the context of climate change. According to the EEA, agriculture has been responsible, in the last two decades, for about 10% of the total annual emissions of greenhouse gases emitted in Europe. The EU Trading Scheme does not consider the agricultural sector as part of the negotiations of carbon credits[1], nevertheless countries are concerned about adopting other environmental policies that aim at reducing GHG emissions in the agricultural sector, thereby contributing to the achievement of Kyoto Protocol goals[2]. For the design of a policy of this kind, it is important to understand how the intensity of Greenhouse Gases (GHG) emissions (GHG emissions/ agricultural value added) has evolved and what factors contribute to the variation of that intensity.

The objective of this work is to identify the effects in which the intensity of GHG emissions in agriculture can be broken down and analysed, as well as their evolution and which of them has more importance in determining the intensity of emissions in agriculture.

The use of fossil fuels in agricultural machinery and power generation in greenhouses and farms leads to GHG emissions (through CO2 emissions). We observed that, in general, the GHG emissions in the agricultural sector has suffered a negative change, while the consumption of fossil fuels in agriculture has greatly increased in some countries (such as Belgium and Germany) and significantly decreased in others (such as Sweden and Finland) (see figure A5.1 in appendix).

[1] See European Commission for information about the sectors included in EU Trading Scheme [1]
[2] See OECD [2]

However, Nitrogen, an essential nutrient for agricultural productivity, is the cause of most emissions in this sector. Furthermore, it is noteworthy that the intensity of N_2O is 298 times stronger than CO_2 in the greenhouse effect. The use of this nutrient per acreage has been declining for most countries (see figure A5.2 in appendix), with some exceptions such as Spain, Austria and Slovakia. Belgium and the Netherlands are countries where this ratio was reduced quite significantly.

Therefore we hold that emissions in the agricultural sector are caused primarily by two sources: the use of fossil fuels and the use of Nitrogen. Observing the relationship between these two variables we can see (figure A5.3 in appendix) this has increased for most countries except for Spain, France, Finland and Sweden. This increase holds up with the decrease in the use of Nitrogen and increased use of fossil fuels, which highlights the bigger importance of fossil fuel pollution caused by the agricultural sector.

The utilized agricultural area also becomes an important variable when studying the emission intensity of agriculture, as countries that face shortage of land tend to increase the use of agrochemicals such as Nitrogen, to augment land productivity. Land abundant countries will tend to increase the cultivated land area by farmer, by using labor-saving inputs, like more machinery. We observed (see figure A5.4 in appendix) that the countries that increase the ratio area/labour more are Denmark and Sweden and the ones that increase less are Portugal, Spain, Greece, Italy and the Netherlands.

With the exception of Finland and Greece, agricultural labor productivity has increased in many countries (see figure A5.5 in appendix)). This highlights, on the one hand, the increase in total production, and also a reduction in the number of workers in favor of a more mechanized production. This variable (agricultural labor productivity) should be considered as a decomposing factor of agricultural emissions intensity, since the described behavior may lead to a higher consumption of fossil fuels, by the increase in machinery and by the increase in production, and also to a more intensive use of Nitrogen.

Considering the previous analysis, we decided to use the 'complete decomposition' technique developed by Sun [3] and applied by Zhang et al. [4] to examine agriculture GHG emissions intensity and to decompose it in several effects or components, based on the variables presented above. We considered agriculture emissions intensity for 15 countries as well as its reflecting changes over the 1995-2008 period.

Although there are studies that do this kind of decomposition of CO2 emissions intensity or of GHG emissions intensity, they focus on the economy as a whole or in particular industries. To our knowledge, there is no literature that applies this decomposition technique specifically to the agriculture sector. In addition, we detected a gap in the literature dealing with the decomposition of the agriculture emission intensity, addressing it in the same way as the intensity of emissions in other sectors, while the agricultural sector has certain specific characteristics. Thus, this study introduces in the decomposition of the intensity of emissions, variables such as the agricultural area, labor productivity and the use of nitrogen as a fertilizer.

The study is divided into five sections including this introduction. In Section 2 we make a brief literature review, in Section 3 we present the data and methodology, in Section 4 the main results and in Section 5 the conclusions.

5.2 Literature Review on decomposition methods

A number of studies in energy economics have examined and used some methods of decomposition of energy consumption, energy intensity (energy/GDP) and /or emissions intensity (emissions/GDP). It is useful to understand the methods of decomposition used to explore the relative contribution of the different factors affecting the changes in these variables. For example, among others, Reither et al. [5], Sun and Malaska [6] and Liaskas et al. [7], considered factors like the level of production, the energy intensity, the fuel mix and the structural effect, the last two being identified as most relevant.

In the particular case of the European Union (EU) and subsets of industrialized countries including EU countries, several studies have investigated the factors behind changes in industrial energy consumption (e.g. Howarth et al. [8]; Greening et al. [9]; Unander et al. [10]) or industrial carbon emissions (e.g. Torvanger [11]; Greening et al. [12]; Liaskas et al. [7]; Schipper et al. [13]).

Recently, Bhattacharyya and Matsumura [14] analysed the reduction in greenhouse gas emissions in 15 countries of the European Union between 1990 and 2007 to find out the contribution of different countries. Using the log-mean Divisia, index decomposition approach, it identifies the driving factors of emissions related to energy and other industrial activities. This important study shows that the emission intensity reduced significantly in both energy-related activities and other processes at the aggregate level, while the performance varied significantly at the individual country level. Changes in the energy mix as well as a reduction in energy intensity and a reduction in the emission intensity from other process related emissions were mainly responsible for the success in the EU-15.

Also, when looking at the sectoral subject, many studies in relevant literature have examined energy intensity and/or emission intensity of the manufacturing sector. We consider the link of studies of industry sectors and sub-sectors relevant. Zhang [15], Zhao et al. [16], Akbostanci et al [17] and Sheinbaum-Pardo et al [18], represented earlier studies of energy intensity or CO2 emissions intensity in industrial sectors *or* sub-sectors. Between energy intensity, the economic activity, the carbon index (emissions per energy), the fuel mix and the structural effect, the energy intensity and the economic activity are the most relevant factors in the decomposition.

To put our study in context, it is important to focus on other studies in literature that study the impacts of structural change on trends in energy use in the agricultural sector. For example, Shyamal and Bhattacharya [19] suggest that, in the Indian agricultural sector, the fuel substitution and abatement technologies for reducing pollution were not present, and shows that the strength of the pollution coefficient component (the ratio of

CO_2 emissions and energy use) is relatively low in the sub-periods analysed: 1985–90 and 1990–96.; the energy intensity component (positive) is also an important factor for increasing CO_2 in the agricultural sector. This positive intensity component indicates that the agricultural sector in India failed to use energy efficiently and that the supply of energy to agricultural sector is highly subsidised.

Zhang et al [4], found through decomposition analysis, that the economic activity is the biggest factor to influence CO_2 emission in the agricultural sector. During the first two sub-periods (1991–1996, 1996–2001), CO_2 intensities are positive. However in the third sub-period and in the entire period, CO_2 intensities are negative, which lead to CO_2 emission reduction. In the sub-period of 2001–2006, the positive energy intensity indicates that there has been a mechanization transition in the agricultural sector.

Ilyoung Oh et al [20] analysed the specific trends and influencing factors that have caused changes in emissions patterns in South Korea over a 15-year period (1990-2005). For this effect, they employed the Log Mean Divisia index method with five energy consumption sectors and seven sub-sectors in terms of fuel mix (FM), energy intensity (EI), structural change (SC) and economic growth (EG). In agriculture, energy intensity seems to be determined primarily by oil prices. Oil is likely to be substituted with gas and electricity to avoid the less stable oil prices. A slight shift from heavy oil to natural gas and electricity explains the low levels of CO_2 reduction. The reduction effects in change of structure share (SC) are the result of lower growth rate (i.e., 1.4% per year) than that of the GDP (8.3% per year).

The existing literature has elucidated us about the most important factors affecting the intensity of emissions in economic activities. But even in the articles that addressed the agricultural sector, this was approached in the same way as other economic sectors. Deeming that the agricultural sector has certain features which differentiate towards other sectors, in relation to the intensity of their emissions, we felt there was a gap in the literature, not considering the specific effects on the decomposition of the intensity of emissions from the agricultural sector. Therefore in this study we include variables such as the agricultural area, labour productivity and the use of nitrogen as a fertilizer.

5.3 Data and Methodology

This paper includes data for the time span 1995-2008, for a set of countries: Belgium, Denmark, Germany, Ireland, Greece, Spain France, Italy, Luxembourg, Netherlands, Austria, Portugal, Slovakia, Finland and Sweden. We considered the period 1995 – 2008, because it was the most recent period for which we had common data for all countries. The countries were chosen because they were the European countries that had a greater period of availability of the variables under study.

All data were collected from Eurostat web page and is related to the agriculture sector. We considered data about emissions of greenhouse gases (CO2 equivalent) in Millions of tonnes, denoted by “E”. This variable was available in Agri-environmental indicators, in pressure and risk folder. Fossil Energy Consumption (Lubricants) was considered in Millions of Euros at constant prices of 2005 and is denoted by “F”. This variable was available in Economic accounts for agriculture. Nitrogen in tonnes is denoted by “N”, and was available in the Gross Nutrient Balance, included in Agri-environmental indicators, in pressure and risk folder. Utilized agricultural area in 1000 ha is denoted by “A” and was available in Regional Agriculture Statistics, Land use by NUTS 2 regions folder. Total labour force input in 1 000 annual work units, is denoted by “L” and was available in Economic Accounts for Agriculture, Agricultural Labour Input Statistics (absolute figures) folder. Net Value Added at basic prices and at constant prices of 2005, in Millions of Euros, is denoted by “VA” and was available in Economic Accounts for Agriculture.

This study uses a decomposition technique similar to the one used by Sun [3] and Zhang et al. [4]. The GHG emissions intensity (EI) of the agriculture sector can be decomposed as follows:

$$EI = \frac{E^t}{VA^t} = \sum_i \frac{E_i^t}{F_i^t}\frac{F_i^t}{N_i^t}\frac{N_i^t}{A_i^t}\frac{A_i^t}{L_i^t}\frac{L_i^t}{VA_i^t} = \sum_i EF_i^t FN_i^t NA_i^t AL_i^t LVA_i^t \qquad \textbf{[1]}$$

The change of GHG emissions intensity between a base year 0 and a target year t, denoted by ΔEI, can be decomposed into five effects: (i) the changes in GHG emissions compared to the fossil fuels consumption (denoted by EF effect), (ii) the changes in the fossil fuels consumption compared to the use of Nitrogen in agriculture (denoted by FN effect), (iii) the change in use of Nitrogen in agriculture per ha of utilized agricultural area (denoted by NA effect), (iv) the change in utilized agricultural area per worker (denoted by AL effect) and the inverse of average labour productivity in agriculture (denoted by LVA effect), as follows:

$$\Delta EI = EI^t - EI^0 = EF_{effect} + FN_{effect} + NA_{effect} + AL_{effect} + +LVA_{effect} \qquad \textbf{[2]}$$

For the calculation of the effects we only exemplify for EF effect. The other effects are calculated in a similar way:

$$\begin{aligned} EF_{effect} = & \sum_i \Delta EF_i\, FN_i^0 NA_i^0 AL_i^0 LVA_i^0 \\ & + \frac{1}{2}\sum_i \Delta EF_i\, (\Delta FN_i NA_i^0 AL_i^0 LVA_i^0 + FN_i^0 \Delta NA_i AL_i^0 LVA_i^0 + FN_i^0 NA_i^0 \Delta AL_i LVA_i^0 \\ & + FN_i^0 NA_i^0 AL_i^0 \Delta LVA_i) \\ & + \frac{1}{3}\sum_i \Delta EF_i\, (\Delta FN_i\, \Delta NA_i AL_i^0 LVA_i^0 + \Delta FN_i\, NA_i^0 \Delta AL_i LVA_i^0 + \Delta FN_i NA_i^0 AL_i^0 \Delta LVA_i \\ & + FN_i^0 \Delta NA_i \Delta AL_i LVA_i^0 + FN_i^0 \Delta NA_i AL_i^0 \Delta LVA_i + FN_i^0 NA_i^0 \Delta AL_i \Delta LVA_i) \\ & + \frac{1}{4}\sum_i \Delta EF_i\, (\Delta FN_i \Delta NA_i \Delta AL_i LVA_i^0 + \Delta FN_i \Delta NA_i AL_i^0 \Delta LVA_i + \Delta FN_i NA_i^0 \Delta AL_i \Delta LVA_i \\ & + FN_i^0 \Delta NA_i \Delta AL_i \Delta LVA_i) + \frac{1}{5}\sum_i \Delta FN_i \Delta NA_i \Delta AL_i \Delta LVA_i \end{aligned}$$

[3]

EF effect can be used to evaluate the fossil fuel quality and the substitution between fossil fuels; through FN effect it is possible to see which source of pollution (fossil fuel consumption or use of Nitrogen) has gained more importance in agriculture. We found a negative relationship (although weak) between the two variables. That is, countries that diminished the use of nitrogen, raised fossil fuels, and countries that raised nitrogen, diminished fossil fuels. There are only 5 countries that don't show this relation. Despite this relationship, which does not guarantee the existence of substitutability/competition between the two sources of pollution, we can make the following interpretation of FN effect. If for example this effect is important and it is positive, it means that if we raise this ratio, GHG emissions will rise. That is, if the use of fossil fuels gains importance compared to the application of Nitrogen, then GHG will rise. If the opposite happens, i.e., if the effect is negative, it means that if we lower this ratio, GHG emissions will rise. That is, if the use of fossil fuels loses importance compared to the application of Nitrogen, then GHG will rise. In short, this effect allows us to see, in relative terms, the impact of each source of pollution on the verified GHG emissions from agriculture.

NA effect shows the evolution of the use of Nitrogen per hectare of utilized area, highlighting the need to increase land productivity compared to its increasing availability or scarcity. AL effect shows the evolution of cultivated land area by farmer, and can be interpreted as an indicator of the use of a more mechanized agriculture. LVA effect gives us information about the growth of the inverse of labour productivity in agriculture, which influences the use of machinery and the final production, though affecting consumption of fossil fuels, and the use of Nitrogen.

The effects are calculated for all previous referred countries, for every year in the period 1996-2008, and between the last and the first year.

One drawback of this methodology is that the decomposition of CO2 emissions intensity is a multiplicative identity, hereby assuming that the effects of different ratios are proportional, ceteris paribus. On the one hand, these ratios may be correlated, that is, factors may affect each other, and this methodology ignores these mutual effects. This limitation could be surpassed with a future research work that through econometric analysis assesses the relationship between these variables and their impact on the dependent variable EI.

On the other hand, the methodology of decomposition presents several alternative methods and in this paper we seek to adapt the method of Log Mean Divisia index method as it is the most commonly used in the literature, and also seek to expand the mathematical expression according to the effects theoretically sustained and that contribute to the temporal change in the emissions.

5.4 Results and Discussion

In most countries studied, there was an increase in agriculture emissions intensity, and in only five countries this variable declined. The greatest decrease was seen in Italy. On the other hand, the highest raises were found in the Netherlands, Belgium and Luxembourg (see table 5.1a). NA effect and LVA effect were the ones that had a greater contribution to the variation of emissions intensity for the period studied (see table 5.1b). NA contributes positively to the variation of EI.

The average growth rate of the value added of agriculture, for countries and period considered has declined gradually, according to Eurostat data. The weight of this activity in the economy of the countries has also decreased, but this is a natural tendency of the industrialized countries. The recent economic crisis has further contributed to this decrease of activity, associated with reduced income and global demand, and also to the fall in food industry activity, which has also caused a decrease in employment in the agriculture sector. In this study, we focus on the intensity of emissions, which increased in most countries studied meaning that the reduction of the economic activity was not followed by a proportional reduction in emissions.

Regarding the policy adopted in Europe for this period, we noted that the CAP (Common Agricultural Policy), until 2004, promoted a large expansion of agricultural production, allowing less ecological practices to enhance production, such as the indiscriminate use of fertilizers and pesticides [21]. Therefore we see that one of the main factors determining the emissions intensity in this study was the NA effect. In the countries in which the variation of EI is positive, the effect of NA is the main one responsible for this increase, which means that the use of Nitrogen per cultivated area is an important factor of emissions.

Since 2004, as a result of agricultural surpluses generated and the growing concerns and targets related with the environmental pollution, there has been a refocusing of agricultural support, valuing the environment, as they bind payments to farmers to strict environmental standards, the so called cross compliance scheme [21].

We concluded that the effect LVA proves to be the most important, specifically in the countries where the change in EI is negative, with the exception of Ireland. This means that in countries where labour productivity increases (LVA decreases) emissions intensity tends to decrease. The CAP in recent years has helped farmers to be more productive and improve their technical skills. The research and development have also been important to help farmers to produce more with less.

In addition, emissions by fossil fuels appear as the main determinant in some years for some countries, which means that substitution between fossil fuels in these countries could lead to relevant changes in emissions intensities of agriculture. Accordingly, reducing emissions is also going through measures that help modernize farms, through more energy efficient buildings and equipment. Supports to the use of biogas and compensations given to farmers who voluntarily help to protect the environment (agri-environmental schemes) have also contributed to the overall decrease in the intensity of emissions in the sector.

In this study, the analysis by country was also made for each year of the period considered (see table A5.1 in appendix). In the case of Belgium, although during the whole period EI increased, there are more years with a decrease in emission intensity, and LVA effect is the determining factor. This means that a decrease of LVA or an increased labour productivity has reduced emissions per unit of output in agriculture. However, there are some years where EI increases, as in 2001, 2003, 2005, 2006, 2007 and 2008. These increases are given to the effects FN, NA and EF.

For Denmark, there are seven years where EI decreases and six years where EI increases. In almost every year, the most relevant factor is LVA effect. Nevertheless, in some years when EI rises, the most important factor is NA effect.

In the case of Germany, the years in which EI increases are predominant. Besides LVA effect, FN effect shows up the main factor of influence in several years in which EI increases, that is, the intensive use of fossil fuels face to the use of Nitrogen increases the emissions intensity of the sector.

Table 5.1a - Effects of decomposition of emissions intensity change (1995-2008) by country

	EF effect	FN effect	NA effect	AL effect	LVA effect	Var EI
Belgium	-0,02851	0,038165	0,328416	0,012402	-0,07368	0,2768
Denmark	-0,00278	0,0035	0,157328	0,005875	-0,00876	0,155164
Germany	-0,0072	0,007307	2,97E-05	0,005145	-0,00984	-0,00456
Ireland	-0,00786	0,011017	0,041798	0,020314	-0,05425	0,011022
Greece	-0,0002	0,000447	0,009325	0,000362	6,15E-05	0,009999
Spain	0,000387	-0,00044	0,00104	0,000125	-0,00171	-0,0006
France	0,000149	-9E-05	0,027875	0,002152	-0,00198	0,028103
Italy	-0,00088	0,001234	-6,2E-05	0,001098	-0,01141	-0,01002
Luxembourg	-0,0017	0,004244	0,210856	0,007617	-0,01828	0,202732
Netherlands	-0,00119	0,001765	0,394236	0,000659	-0,00116	0,394309
Austria	-0,00257	0,001904	0,000187	0,003162	-0,01078	-0,0081
Portugal	-0,00074	0,001014	0,000328	0,000571	-0,00066	0,000514
Slovakia	-0,00263	0,000941	0,002368	0,007111	-0,0062	0,001595
Finland	0,000709	-0,00033	0,028078	0,003062	-0,01402	0,017498
Sweden	0,009664	-0,00958	0,010302	0,009387	-0,02455	-0,00477

Table 5.1b - Effects of decomposition of emissions intensity change (1995-2008) by country in % of emissions intensity variation

%	EF effect	FN effect	NA effect	AL effect	LVA effect	Var EI
Belgium	-10,3	13,8	118,6	4,5	-26,6	100
Denmark	-1,8	2,3	101,4	3,8	-5,6	100
Germany	157,9	-160,4	-0,7	-112,9	216,0	100
Ireland	-71,3	100,0	379,2	184,3	-492,2	100
Greece	-2,0	4,5	93,3	3,6	0,6	100
Spain	-64,6	74,0	-173,8	-20,9	285,3	100
France	0,5	-0,3	99,2	7,7	-7,1	100
Italy	8,7	-12,3	0,6	-11,0	113,9	100
Luxembourg	-0,8	2,1	104,0	3,8	-9,0	100
Netherlands	-0,3	0,4	100,0	0,2	-0,3	100
Austria	31,7	-23,5	-2,3	-39,0	133,1	100
Portugal	-143,1	197,3	63,8	111,0	-129,1	100
Slovakia	-164,8	59,0	148,4	445,8	-388,5	100
Finland	4,1	-1,9	160,5	17,5	-80,2	100
Sweden	-202,5	200,7	-215,9	-196,7	514,3	100

LVA effect is also the most crucial for Ireland, where predominantly EI decreases. Only NA effect and EF effect are shown as predominant in two years where EI increases.

Greece has only one year in which EI decreases. In almost every year there is an increase and over four years Greece keeps the emission intensity stable. But despite the fact LVA effect is predominant in some years, there are other important effects for this country, as AL in 1996, EF and FN in 2000, 2002 and 2004, and NA in 2005. In particular, emissions from fossil fuels have a strong negative effect in two years, which means Greece is using less polluting fossil fuels that means that there could have been a change in the mix of fossil fuels in favour of “cleaner” ones, for example, changing from coal to natural gas.

The relationship between fossil fuels and Nitrogen presents positive in two years, offsetting the negative effect of EF, which means that the consumption of fossil fuels in relation to Nitrogen increased, leading to an increase in emissions intensity.

Although Spain is a country where there is a decrease of EI in the period considered, there are two years in which this variable increases and three years in which it keeps constant. Here LVA effect is not always predominant. NA and AL effects are shown as the most important once, FN effect twice and EF effect four times in the period considered. The latter effect may prove that to Spain the mix of fossil fuels used may have had an important influence in some years, in the variation of emissions intensity.

France is a case in which there are more years when the intensity of agricultural emissions increases than years in which it maintains or decreases. LVA effect proves to be important in these variations but there are also other important effects in some years, such as NA, AL and EF effects.

In Italy, the years in which EI decreases are dominant, and LVA effect is the most decisive effect in more than half of the variations in the intensity of emissions. In the remaining years there are other factors that are shown as the most important, such as FN, NA, EF and AL effects.

In Luxembourg despite having more years in which EI decreases, the net effect is positive. LVA is the most decisive effect, but in two years NA effect is the most important, as AL, EF and FN effect are in three other years.

Netherlands has many years in which EI increases and this is also the result for the whole period. This country presents a difference compared to other countries, which is the great importance of NA effect in determining the intensity of emissions. This means that emissions from agriculture are mainly influenced by the use of Nitrogen per unit area cultivated.

For Austria, the influence of LVA effect is dominant, and only in three years EF effect is the most important in order to decrease the emissions intensity. This may show a substitution between the mix of fossil fuels in favour of cleaner ones.

Portugal has the same number of years in which EI increases in comparison with the years in which EI decreases. In any one of them the dominant effect is LVA. Furthermore, in three years EI remains constant, where the dominant effects are EF and FN.

In Slovakia the dominant effects are LVA, EF and AL effects. In Finland we have a predominance of years in which EI rises and where the LVA effect dominates. However in three years, EF, FN and NA effects are also shown to be very important in determining EI.

In Sweden we only have three years in which EI rises. In almost all years the most important effect is LVA, but we have three years in which this does not happen, and the relevance is given to the effects EF, AL and NA. These last two effects are important in two years in which EI increases (2004 and 2005). This means that the increase in cultivated area per worker and the increased use of Nitrogen by area contributed greatly to the increase of emissions in those years.

The results in this paper are not directly comparable with the existing literature, since the effects that decompose the intensity of emissions are distinct, particularly because in this study new variables are introduced, such as the use of Nitrogen, the utilized area and labour. But somehow we can liaise, for instance, with Shyamal and Battacharya [17], who state that energy intensity has a strong impact on the determination of emissions intensity. In our case, despite using fossil fuel consumption, the most important factors were the inverse of labor productivity (LVA) and the use of Nitrogen per cultivated area (NA). But EF effect (that could be an indicator of trends in the use of fossil fuels or in the changing mix of fossil fuels), appears as the main determinant in some years for some countries, such as Ireland, Greece, Spain, France, Italy, Austria, Portugal, Slovakia and Sweden, which means that the substitution between fossil fuels in these countries could lead to relevant changes in emissions intensity of agriculture.

5.5 Conclusions

Is this paper, we used the 'complete decomposition' technique to examine GHG emissions intensity and its components, for the agriculture sector in the 1995-2008 period, for a set of European countries.

It is shown that NA effect and LVA effect were the ones that had a greater contribution to the variation of EI. This means that the use of Nitrogen per cultivated area is an important factor of emissions and that in those countries where labour productivity increases, emissions intensity tends to decrease.

These results imply that the way to reduce emissions in agriculture could pass for a better training of agricultural workers to increase their productivity, which would lead to a less need for energy and use of Nitrogen. On the other hand, there may be an exaggerated focus on the use of fossil fuels as a source of emissions, while this paper shows that the use of Nitrogen represents a more important role in determining emissions than the use of fossil energy.

Apart from its relation to GHG emissions, nitrates are also a major source of water pollution, so it is important to establish a European strategy for the effective adoption of sustainable agricultural practices, namely by reducing the use of nitrates and other fertilizers or their application in divided doses.

European legal framework already exists through Nitrates Directive (1991/676/CEE) and initiatives such NEV2013, Workshop on 'Nitrogen, Environment and Vegetables', but it is necessary to obtain further information and monitoring of the agricultural sector in this field.

In addition, emissions by fossil fuels appear as the main determinant in some years for some countries, which means that substitution between fossil fuels in these countries could lead to relevant changes in emissions intensities of agriculture.

Future research could be to study econometrically the relationship between the effects studied here, to see if there might be some kind of causality between them. For example, a higher labour productivity may cause a lower ratio of emissions by fossil energy, or the lower use of Nitrogen per cultivated area. Another factor to include could be related to the use of renewable energy in agriculture.

References

[1] European Commission. Questions and Answers on the Commission's proposal to revise the EU Emissions Trading System, MEMO/08/35 (2008), Retrieved from http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/08/35&format=HTML &aged=0&language=EN&guiLanguage=en.

[2] OECD. "Climate Change and Agriculture: Impacts, Adaptation, Mitigation and Options for the OECD (2009), [COM/TAD/CA/ENV/EPOC(2009)13].

[3] Sun JW. Is CO2 emission intensity comparable? Energy Policy. 2000;28(15):1081-4.

[4] Zhang M, Mu H, Ning Y, Song Y. Decomposition of energy-related CO2 emission over 1991-2006 in China. Ecological Economics. 2009;68(7):2122-8.

[5] Reither W, Rudolph M, Schacfer M. Analysis of the factors influencing energy consumption in industry: a revised methods. Energy Economics. 1987;9:145-8.

[6] Sun JW, Malaska P. CO2 emission intensities in developed countries 1980-1994. Energy. 1998;23(2):105-12.

[7] Liaskas K, Mavrotas G, Mandaraka M, Diakoulaki D. Decomposition of industrial CO2 emissions: The case of European Union. Energy Economics. 2000;22(4):383-94.

[8] Howarth RB, Schipper L, Duerr PA, Strøm S. Manufacturing energy use in eight OECD countries: Decomposing the impacts of changes in output, industry structure and energy intensity. Energy Economics. 1991;13(2):135-42.

[9] Greening LA, Davis WB, Schipper L, Khrushch M. Comparison of six decomposition methods: application to aggregate energy intensity for manufacturing in 10 OECD countries. Energy Economics. 1997;19(3):375-90.

[10] Unander F, Karbuz S, Schipper L, Khrushch M, Ting M. Manufacturing energy use in OECD countries: decomposition of long-term trends. Energy Policy. 1999;27(13):769-78.

[11] Torvanger A. Manufacturing Sector Carbon-Dioxide Emissions in 9 Oecd Countries, 1973-87 - a Divisia Index Decomposition to Changes in Fuel Mix, Emission Coefficients, Industry Structure, Energy Intensities and International Structure. Energy Economics. 1991;13(3):168-86.

[12] Greening LA, Davis WB, Schipper L. Decomposition of aggregate carbon intensity for the manufacturing sector: Comparison of declining trends from 10 OECD countries for the period 1971-1991. Energy Economics. 1998;20(1):43-65.

[13] Schipper L, Murtishaw S, Khrushch M, Ting M, Karbuz S, Unander F. Carbon emissions from manufacturing energy use in 13 IEA countries: long-term trends through 1995. Energy Policy. 2001;29(9):667-88.

[14] Bhattacharyya SC, Matsumura W. Changes in the GHG emission intensity in EU-15: Lessons from a decomposition analysis. Energy. 2010;35(8):3315-22.

[15] Zhang ZX. Why did the energy intensity fall in China's industrial sector in the 1990s? The relative importance of structural change and intensity change. Energy Economics. 2003;25(6):625-38.

[16] Zhao M, Tan LR, Zhang WG, Ji MH, Liu YA, Yu LZ. Decomposing the influencing factors of industrial carbon emissions in Shanghai using the LMDI method. Energy. 2010;35(6):2505-010.

[17] Akbostanci E, Tunc GI, Turut-Asik S. CO2 emissions of Turkish manufacturing industry: A decomposition analysis. Applied Energy. 2011;88(6):2273-8.

[18] Sheinbaum-Pardo C, Mora-Perez S, Robles-Morales G. Decomposition of energy consumption and CO2 emissions in Mexican manufacturing industries: Trends between 1990 and 2008. Energy Sustainaible Development. 2012;16(1):57-67.

[19] Shyamal P, Bhattacharya RN. CO2 emission from energy use in India: a decomposition analysis. Energy Policy. 2004;32(5):585-93.

[20] Oh I, Wehrmeyer W, Mulugetta Y. Decomposition analysis and mitigation strategies of CO2 emissions from energy consumption in South Korea. Energy Policy. 2010;38(1):364-77.

[21] European Commission. The EU explained: Agriculture. Directorate-General for Communication Publications. 1049 Brussels. BELGIUM. 2013.

Appendix

Table A5.1 - Effects of decomposition of emissions intensity change by year and by country

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Belgium													
EF effect	-0,00794	-0,00127	-0,00081	0,00101	-0,00126	-0,00111	-0,00013	-0,00042	-0,00028	-0,00117	-0,00034	-0,00062	0,00071
FN effect	0,00882	0,00122	0,00107	-0,00085	0,00099	0,00142	0,00000	0,00054	0,00028	0,00123	0,00034	0,00087	-0,00072
NA effect	-0,00087	-0,00028	-0,00021	-0,00010	-0,00005	-0,00060	-0,00008	0,00101	-0,00003	0,00015	0,00009	0,00014	-0,00006
AL effect	0,00330	0,00043	0,00098	0,00034	0,00014	-0,00007	0,00006	0,00019	0,00010	0,00017	0,00008	0,00023	0,00016
LVA effect	-0,02629	-0,01661	-0,01254	-0,00770	-0,00218	0,00158	-0,00334	-0,00075	-0,00073	-0,00017	0,00058	0,00071	0,00061
var EI	-0,02299	-0,01651	-0,01150	-0,00729	-0,00237	0,00122	-0,00348	0,00058	-0,00066	0,00022	0,00075	0,00134	0,00071
Denmark													
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	-0,00263	-0,00007	0,00051	-0,00077	-0,00022	-0,00048	0,00038	-0,00065	0,00043	-0,00023	0,00029	0,00000	0,00042
FN effect	0,00244	-0,00006	-0,00018	0,00102	0,00014	0,00067	-0,00005	0,00039	-0,00041	0,00028	-0,00019	0,00023	-0,00070
NA effect	0,01831	0,00021	-0,00005	0,00155	-0,00009	-0,00413	0,00012	-0,00006	0,00004	0,00070	0,00000	0,00017	0,00050
AL effect	0,00172	0,00019	0,00074	0,00077	0,00025	-0,00116	0,00047	0,00018	0,00048	0,00071	0,00032	0,00034	0,00009
LVA effect	-0,00019	-0,00063	-0,00186	-0,00089	-0,00081	-0,00125	-0,00054	-0,00138	-0,00103	0,00012	0,00155	0,00134	-0,00225
var EI	0,01966	-0,00037	-0,00084	0,00169	-0,00073	-0,00635	0,00037	-0,00152	-0,00050	0,00158	0,00197	0,00208	-0,00194
Germany													
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	0,00028	-0,00101	-0,00094	-0,00076	-0,00083	-0,00210	-0,00076	-0,00074	-0,00048	-0,00047	-0,00027	-0,00018	0,00145
FN effect	-0,00013	0,00099	0,00094	0,00075	0,00043	0,00247	0,00058	0,00081	0,00031	0,00057	0,00008	0,00066	-0,00166
NA effect	-0,00006	-0,00011	0,00000	0,00037	0,00093	-0,00010	-0,00016	-0,00018	0,00064	-0,00016	0,00004	-0,00019	0,00125
AL effect	0,00057	0,00040	0,00027	0,00006	0,00048	0,00051	0,00055	0,00057	0,00038	0,00017	0,00022	0,00030	0,00027
LVA effect	-0,00218	-0,00119	0,00046	-0,00241	0,00039	0,00128	0,00043	-0,00033	-0,00643	0,00284	0,00058	0,00072	-0,00334
var EI	-0,00152	-0,00091	0,00072	-0,00199	0,00139	0,00207	0,00064	0,00013	-0,00558	0,00294	0,00066	0,00131	-0,00204

Ireland													
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	-0,00367	0,00111	0,00056	0,00035	0,00031	-0,00297	0,00140	0,00045	0,00029	-0,00118	-0,00076	-0,00128	0,00059
FN effect	0,00479	0,00025	-0,00161	-0,00097	-0,00013	0,00351	-0,00139	-0,00068	-0,00013	0,00104	0,00088	0,00188	-0,00029
NA effect	0,00072	-0,00071	0,00304	-0,00013	0,00702	-0,00093	-0,00004	0,00009	-0,00010	-0,00004	-0,00007	-0,00088	-0,00002
AL effect	-0,00075	0,00473	0,00082	0,00279	0,00616	-0,00026	-0,00066	-0,00045	0,00010	0,00081	-0,00081	0,00058	-0,00007
LVA effect	-0,01249	-0,01573	-0,00803	-0,00762	-0,01176	-0,00354	-0,00298	-0,00410	-0,00214	0,00579	0,01403	-0,00130	0,00046
var EI	-0,01142	-0,01035	-0,00522	-0,00559	0,00160	-0,00418	-0,00368	-0,00469	-0,00198	0,00642	0,01327	-0,00101	0,00068

Greece													
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	-0,00002	-0,00003	-0,00003	-0,00001	-0,00007	-0,00002	-0,00010	-0,00012	0,00024	-0,00008	-0,00006	0,00018	-0,00004
FN effect	0,00002	0,00005	0,00003	0,00001	0,00010	0,00002	0,00012	0,00013	-0,00024	0,00012	0,00009	-0,00024	0,00019
NA effect	0,00003	-0,00002	0,00000	-0,00001	-0,00004	-0,00002	-0,00003	-0,00002	0,00004	-0,00003	-0,00003	0,00016	0,00137
AL effect	0,00005	0,00004	0,00001	0,00000	0,00000	0,00002	0,00003	-0,00014	-0,00001	0,00003	0,00004	0,00005	0,00025
LVA effect	0,00001	-0,00006	-0,00006	-0,00001	0,00001	0,00005	0,00003	0,00033	-0,00024	-0,00002	0,00014	0,00017	-0,00032
var EI	0,00008	-0,00001	-0,00004	-0,00001	-0,00001	0,00005	0,00006	0,00017	-0,00021	0,00003	0,00017	0,00032	0,00146

Spain													
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	0,00023	-0,00006	0,00007	0,00007	0,00003	0,00006	-0,00007	0,00010	-0,00006	-0,00008	0,00007	0,00015	-0,00011
FN effect	-0,00020	-0,00008	-0,00001	-0,00008	0,00003	-0,00006	0,00004	0,00002	-0,00008	0,00013	0,00002	-0,00011	-0,00004
NA effect	0,00017	0,00007	0,00002	0,00014	0,00002	-0,00003	0,00000	-0,00001	0,00003	-0,00012	0,00001	-0,00002	0,00001
AL effect	-0,00002	-0,00001	-0,00007	0,00007	0,00000	0,00000	0,00004	0,00007	0,00004	0,00000	-0,00006	0,00007	-0,00003
LVA effect	-0,00092	-0,00024	-0,00004	0,00001	-0,00015	-0,00005	-0,00015	-0,00015	-0,00001	0,00035	-0,00007	-0,00036	0,00003
var EI	-0,00074	-0,00032	-0,00004	0,00020	-0,00006	-0,00007	-0,00014	0,00003	-0,00008	0,00027	-0,00003	-0,00027	-0,00015

France													
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	-0,00010	-0,00002	-0,00003	0,00002	0,00015	-0,00019	0,00007	-0,00018	0,00009	-0,00001	0,00001	0,00013	0,00018
FN effect	0,00006	-0,00001	0,00002	-0,00004	-0,00017	0,00030	-0,00006	0,00017	-0,00008	0,00001	0,00001	-0,00003	-0,00024
NA effect	0,00015	0,00017	0,00000	-0,00001	0,00011	0,00004	0,00002	-0,00004	-0,00068	-0,00002	-0,00004	-0,00004	0,02321

AL effect	0,00013	0,00012	0,00009	0,00008	0,00006	0,00013	0,00011	0,00012	-0,00021	0,00011	0,00011	0,00010	0,00105
LVA effect	-0,00057	-0,00022	-0,00021	-0,00032	0,00011	0,00027	-0,00064	0,00108	-0,00151	0,00030	0,00004	0,00009	-0,00027
var EI	-0,00033	0,00004	-0,00013	-0,00026	0,00026	0,00055	-0,00049	0,00115	-0,00238	0,00039	0,00012	0,00025	0,02392

Italy

	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	-0,00016	0,00033	-0,00008	0,00006	-0,00011	-0,00013	0,00000	-0,00009	0,00002	-0,00009	-0,00004	0,00008	-0,00004
FN effect	0,00015	-0,00014	-0,00001	-0,00002	0,00019	0,00004	0,00001	0,00012	0,00005	0,00014	0,00011	-0,00016	-0,00006
NA effect	0,00001	0,00001	-0,00002	-0,00003	-0,00008	0,00004	-0,00004	0,00009	0,00003	-0,00031	-0,00004	0,00025	-0,00002
AL effect	0,00024	0,00008	0,00018	0,00022	0,00004	-0,00005	0,00008	-0,00001	0,00010	-0,00019	-0,00011	0,00006	0,00010
LVA effect	-0,00421	-0,00281	-0,00205	-0,00160	0,00013	0,00005	0,00002	0,00012	-0,00054	0,00007	0,00010	-0,00005	-0,00016
var EI	-0,00397	-0,00252	-0,00197	-0,00136	0,00017	-0,00005	0,00007	0,00023	-0,00033	-0,00038	0,00002	0,00017	-0,00018

Luxembourg

	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	-0,00190	-0,00035	-0,00178	0,00001	0,00315	-0,00392	0,00270	-0,00138	0,00049	-0,00139	0,00047	0,00104	-0,00020
FN effect	0,00236	0,00039	0,00189	-0,00014	-0,00296	0,00506	-0,00309	0,00251	-0,00218	0,00209	-0,00038	-0,00075	0,00039
NA effect	0,00006	0,00238	0,00050	0,00056	0,00554	-0,00113	0,00016	-0,00056	0,00762	-0,00270	-0,00020	-0,00012	-0,00008
AL effect	0,00106	0,00188	-0,00043	0,00055	0,00204	-0,00071	0,00061	0,00051	0,00082	-0,00034	0,00041	0,00031	0,00060
LVA effect	-0,00422	-0,00020	-0,00474	0,00194	0,00076	0,00035	-0,00332	0,00936	-0,01558	0,00342	-0,00781	-0,00180	0,00421
var EI	-0,00264	0,00409	-0,00456	0,00292	0,00854	-0,00036	-0,00295	0,01043	-0,00882	0,00107	-0,00750	-0,00131	0,00492

Netherlands

	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	-0,00059	0,00026	-0,00026	-0,00004	-0,00022	-0,00003	-0,00019	-0,00014	-0,00005	0,00003	-0,00004	0,00017	-0,00014
FN effect	0,00058	-0,00031	0,00024	0,00011	0,00031	0,00018	0,00018	0,00013	0,00008	-0,00002	0,00007	-0,00006	0,00020
NA effect	-0,00041	0,00001	0,00069	-0,00006	0,00035	0,00055	0,00101	-0,00002	0,00004	-0,00003	-0,01491	0,02700	0,00166
AL effect	-0,00011	-0,00005	0,00010	0,00001	0,00002	0,00009	0,00009	0,00003	0,00015	0,00001	-0,00031	0,00035	0,00017
LVA effect	0,00024	0,00033	-0,00053	-0,00035	-0,00008	0,00049	0,00001	-0,00032	-0,00041	-0,00001	-0,00003	-0,00018	-0,00014
var EI	-0,00029	0,00024	0,00024	-0,00033	0,00037	0,00128	0,00110	-0,00032	-0,00018	-0,00002	-0,01521	0,02728	0,00175

Austria													
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	-0,00203	-0,00058	0,00061	-0,00019	-0,00036	-0,00064	-0,00014	-0,00017	-0,00021	0,00015	0,00001	0,00046	-0,00001
FN effect	0,00107	0,00063	-0,00044	0,00043	0,00039	0,00059	0,00016	0,00059	-0,00003	-0,00027	-0,00002	-0,00040	-0,00031
NA effect	0,00015	-0,00001	-0,00015	-0,00030	-0,00024	-0,00001	-0,00015	-0,00032	0,00039	0,00006	0,00014	0,00003	0,00077
AL effect	0,00072	0,00012	0,00039	0,00004	0,00013	0,00012	0,00012	0,00057	-0,00013	0,00032	0,00036	0,00021	0,00008
LVA effect	-0,00063	-0,00036	-0,00300	-0,00150	0,00052	-0,00008	0,00049	0,00005	-0,00252	0,00054	-0,00013	-0,00228	-0,00140
var EI	-0,00073	-0,00020	-0,00260	-0,00152	0,00044	-0,00001	0,00048	0,00071	-0,00249	0,00080	0,00037	-0,00199	-0,00086

Portugal													
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	0,0005	0,0001	0,0003	-0,0003	-0,0001	-0,0006	-0,0003	-0,0007	-0,0003	0,0002	0,0003	0,0002	-0,0001
FN effect	-0,0006	-0,0001	-0,0002	0,0002	0,0000	0,0006	0,0002	0,0010	0,0002	0,0000	-0,0001	-0,0004	0,0002
NA effect	0,0002	0,0000	0,0000	0,0000	0,0001	-0,0001	0,0000	-0,0007	0,0003	-0,0002	-0,0001	0,0002	-0,0002
AL effect	-0,0001	0,0000	0,0000	0,0003	-0,0002	-0,0001	0,0003	0,0000	0,0002	0,0000	0,0002	-0,0001	0,0001
LVA effect	-0,0001	0,0004	0,0003	-0,0011	0,0005	0,0002	-0,0007	0,0004	-0,0007	0,0007	-0,0004	0,0001	-0,0003
var EI	0,0000	0,0003	0,0004	-0,0008	0,0004	0,0000	-0,0005	0,0000	-0,0002	0,0007	-0,0002	0,0000	-0,0002

Slovakia													
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	-0,00116	-0,00087	-0,00127	-0,00098	0,00073	0,00283	-0,00108	0,00149	-0,00057	0,00092	-0,00090	0,00046	-0,00019
FN effect	0,00081	0,00014	0,00096	0,00113	-0,00089	-0,00252	0,00051	-0,00139	0,00081	-0,00105	0,00097	-0,00055	0,00008
NA effect	-0,00005	0,00036	-0,00036	-0,00025	0,00032	0,00122	0,00113	-0,00070	0,00105	0,00007	-0,00021	0,00064	-0,00043
AL effect	0,00029	0,00045	0,00112	0,00107	0,00095	0,00017	-0,00007	0,00208	-0,00042	0,00076	0,00095	-0,00007	0,00020
LVA effect	-0,00091	-0,00005	0,00020	-0,00343	0,01302	-0,00424	-0,00112	0,00076	-0,01155	0,00097	-0,00029	0,00497	-0,00622
var EI	-0,00102	0,00002	0,00067	-0,00246	0,01413	-0,00254	-0,00062	0,00223	-0,01068	0,00165	0,00052	0,00546	-0,00657

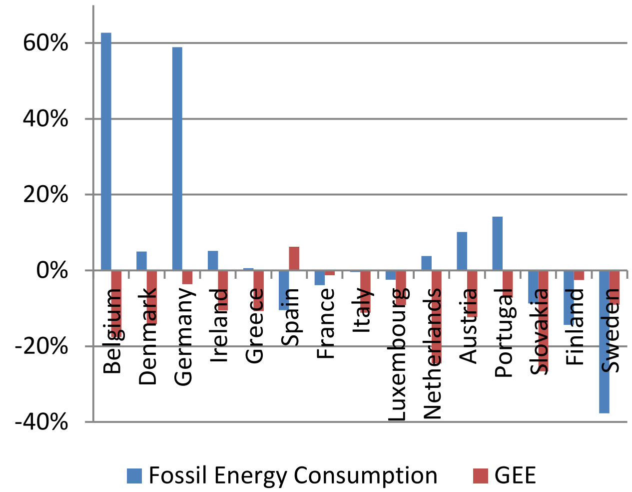
Finland													
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	-0,00047	0,00120	-0,00131	0,00086	0,00150	-0,00161	0,00029	-0,00027	0,00137	0,00059	-0,00031	-0,00019	-0,00006
FN effect	0,00080	-0,00091	0,00085	-0,00046	-0,00157	0,00155	0,00004	0,00036	-0,00134	-0,00032	0,00036	0,00021	0,00011
NA effect	-0,00036	-0,00027	-0,00015	-0,00053	0,00024	-0,00014	-0,00026	-0,00012	-0,00021	-0,00022	-0,00015	0,00000	0,00009

AL effect	0,00017	0,00033	0,00123	0,00142	0,00107	0,00031	0,00036	0,00008	0,00047	0,00106	0,00049	0,00010	-0,00003
LVA effect	0,00165	-0,00119	0,01018	-0,00577	-0,00396	-0,00063	-0,00123	0,00121	0,00012	-0,00381	-0,00143	-0,01199	-0,00004
var EI	0,00180	-0,00084	0,01080	-0,00448	-0,00271	-0,00053	-0,00080	0,00126	0,00041	-0,00271	-0,00104	-0,01187	0,00007

Sweden

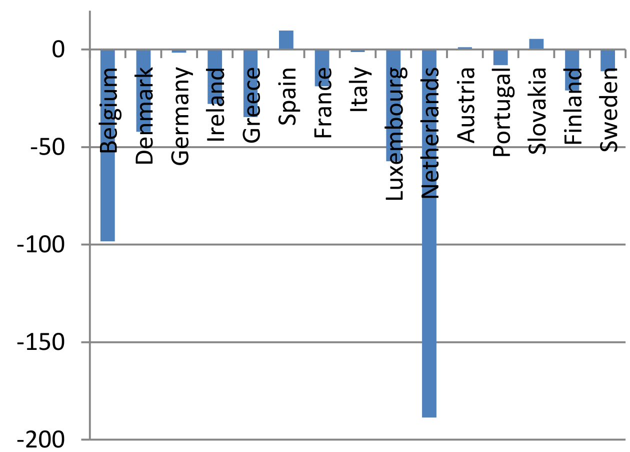
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
EF effect	0,00497	-0,00017	-0,00232	-0,00011	0,00203	-0,00018	0,00212	-0,00011	0,00060	0,00044	0,00118	-0,00017	0,00024
FN effect	-0,00467	-0,00025	0,00200	0,00178	-0,00260	-0,00043	-0,00150	0,00000	-0,00041	-0,00011	-0,00104	-0,00020	-0,00078
NA effect	-0,00082	0,00085	-0,00008	-0,00150	0,00057	0,00084	-0,00082	-0,00009	-0,00024	-0,00047	-0,00023	0,00035	0,00141
AL effect	0,00183	0,00087	0,00135	0,00151	-0,00004	-0,00021	0,00080	0,00019	0,00039	0,00015	0,00026	0,00113	0,00025
LVA effect	-0,00537	-0,00310	0,01056	-0,00560	-0,00360	-0,00362	-0,00416	-0,00041	-0,00290	-0,00243	-0,00179	-0,00065	0,00018
var EI	-0,00407	-0,00180	0,01151	-0,00392	-0,00364	-0,00360	-0,00356	-0,00041	-0,00256	-0,00242	-0,00162	0,00046	0,00130

Figure A5.1 – Variation (%) of Greenhouse Gas Emissions and fossil energy consumption in agriculture, in 1995-2008



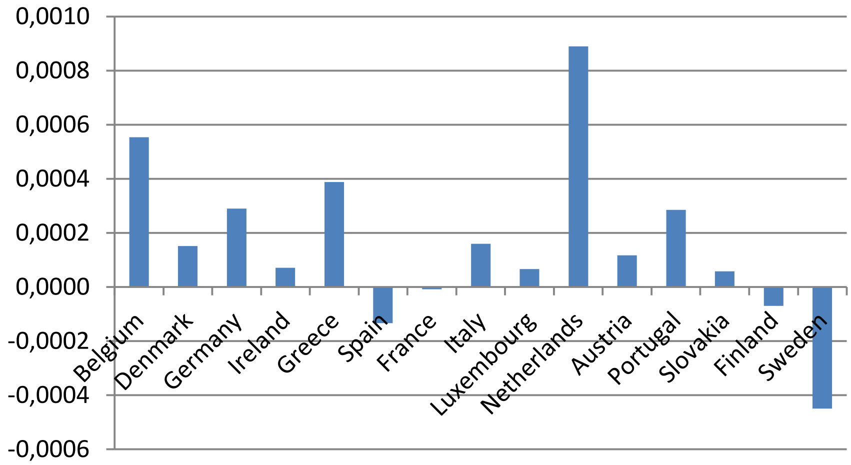
Source: Own elaboration using data from Eurostat

Figure A5.2 - Variation of Nitrogen (tonnes) per utilised agricultural area (1000 ha) in 1995-2008



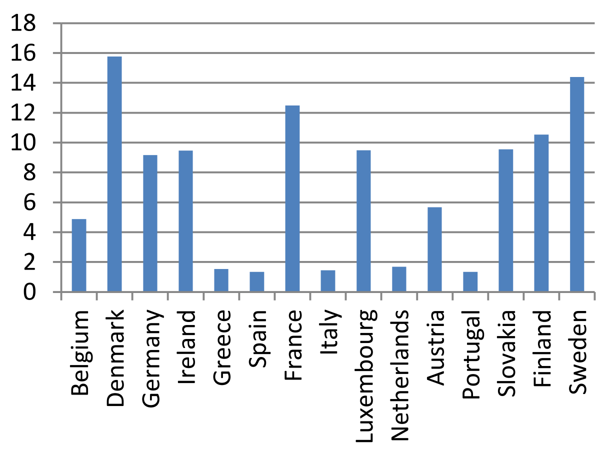
Source: Own elaboration using data from Eurostat

Figure A5.3 - Variation of Consumption of fossil energy (Million euros at constant prices) by tonnes of Nitrogen in agriculture, 1995-2008



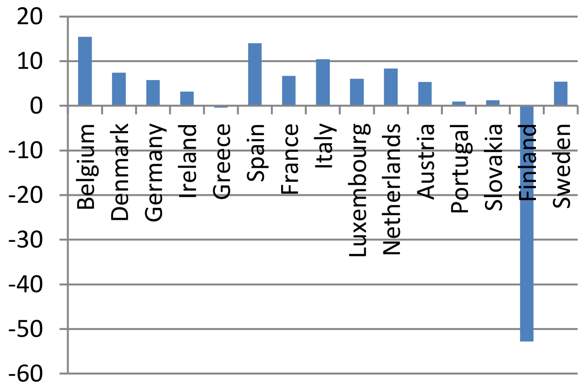
Source: Own elaboration using data from Eurostat

Figure A5.4 - Variation of Utilized Agricultural Area (1000ha) per labour force (1 000 annual work units), 1995-2008



Source: Own elaboration using data from Eurostat

Figure A5.5 - Variation of Average Agricultural Labour Productivity (net value added in millions of euro by total labour force input in 1000 annual work units) in 1995-2008



Source: Own elaboration using data from Eurostat

Chapter 6

Is the share of renewable energy sources determining the CO2 kWh and Income relation in electricity generation?

6.1 Introduction

European countries have shown a special concern in reducing emissions of greenhouse gases (GHG) that materialized in a practical way with the signing of Kyoto Protocol, with the implementation of the European Union Emissions Trade System (EUETS) and more recently with the adoption of the "20-20-20" targets. In 2020, these targets specifically aim for a 20% cut in GHG emissions from 1990 levels; for an increase of renewable energy sources to 20%; and for a 20% improvement in the energy efficiency.

The use of fossil fuels is the biggest culprit of anthropogenic air pollution (in particular by the emission of Carbon Dioxide (CO2)), being responsible for about 90% of total global CO2 emissions. Despite the recent economic crisis, it is expected that the use of fossil fuels will continue to increase in the future (Olivier et al. [1]).

In the European electricity sector, more than 50% of the primary energy used is based on fossil fuels, coal representing approximately 30%. This translated into CO2 emissions represents 70% of total emissions in electricity production and 24% of the emissions of all European sectors (Commission of European Communities [2]).

This makes the European Union (EU) have a growing concern in creating and implementing policies to limit CO2 emissions, primarily through the reduction of the use of coal in the electricity sector. For instance, through the EUETS, EU limited the allowances allocated to installations that produce electricity as well as to energy-intensive industries, in order to cut 21% compared to 2005 levels (European Commission [3]).

There are several articles that have studied the connection between economic growth and emissions, testing the hypothesis of the Environmental Kuznets Curve (EKC). This hypothesis suggests that there is an inverse U-shaped relationship between income and environmental pollution, which means that there is an increase in pollution as the economy grows, but from a certain point, the economy can grow decreasing environmental degradation.

The relation between emissions from electricity production and GDP is not focused on literature. Those studies that include electricity are based on the amount of energy consumed, which is inherently linked to a volume of emissions, but don't directly include the emissions resulting from its production. Studies focus specifically on the relationship between economic growth and energy consumption, in particular electricity consumption. The study of the latter relationship is important because electricity production is, as we have seen, a major source of emissions, but on the other hand it is also an important way to reduce them, if there is a replacement of fossil fuels with renewable energy in electricity production. It is then important to analyze, how the reduction of emissions in this sector may undermine the economic growth of European countries.

Moreover, it is important to analyze how the percentage of renewable energy used for electricity production affects the relationship between economic growth and emissions from this sector. The study of these relationships is important from the point of view of environmental and energy policy as it gives us information on the costs in terms of economic growth, on the application of restrictive levels of emissions and also on the effects of the policies concerning the use of renewable energy in the electricity sector (see for instance European Commission Directive 2001/77/EC, [4]).

For that purpose, in this study we use Cointegration Analysis on the set of cross-country panel data between CO_2 emissions from electricity generation (CO2 kWh), economic growth (GDP) and the share of renewable energy for 20

European countries. We estimated the long–run equilibrium to validate the EKC with a new approach specification.

Additionally, we have implemented the Innovative Accounting Approach (IAA) that includes Forecast Error Variance Decomposition and Impulse Response Functions (IRFs), applied to those variables. This can allow us, for example, to know (i) how CO2 kWh responds to an impulse in GDP and (ii) how CO2 kWh responds to an impulse in the share of renewable sources.

By combining these two methodologies, we will not only give an outline of what has been a past reality for CO2 kWh emissions and their relation to economic growth and to the use of renewable energy in European countries, but also how the last two variables can influence CO2 kWh emissions in the future.

This paper is divided into five sections including this introduction. In Section 2 we make a brief literature review, in Section 3 we present the data and the model, in Section 4 the econometric methodology and the main results are presented and in Section 5 the conclusions and policy recommendations.

6.2 Literature review

First, we will present some studies that relate emissions to economic growth, that is, that study the validity of EKC hypothesis. Some studies validate the hypothesis like Hettige et al. [5], Martinez-Zarzoso and Bengochea-Morancho [6] for OCDE countries, Acaravci and Ozturk [7] for Europe, Cropper and Griffiths [8] for non-OECD countries in Africa, Asia, and Central and South America, Pao et al. [9] for Russia, Apergis and Payne [10] for Central America, Iwata et al. [11], for 28 countries (OECD countries, and non-OECD countries), Mongelli et al. [12], for Brazil, Ang [13], [14] for France and Malaysia, Jalil and Mahmud [15] for China, Halicioglu [16] for Turkey, Alam et al. [17] for India, Fodha and Zaghdoud [18] for Tunisia and Nasir and Rehman [19] for Pakistan, are some examples.

Secondly, as mentioned in the introduction, the relation between emissions from electricity production and GDP is not focused on literature. Electricity is included in the causality relations through the amount of energy consumed and not through the emissions resulting from its production. Representative studies are for instance: Aqeel and Butt [20], Shiu and Lam [21], Lee and Chang [22], Altinay and Karagol [23], Yuan et al [24], Halicioglu [25]. They concluded that electricity consumption causes economic growth and as a result supports the growth hypothesis. The opposite causality is also found running from economic growth to electricity consumption, supporting the conservation hypothesis, by Narayan and Smith [26], Yuan et al [27], Squalli [28], Mozamder and Marathe [29], Hu and Lin [30], Reynolds and Kolodziej [31], Sari et al [32], Halicioglu [25]. Akbostanci et al [33], Dhakal [34], Jalil and Mahmud [15], Fodha and Zaghdoud [18], Gosh [35], Payne [36]. Other studies like Lean and Smith [37], found a unidirectional relationship, and support the growth effect for the period 1980-2006 in Asian countries. They found a statistically significant positive association between electricity consumption and emissions and a non-linear relationship between emissions and real output. In the long-run they found a unidirectional causality running from electricity consumption and emissions to economic growth and in the short-run found unidirectional causality running from emissions to electricity consumption.

In a third strand of literature, some studies include renewable energy in the relation of causality with GDP. There is a wide variety of research for different countries and groups of countries, of which we shall give some examples. The following studies obtained positive results in what concerns causal relationships between the referred variables. Bidirectional causality between GDP and renewable energy consumption was found for Eurasian countries (Apergis and Payne [38]), for OECD countries (Apergis and Payne [39]), for emerging economies (Sadorsky [40]), for six Central American countries (Apergis and Payne [41]), for 80 countries (Apergis and Payne [42]) and for Brazil (Pao and Fu [43]).

Al-mulali et al. [44] examined high income, upper middle income and lower middle income countries and found a feedback hypothesis in 79% of the countries, with a positive bidirectional long-run between renewable energy consumption and real GDP. 19% of the countries represent the neutrality hypothesis (no long causality exists), while 2% of the countries confirm the conservation hypothesis (a one way long-run relationship between GDP and CO2 emissions). Frequently, as in Al-mulali et al [44], and the referred studies of Apergis and Payne [42], the electricity consumption from renewable sources measured in kilowatt-hour is used as an indicator of renewable energy consumption. Silva et al. [45] studied the relation between renewable energy, GDP and CO2 emissions, using the share of Renewable Energy Sources on Electricity generation. They concluded for a sample of four countries, that an increase on the share of renewable energy led to economic costs in terms of GDP per capita and to a decrease on CO2 emissions per capita.

Bowden and Payne [46], employ a Toda-Yamamoto approach to study the relationship between real GDP, renewable and non-renewable energy in the USA, and found that renewable and non-renewable energy directly and indirectly affects the real GDP. Tiwari [47] analyzed the relationship between renewable energy, economic growth, and CO2 emissions for India, using a SVAR and concluded that an increment on renewable energy increases GDP and decreases CO2 emissions, and an increase on GDP has a strong positive impact on CO2 emissions.

Less positive results were obtained for the following studies. Menyah and Wolde-Rufael [48], using a modified version of the Granger causality test found that in the US there is no causality running from renewable energy to CO2 emissions, which means the renewable energy consumption has not reached a level where it can make a contribution to mitigate the emissions; on the other hand, Menegaki [49] used a random effect model to study the relationship between growth and renewable energy in 27 European countries and suggested empirical evidence of the neutrality hypothesis in both short and long-run. Nevertheless, there is evidence of causality of emissions and employment to economic growth and vice versa. Tugcu et al. [50] employed the Autoregressive Distributed Lag Approach (ARDL), and their long-run estimates showed evidence of no causal relationship between renewable energy consumption and real GDP in France, Italy, Canada and USA; however, the feedback is present for England and Japan and the conservation hypothesis is supported for Germany.

6.3 Data and EKC model

This study covers annual data from 2001 to 2010 from 20 OECD European countries: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Slovenia, Poland, Portugal, Slovak Republic, Spain, Sweden, Estonia and United Kingdom. Given the interest in analyzing the effects of the European Directive 2001/77/EC [4], and the fact that there was a lack of data for the share of renewable energy before 2000 and after 2011 for certain variables, the period considered was 2001 to 2010.

The variables used are CO2 emissions from electricity generation (CO2 kWh), economic growth (GDP) and the share of renewable energy sources in electricity generation (RES). CO2 per kWh is a ratio that in the numerator includes emissions from fossil fuels, industrial waste and non-renewable municipal waste that are consumed for electricity generation and in the denominator includes electricity generated from fossil fuels, nuclear, hydro (excluding pumped storage), geothermal, solar, biofuels, and so on. (IEA [51]). GDP, is the growth of real Gross Domestic Product (billions of dollars, 2005), based on World Bank World Development indicators [52] and International Financial Statistics of the International Monetary Fund. RES is presented as a percentage of gross electricity consumption and is the ratio between the electricity produced from renewable energy sources and the gross national electricity consumption. Electricity produced from renewable energy sources comprises the electricity generation from hydroelectric sources (excluding pumping), wind, solar, geothermal, and electricity from biomass/wastes. Gross domestic national electricity consumption comprises the total gross national electricity of all fuels (including auto production), plus electricity imports, minus exports (source: Eurostat).

The existence of multicollinearity between variables can cause problems in the accuracy of the estimates and the size of the standard errors. To investigate whether the variables used had this problem, we estimated the correlation coefficients (see Table A6.1 and A6.2 in Appendix) and applied the Variance Inflation Factor (VIF) test. Both procedures suggest that there is no collinearity between variables. The VIF test presents 4.72 as individual largest value and a mean of 4.72, with the critical value being 10.

We estimated the long–run equilibrium to validate the EKC, which assumes a homogeneous pattern for all countries. In this analysis we studied the relation between CO2 kWh, GDP and RES, through the equation 1 as follows:

$$\log CO_2Kwh_{it} = \alpha_{i,t} + \beta_1 \log GDP_{i,t} + \beta_2 \log GDP^2{}_{i,t} + \beta_3 \log RES_{i,t} + \varepsilon_{i,t} \ , \qquad \text{(Equation 1)}$$

Where the subscripts *i* and *t* refer to country and time respectively, the prefix “log” represents the natural logarithm, whereas $\beta_{1,}$ β_2 and β_3 are the slope parameters to be estimated and ε is the model´s error term.

The EKC hypothesis postulates that as GDP increases, CO2 kWh increase until a certain level of GDP is attained, and after that, emissions start to decline. The EKC hypothesis is verified if β_1 is significantly positive and $\beta 2$ significantly negative. The GDP turning point (in natural logarithms) can be estimated as $-\frac{\beta_1}{2\beta_2}$.

Accordingly, β_3 in equation 1, is expected to be negative since higher share of renewable source use in electricity tends to reduce the CO2 kWh.

However, for examining our central hypothesis where the share of renewable energy in electricity output can be a potential determining factor of the difference in the emissions-economic growth relation across European countries (in particular after European Directive 2001/77/EC), we included the share of renewable energy in electricity output connected with GDP and with GDP squared, as in equation 2:

$$\log CO_2Kwh_{it} = \alpha_{i,t} + \beta_1 \log GDP_{i,t} + \beta_2 \log GDP^2{}_{i,t} + \beta_3 \log RES_{i,t} + \\ + \beta_1^* \left(\log GDP \times RES\right) + \beta_2^* \left(\log GDP^2 \times RES\right)_{i,t} + \varepsilon_{i,t} \quad \text{(Equation 2)}$$

Based on that new relation, the EKC is supported when $\beta_1 + \beta_1^* \left(\log GDP * \mathrm{R}\, ES\right)$ is positive and $\beta_2 + \beta_2^* \left(\log GDP^2 \times RES\right)$ is negative and the income turning point (in natural logarithms) is $-\frac{\left[\beta_1 + \left(\beta_1^* \times RES\right)\right]}{2\left[\beta_2 + \left(\beta_2^* \times RES\right)\right]}$

The expected signals of *β1, β2* and *β3* are positive, negative and negative, respectively, as explained for equation 1.

The cross between RES and GDP allows us to see if there is any synergy between the two variables in explaining emissions. For example if β_1^* is negative, it means that the higher the percentage of renewable energy, the less the positive effect of GDP on emissions, or the higher the GDP, the less the negative effect of RES on emissions. In fact, the expected signals for β_1^* and for β_2^* are negative and positive respectively. Specifically, as countries invest more in renewable energy, they can grow without compromising the environment significantly, or as they become richer, they need not increase the share of renewable energy proportionally to reduce emissions.

If β_2^* is positive , it means that the higher the percentage of renewable energy, the higher the negative effect of GDP squared on emissions, or the higher the GDP squared, the less the effect of RES on emissions. If the income level of the country is already very high, a higher percentage of renewable energy will enhance the ease of economic growth without compromising the environment, otherwise we do not need to increase renewable energy too much to reduce emissions.

Moreover, from this new model, we can also infer that the share of renewable energy in electricity output will have significant influence on the shape of the

EKC if β_1^* is significantly negative. This means that EKC will shift downward as RES increases, suggesting lower (environmental) costs of development. The income turning point is lowered with higher level of share of renewable energy in electricity output if β_2^* is significantly less than 0. However, if β_2^* is positive, whether share of renewable energy in electricity output lowers or increases the turning point depends on the relative size (in absolute term) of β_1^* and β_2^*.

6.4 Econometric Methodology and Results

We will try to answer our goal-research using a methodology that goes through five different but complementary types of tests or estimations: (i) Panel Unit root tests, (ii) Panel Cointegration tests, (iii) Panel Long run Estimates; (iv) Panel Granger Causality and (v) Innovative Accounting Approach (which comprises Variance Decomposition Analysis and Impulse Response Functions).

6.4.1 Panel Unit root tests

Panel data is generally characterized by unobserved heterogeneity with parameters that are cross-section specific, although in some cases it is not appropriate to consider independent cross-section units. The test outcomes are difficult to interpret because the rejection of the null hypothesis of no unit root means that a significant fraction of cross-section units is stationary; however, there is no explicit quantification of the size of this fraction.

The unit root test was employed to ascertain whether or not the time series of each variable included in the Autoregressive Distributed Lag (ADL) contained a stochastic trend and to test whether the set of variables are stationary or not.

The panel unit root test is based on the following autoregressive specification (Mahadevan and Asafu-Adjaye [53]): $y_{it} = \rho_i \cdot y_{it-1} + \Delta_i \cdot X_{it} + \mu_{it}$, where $i = 1, 2, ..., N$, represents countries observed over periods $t = 1, 2, ..., T$. X_{it} are exogenous variables in the model including individual deterministic effects, such as constants (fixed effects) and linear time trends, which capture cross-sectional heterogeneity, and ρ_i are the autoregressive coefficients. If $\rho_i < 1$, y_i is said to be weakly trend-stationary. Conversely, if $\rho_i = 1$, then y_i contains a unit root; μ_{it} are the stationary error terms.

In order to test, under the null hypothesis, that all individual series of the panel contain a unit root, Levin, Lin and Chu [54] proposed the following panel-based ADF test that restricts parameters by keeping them identical across sectional regions: $\Delta y_{it} = c_i + \rho_i \cdot y_{it-1} + \sum_{j=1}^{k} c_j + \rho_i \cdot y_{it-j} + \varepsilon_{it}$, where $t = 1, 2, ..., T$ represents time periods and $i = 1, 2, ..., N$ represents members of the panel. The Levin-Lin-Chu test (LLC) adopts the null hypothesis of $\rho_i = \rho = 0$ for all *i,* against the alternative $\rho_1 = \rho_2 = ... = \rho < 0$ for all *i*, with the test based on the statistics $t_\rho = \hat{\rho} / s.e.(\hat{\rho})$. However, one drawback is that ρ is restricted by being kept identical across regions under both the null and alternative hypotheses.

Im, Pesaran and Shin [55] (hereafter IPS) assume that panels share a common autoregressive parameter. However the null hypothesis is only rejected if there is sufficient evidence against it (according to classical statistical methods). The IPS test uses a null hypothesis of $\rho_i = 0$ against the alternative $\rho < 0$ for all *i*, and is based on the mean-group approach which uses the average of the t_ρ statistics to obtain the z statistic.

We also perform the Hadri [56] method that tests the null hypothesis that the data are stationary against the alternative hypothesis that at least one panel contains a unit root. Hadri [56], regardless of the alternative hypothesis used, implements heterogeneous and serially correlated errors on account of their improved explanatory power. The results of panel tests are difficult to interpret if the null hypothesis is rejected. In the LLC and IPS tests, cross-sectional means are subtracted to minimize problems arising from cross-section dependence.

Table 6.1 displays the results of panel unit root tests in level and in the first differences for all the variables. We performed a LLC, IPS and Hadri test including an intercept and a linear trend. The non-stationarity of the variables CO2 kWh, GDP, GDP squared and RES, can be seen, indicating the possibility of long-term relationships between those variables.

In general, the remaining statistics provide strong evidence that the variables contain a panel unit root. Given that the variables CO_2 kWh, GDP and RES are integrated of the same order, it is natural that we proceed by testing the cointegration in order to establish if a long term equilibrium relationship among certain variables exists.

Table 6.1: Panel Unit Root Tests Results- period 2001- 2010

	Levels			First differences		
	LLC	**IPS**	**Hadri**	**LLC**	**IPS**	**Hadri**
Ln CO2 kWh	-12.459*** [0.0000]	-2.8596*** [0.0021]	11.4042*** [0.0000]	-14.8861*** [0.0000	-4.4267*** [0.0000	19.3053*** [0.0000]
Ln GDP	-9.8880*** [0.0014]	-1.7146** [0.0432]	9.3851*** [0.0000]	-8.7320*** [0.0000]	-1.34011* [0.09806]	14.9028*** [0.0000]
Ln GDP^2	-9.0567*** [0.0000]	-1.9245** [0.0271]	9.4069*** [0.0000]	-8.7372*** [0.0000]	-1.35270* [0.0881]	15.1796*** [0.0000]
Ln RES	-14.0879*** [0.0000]	-3.8479*** [0.0001]	10.7574*** [0.0000]	-12.7156*** [0.0000]	-3.1782*** [0.0000]	17.9613*** [0.0000]

Notes: *, ** and * represent significance at the 10%, 5% and 1% levels respectively.**

6.4.2 Panel Cointegration tests

The Engle-Granger methodology (Engle and Granger, [57)] is usually used in testing cointegration. It examines the residuals of a regression and contends that there is cointegration if $u_t \sim I(0)$. The first contribution, among others, for this approach, has been presented by Pedroni [58], [59], [60] and Kao and Chiang [61].

Given the following equation: $y_{it} = \alpha_i + \delta_{it} + \beta_{1i} \cdot x_{1i,t} + \beta_{2i} \cdot x_{2i,t} + ... + \beta_{ki} \cdot x_{ki,t} + \varepsilon_{it}$ where i = 1,2,…N, for each country in panel; $t = 1, 2, ..., T$, refers to the time period; parameter *α* refers to the possibility of country-specific fix effects and the parameter δ refers to the possibility of deterministic trends. It is further assumed that variables y and x are integrated of order one, that is, I(1). Thus, under the null hypothesis that there is cointegration, the residuals will also be I (1).

Pedroni [58], [59], [60] proposes several cointegration tests that allow the heterogeneity of the intercepts and coefficients among individuals. Their alternative hypothesis can be considered homogeneous or heterogeneous. The residuals from the static long-run regression are used to build seven panel cointegration test statistics: four of them are based on pooling, which assumes homogeneity of the AR term, whilst the remaining are less restrictive, as they allow for heterogeneity of the AR term.

The statistics based on the homogeneous alternative hypothesis consist of estimates of pooled type, which ([59], [60]) call statistics within-groups. When considering the heterogeneous alternative hypothesis, test statistics are formed by means of the estimated individual values for each panel unit i, which ([59], [60]) call between-group estimators.

The results of panel cointegration tests are shown in table 6.2. It can be seen that four of the seven panel tests indicate that the null hypothesis of no cointegration is rejected at the 1% level, more specific, there are two panel statistics that reject the null hypothesis of no cointegration and two other statistics admit there is no cointegration between the variables. In group cointegration tests, two group statistics reject the null hypothesis and one admits it.

Table 6.2: Results of Panel Cointegration Tests

	Kao Statistics	Pedroni Statistics			
Equation 1	-2.3777* [0.008]*	Panel v-Statistic	-1.253915 [0.974]	Group rho-Statistic	5.47486 [1.000]
		Panel rho-Statistic	2.790618 [0.999]	Group PP-Statistic	-14.6521*** [0.000]
		Panel PP-Statistic	-4.6363*** [0.000]	Group ADF-Statistic	-2.2542*** [0.000]
		Panel ADF-Statistic	2.15667* [0.081]		
Equation 2	-2.2307** [0.0128]	Panel v-Statistic	-2.1416 [0.9839	Group rho-Statistic	6.31205 [1.000]
		Panel rho-Statistic	4.0760 [1.000]	Group PP-Statistic	-7.81559*** [0.000]
		Panel PP-Statistic	0.34096*** [0.000]	Group ADF-Statistic	-2.3145*** [0.0100
		Panel ADF-Statistic	-0.0960*** [0.008]		

Notes: Tests results were generated by Eviews. Pedroni's and Kao Panel statistics as well as all of variables. Values in [ ] are robust p-values generated through bootstrapping because of cross-sectional dependence in the residuals. *, **, and *** indicates significance at 10%, 5% and 1% respectively.

We decided it may be reasonable to accept the existence of cointegration relationship if we consider the fact that rho-statistics have lower power than the PP-statistics.

6.4.3 Panel Long run Estimates

Based on error correction models, we used the Full Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) methods. This procedure follows Pedroni's [58] recommendations, in which FMOLS and DOLS estimators are more advantageous in other group-means versions, due to the greater flexibility under the presence of heterogeneity in the cointegration vectors and to the lower size distortion, than the estimators within groups. This allows to correct both the endogeneity bias and serial correlation, and to achieve consistent and efficient estimators of the long-run relationship.

The results from the estimation of the model proposed are given in table 6.3, and confirm our expectations that CO2 kWh tend to decrease with the share of renewable energy sources used. In Model 1, the FMOLS estimates indicate for the long-run relationship, that GDP has a positive statistically significant impact on CO2Kwh and GDP squared has a negative statistically significant impact on CO2 Kwh at 10% level significance. Moreover, the share of renewable energy sources has a negative statistically significant impact on CO2 Kwh at 10% level significance. The results suggest that a 1% increase in the share of renewable energy is related to the decrease in expected CO2Kwh by 0.05%.

Table 6.3: Panel Cointegration Estimation Results

	Model 1		Model 2	
2001 – 2010	**FMOLS**	**DOLS**	**FMOLS**	**DOLS**
Dependent variable:	**CO2 kWh**	**CO2 kWh**	**CO2 kWh**	**CO2 kWh**
Ln GDP	**7.2381*** **(0.094)**	5.9678 (0.206)	**5.7280*** **(0.089)**	4.5422 (0.128)
Ln GDP^2	**-3.6745*** **(0.091)**	-2.9256 (0.138)	**-2.9427*** **(0.088)**	-2.4138 (0.119)
Ln RES	**-0.05012*** **(0.098)**	-0.0501* (0.0101)	**-0.0605*** **(0.071)**	-0.0102* (0.092)
Share of RES* Ln GDP			**-0.29312**** **(0.033)**	-0.2391* (0.102)
Share of RES*Ln GDP^2			**0.14551**** **(0.034)**	0.101* (0.103)
R-squared (r^2)	**0.981**	0.984	**0.983**	0.985
No. of Countries	20	20	20	20
No. of Observations	200	200	200	200

Notes: Values in [ ] are robust p-values ; the *, **, and *** indicate significance at 10%, 5% and 1% respectively.

According to our central hypothesis, from FMOLS estimation, we obtain empirical support for the presence of the EKC, as indicated by the significantly positive effect of GDP and significantly negative coefficient of GDP squared in both equations 1 and 2. However, the results are more statistically significant in equation 2. They suggest that 1% increase in the share of renewable energy decreases CO2 kWh by 0.06%; while 1% increase in the interactive effect between the share of renewable energy and GDP decreases CO2 kWh by 0.29%. On the other hand, the validity of EKC is confirmed by the positive coefficient of GDP, that is 5.7280 - (0.29312 x RES), and by the negative coefficient of GDP squared, that is -2.942 + (0.1455 x RES).

These results suggest several noteworthy points. First, they do not overturn the validity of the traditional EKC, in fact, the coefficient of GDP remains positive while that of GDP squared remains negative, regardless of the level of proportion of renewable energy sources in electricity generation.

Secondly, as reflected by the statistical significance of the two interactive effects at 5% level of significance, the results suggest the importance of the proportion of renewable energy sources in electricity generation in influencing the EKC. If a country uses more renewable energy, it can grow economically without many environmental costs, because the share of renewable energy will make the EKC drop.

Thirdly, the significant negative coefficient of the interaction between the share of renewable energy and GDP suggest that the environmental costs of European economic development are lower for a European country with a higher level of share of renewable energy sources used in electricity generation. That means the EKC shifts downward as the share of renewable energy sources increases. Finally, the positive coefficient of the interaction between GDP squared and the share of renewable energy sources in electricity generation suggests that the threshold point can be lower or higher for a European country with higher level of share of renewable energy depending on the relative reduction in the coefficient of GDP in relation to the reduction in the coefficient of GDP squared.

6.4.4 Panel Granger Causality

An implication of co-integration is that there must be causality in at least one direction. For this we estimated the following VECM (Vector Error Correction Model). The VECM is the short-run model and it gives the adjustment mechanism when CO2 kWh, GDP, RES and the cross product between RES and GDP and GDP squared deviate, in the short-run, from the long-run equilibrium. We estimated that the simple VECM for the long-run relationship and the short-run equations are as follows for cointegration model:

$$\Delta CO_{2\,Kwh\,it} = \alpha_{1j} + \lambda_{1i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{11ik}\Delta CO_{2\,Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{12ik}\Delta GDP_{it-k} + \sum_{k=1}^{q}\gamma_{13ik}\Delta GDP^{2}{}_{it-k}$$ Eq. 3.1

$$+\sum_{k=1}^{q}\gamma_{14ik}\Delta RES_{it-k} + \sum_{k=1}^{q}\gamma_{15ik}\Delta GDP \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{16ik}\Delta GDP^{2} \times RES_{Kwh\,it-k} + \mu_{1it}$$

$$\Delta GDP_{it} = \alpha_{2j} + \lambda_{2i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{21ik}\Delta GDP_{it-k} + \sum_{k=1}^{q}\gamma_{22ik}\Delta CO_{2\,Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{23ik}\Delta GDP^{2}{}_{it-k}$$ Eq. 3.2

$$+\sum_{k=1}^{q}\gamma_{24ik}\Delta RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{25ik}\Delta GDP \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{26ik}\Delta GDP^{2} \times RES_{Kwh\,it-k} + \mu_{2it}$$

$$\Delta GDP^2{}_{it} = \alpha_{3j} + \lambda_{3i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{31ik}\Delta GDP^2{}_{it-k} + \sum_{k=1}^{q}\gamma_{32ik}\Delta GDP_{it-k} + \sum_{k=1}^{q}\gamma_{33ik}\Delta CO_{2\,Kwh\,it-k}$$

$$+\sum_{k=1}^{q}\gamma_{34ik}\Delta RES_{it-k} + \sum_{k=1}^{q}\gamma_{35ik}\Delta GDP \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{36ik}\Delta GDP^2 \times RES_{Kwh\,it-k} + \mu_{3it}$$

Eq. 3.3

$$\Delta RES_{Kwh\,it} = \alpha_{4j} + \lambda_{4i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{41ik}\Delta RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{42ik}\Delta CO_{2\,Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{43ik}\Delta GDP_{it-k}$$

$$+\sum_{k=1}^{q}\gamma_{44ik}\Delta GDP^2{}_{it-k} + \sum_{k=1}^{q}\gamma_{45ik}\Delta GDP \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{46ik}\Delta GDP^2 \times RES_{Kwh\,it-k} + \mu_{4it}$$

Eq.3.4

$$\Delta GDP \times RES_{Kwh\,it} = \alpha_{5j} + \lambda_{5i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{51ik}\Delta GDP \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{52ik}\Delta CO_{2\,Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{53ik}\Delta GDP_{it-k}$$

$$+\sum_{k=1}^{q}\gamma_{54ik}\Delta GDP^2{}_{it-k} + \sum_{k=1}^{q}\gamma_{55ik}\Delta RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{56ik}\Delta GDP^2 \times RES_{Kwh\,it-k} + \mu_{5it}$$

Eq. 3.5

$$\Delta GDP^2 \times RES_{Kwh\,it} = \alpha_{6j} + \lambda_{6i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{61ik}\Delta GDP^2 \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{62ik}\Delta CO_{2\,Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{63ik}\Delta GDP_{it-k}$$

$$+\sum_{k=1}^{q}\gamma_{64ik}\Delta GDP^2{}_{it-k} + \sum_{k=1}^{q}\gamma_{65ik}\Delta RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{66ik}\Delta GDP \times RES_{Kwh\,it-k} + \mu_{6it}$$

Eq. 3.6

The errors for period *t*-1 are estimated from the long-run equation. The inclusion of the lagged dependent variable as an instrument variable estimator is necessary to account for correlation between the lagged dependent variables and the error term. The coefficients are adjustment parameters, showing the degree with which the respective left hand side variables adjust in period *t* to disequilibrium shocks in period *t*-1.

Table 6.4: Panel Granger Causality Results

Model 2 **EKC approach**		**Eq.3.**1	Eq.3.2	**Eq.3.3**	**Eq.3.4**	**Eq.3.5**	**Eq.3.6**
	ect (-1)	**Δ LCO_2 kWh**	**Δ LGDP**	**Δ LGDP^2**	Δ Renewable	**Δ Renewable x L GDP**	**Δ Renewable x L GDP^2**
Constant		-0.01161 (0.0385)**	0.0174 (0.000) ***	-0.0350 (0.000) ***	-5.4908 (0.000)***	-0.4807 (0.000)***	0.9600 (0.000)***
Δ LCO_2 kWh	0.0427 (0.0427)**		0.0026 (0.1039)	-0.0055 (0.1031)	-0.8535 (0.1023)	-0.0650 (0.1216)	0.1298 (0.1362)
Δ L GDP	-0.139 (0000)***	7.9444 (0.1013)*		2.0214 (0.000)***	289.322 (0.000)***	23.8249 (0.000)***	-47.5750 (0.000)***
Δ L GDP^2	00386 (0.000)***	- 3.9904 (0.1003*)	0.4940 (0.000) ***		-143.292 (0.000)***	-11.7549 (0.000)***	23.4721 (0.000)***
Δ RES	-0.0587 (0.000)***	- 0.1152 (0.096)*	-0.0142 (0.000) ***	0.0287 (0.000)***		0.5007 (0.000)***	1.9988 (0.000)***
Δ RES **x** L GDP	00531 (0.000)***	- 0.2303 (0.068)*	0.0284 (0.000) ***	-0.0574 (0.000)***	-6.4040 (0.000)***		1.9969 (0.000)***
Δ RES **X L** GDP^2	-0.1061 (0.000)***	0.1152 (0.076)*	-0.0142 (0.000) ***	0.0287 (0.000)***	3.2052 (0.000)***	0.5007 (0.000)***	

Notes: *, ** and * represent significance at the 10%, 5% and 1% levels respectively.**

In Equation 3.1, the error correction term indicates the speed of adjustment towards long-run equilibrium and has a statistical significance at the 5% level with a speed of adjustment to long-run equilibrium of 23.42 years. All variables have a statistically significant impact at 10% level of significance on carbon dioxide emissions from electricity generation in the short run.

With respect to Equation 3.2, the GDP squared and the interactive effect between GDP and RES, have a positive and statistically significant impact on GDP while RES and the effect between GDP squared and RES have a negative and statistically significant impact on GDP in the short run. However, carbon dioxide emissions from electricity generation have a statistically insignificant impact on GDP in the short run. The error correction term is statistically significant at 1% level with a speed of adjustment to long-run equilibrium of 7.20 years.

In terms of Equation 3.4, RES is positively affected by GDP and by the interactive effect between GDP squared and the share of renewable energy, and negatively affected by GDP squared and by the effect between GDP and the share of renewable energy sources. Carbon emissions per kWh have a statistically insignificant impact on the share of renewable energy sources in electricity generation output in the short run. On the other hand, the statistical significance of the error correction term suggests that the share of renewable energy sources responds to deviations from long-run equilibrium with an adjustment of roughly 17.04 years.

In Equation 3.5, GDP, RES and RES interactively with GDP squared, have a positive and statistically significant impact on RES interactively with GDP in the short-run, while GDP squared affects it negatively. Carbon emissions per kWh have a statistically insignificant impact on RES interactively with GDP. The error correction term indicates that the speed of adjustment towards long-run equilibrium is approximately 18.82 years.

With regard to Equation 3.6, GDP squared, RES and RES interactively with GDP have a positive and statistically significant impact on RES interactively with GDP squared in the short-run, while GDP has a negative impact and carbon emissions per kWh is statistically insignificant. The correction term is statistically significant with the slowest adjustment equilibrium of 9.43 years.

In summary, the Granger causality tests reveal that there is unidirectional causality from RES interactively with GDP (negative) and from RES interactively with GDP squared (positive), both towards CO_2 kWh, which confirms the ideas exposed in section 3. There is also bidirectional positive causality between GDP and RES interactively with GDP, between RES and RES interactively with GDP squared and between RES interactively with GDP and RES interactively with GDP squared. There is bidirectional negative causality between GDP and RES interactively with GDP squared. Finally, there is bidirectional causality between GDP and RES (positive from GDP to RES and negative from RES to GDP) and between RES and RES interactively with GDP squared (positive from RES to RES interactively with GDP squared and negative from RES interactively with GDP squared to GDP).

6.4.5 The Innovative Accounting Approach

6.4.5.1 Generalized forecast variance decomposition

The generalized forecast variance decomposition approach estimates the simultaneous shock effects using a VAR system to test the strength of causal relationship between CO_2 kWh, GDP and RES of European countries.

The variance decomposition approach indicates the magnitude of the predicted error variance for a panel series accounted by innovations from each of the independent variables over different time horizons (2001-2010). Furthermore, the generalized forecast error variance decomposition approach estimates the simultaneous shocks stemming in other variables.

For instance, if the share of renewable energy sources explains more of the forecast error variance of CO_2 kWh, then we deduce that there is unidirectional causality from renewable energy sources to CO_2 emissions in electricity generation. The bidirectional causality exists if shocks in CO_2 kWh emissions also affect the share of renewable energy sources in a significant way. If shocks occurring in both series do not have any impact on the changes in CO_2 kWh emissions and in the share of renewable energy sources then there is no causality between the variables.

Table 6.5 presents the results of the generalized variance decomposition over a ten-year period for 20 European countries. The variance decomposition explains how much of the predicted error variance of a variable is described by innovations generated from each independent variable in a system, over various time horizons.

Hereafter, we will point out the most important shocks that can change each variable. The empirical evidence indicates that 93.5 per cent of CO2 kWh emissions is due to its own innovative shocks. The standard deviation shock in coefficient of the interaction between GDP and the share of renewable energy sources in electricity generation is the variable that better explains electricity pollutants, although with a low percentage (2.13%). A 7.3 per cent of GDP is explained by one standard deviation shock in CO2 kWh emissions and 91.2 per cent is due to its own innovative shocks. GDP squared is affected mainly by GDP (91.125%) and by CO2 kWh (7.3%). A significant portion of RES is explained by its own shocks (60.3%), by shocks in CO2 kWh (27.3%) and in GDP (10.9%).

The contribution of CO2 kWh and RES to the interactive effect between the share of renewable energy and GDP is 31.6% and 23.7% respectively, while 42.1% per cent is due to its own innovative shocks. The interactive effect between the share of renewable energy and GDP squared is mainly affected by the interactive effect between the share of renewable energy and GDP (42.1%), by CO2 kWh (31.6%) and by RES (23.7%).

Table 6.5: Generalized variance decomposition results

Variance Decomposition of CO2 kWh

Period	CO2 kWh	GDP	GDP^2	RES	RES x GDP	RES x GDP ^2
1	100.0000	0.000000	0.000000	0.000000	0.000000	0.000000
2	95.70979	0.358865	0.002397	0.339409	3.393501	0.196041
3	94.91419	0.691613	0.387879	0.283483	3.383464	0.339370
4	94.58039	0.753891	0.608483	0.219638	3.051695	0.785905
5	94.21208	0.852751	0.739070	0.182729	2.941178	1.072196
10	93.54845	1.006484	1.263403	0.149724	2.133950	1.897989

Variance Decomposition of GDP:

Period	CO2Kwh	GDP	GDP^2	RES	RES x GDP	RES x GDP ^2
1	3.730948	96.26905	0.000000	0.000000	0.000000	0.000000
2	6.454976	92.76140	0.433054	0.062536	0.132503	0.155535
3	6.963128	91.97080	0.773274	0.092796	0.090252	0.109754
4	7.041224	91.80773	0.920940	0.077054	0.076331	0.076723
5	7.240532	91.54068	1.024609	0.061533	0.065428	0.067215
10	7.296354	91.18002	1.371585	0.054998	0.032187	0.064852

Variance Decomposition of GDP^2:

Period	CO2Kwh	GDP	GDP^2	RES	Period	CO2Kwh
1	3.377360	95.64327	0.979370	0.000000	0.000000	0.000000
2	6.189603	92.52312	0.905826	0.050729	0.168586	0.162138
3	6.900450	91.75080	1.042793	0.091057	0.113498	0.101402
4	6.987130	91.66213	1.106393	0.077659	0.095516	0.071172
5	7.197560	91.41858	1.175315	0.062290	0.081849	0.064408
10	7.274337	91.12557	1.440077	0.055482	0.040299	0.064235

Variance Decomposition of RES:

Period	CO2Kwh	GDP	GDP^2	RES	RES x GDP	RES x GDP ^2
1	*4.260251*	*0.471332*	0.080418	95.18800	0.000000	0.000000
2	*24.69815*	*3.241228*	0.953793	70.69848	0.218404	0.189937
3	25.41025	6.013492	0.733833	67.14475	0.466479	0.231194
4	25.28372	7.779919	0.899354	65.38899	0.385814	0.262203
5	26.09383	8.879068	0.866784	63.59838	0.330153	0.231786
10	27.32478	10.90364	0.775544	60.34912	0.484046	0.162862

Variance Decomposition of %RES x GDP :

Period	CO2Kwh	GDP	GDP^2	RES	RES x GDP	RES x GDP ^2
1	0.522200	0.030992	0.005008	36.06358	63.37822	0.000000
2	30.41284	0.847496	0.553905	21.59948	45.01988	1.566395
3	30.57755	0.978598	0.678492	21.47143	45.03736	1.256565
4	29.99322	1.112133	0.542212	22.20978	45.11503	1.027636
5	30.82390	1.254742	0.496109	22.24054	44.29788	0.886831
10	31.55757	1.684093	0.375858	23.71961	42.10195	0.560924

Variance Decomposition of : %RES x GDP ^2

Period	CO2Kh	GDP	GDP^2	RES	RES x GDP	RES x GDP ^2
1	0.522095	0.031450	0.000500	36.09407	63.35042	0.001465
2	30.42772	0.855392	0.561585	21.63125	44.97507	1.548979
3	30.58164	0.987989	0.689062	21.50553	44.99499	1.240788
4	30.00473	1.122238	0.550564	22.23915	45.06900	1.014319
5	30.83652	1.264432	0.503496	22.26653	44.25376	0.875265
10	31.57363	1.690938	0.379969	23.73604	42.06518	0.554247

Taking 5% as a threshold, we can infer that there is unidirectional causality from CO2 kWh to all the other variables. On the other hand, GDP causes GDP squared and RES. The share of renewable energy causes the interaction between GDP with the share of renewable energy sources and the interaction between GDP squared with the share of renewable energy sources. Finally, the interaction between GDP with the share of renewable energy sources causes the interaction between GDP squared with the share of renewable energy sources.

6.4.5.2 Impulse Response Functions

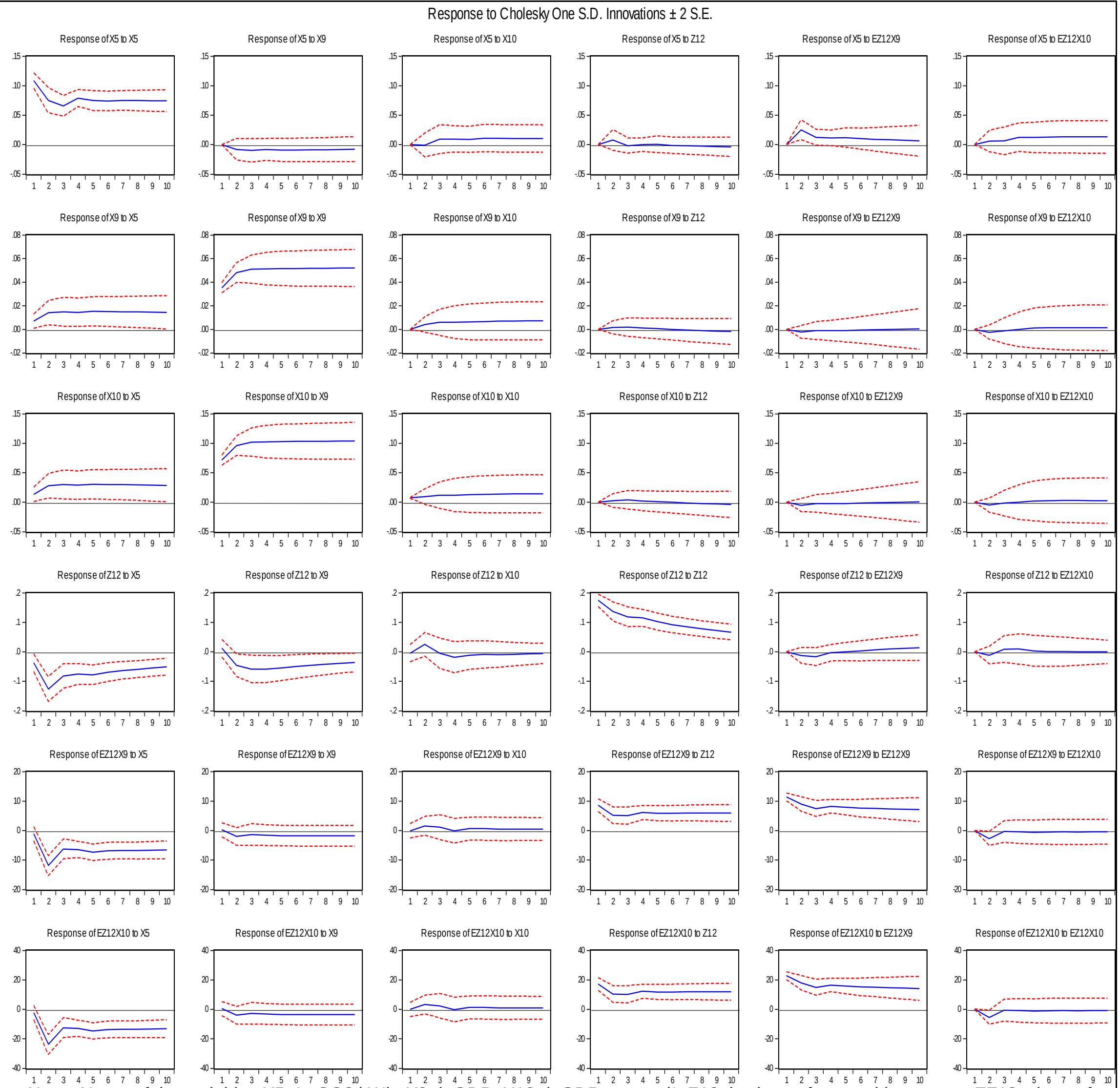
We also provided a rough analysis of how long it takes for the variable to go back to the equilibrium after the long run relationship has been shocked. The IRFs show the dynamic responses of time series to a one period standard deviation shock and indicate the direction of the response to each of the shocks.

One can determine how CO2 kWh responds due to its shock and to shocks in the other variables. For instance, we support the hypothesis that the share of renewable energy sources causes CO2 kWh if the impulse response function indicates significant response of CO2 kWh emissions to shocks in the share of renewable energy sources compared to shocks in the other variables.

We have the IRFs represented in figure 6.1. We can see that CO2 kWh reacts positively and significantly to shocks in the interaction between GDP squared with the share of renewable energy sources in electricity, and reacts negatively to shocks in GDP. The GDP reacts positively to shocks in CO2 kWh. Concerning the share of renewable energy sources, in the short-run the reaction is positive but after the fourth period the reaction is negative. We can see that the share of renewable energy sources in electricity generation reacts negatively to shocks in CO2 kWh and in GDP.

The reaction of the interaction effect between GDP and the share of renewable energy sources in electricity generation is negative to CO2 kWh and positive to RES and to the interaction effect between GDP squared and the share of renewable energy sources.

Figure 6.1: Impulse Response Function (IRF´s results)



Notes:Name of the variables X5- LnCO2 kWh, X9- lnGDP, X10- lnGDP squared*, Z12 -ln share of renewable sources, EZ12- share of renewable sources in electricity generation respectively.

6.5 Concluding remarks

This study aims to evaluate in 2001-2010 the renewable resource and environment efficiency problem in electricity generation of European countries. We specify a new EKC, where the share of renewable energy in electricity production is considered as an important driver for determining the difference in the emissions–income relations across European countries. Our results provide supportive evidence for the validity of EKC, as reflected by the positive coefficient of GDP and negative coefficient of its squared value.

These results have important implications. Among others, the significant evidence that the share of renewable energy in electricity output is a potential driver for reducing the carbon emissions in electricity, tends to be large at the early stage of European economic development. With the obtained estimates, we can see that as countries invest more in renewable energy, they can grow without compromising the environment too much, or as they become richer, they don't need to increase proportionally the share of renewable energy to reduce emissions. We can illustrate this with countries with lower income on average for this period, such as Austria or Sweden that made a strong investment in renewable energy and were able to grow without too many emissions. Richer countries, such as Germany, United Kingdom and France, did not need to significantly increase their share of renewable energy in the period 2000-2010, to reduce emissions (see figure A1 in Appendix). If the income level of the country is already very high, a higher percentage of renewable energy will enhance the ease of economic growth without compromising the environment otherwise we do not need to increase renewable energy significantly to reduce emissions.

Moreover, from this new model, we can also infer that the share of renewable energy in electricity output will have significant influence on the shape of the EKC, which will shift downward as RES increases, suggesting lower (environmental) costs of development. As β_2^* is positive, the share of renewable energy in electricity output lowers the turning point because, in absolute term, β_1^* is greater than β_2^*.

From Panel Granger Causality tests we can highlight the bidirectional causality between GDP and RES (positive from GDP to RES and negative from RES to GDP). From Variance Decomposition analysis we confirm the relation of causality from GDP to RES. This shows that richer countries will naturally have more willingness to invest in renewable energy. The negative causality from RES to GDP can somehow support the results of Menegaki [49], who claims that the leading countries in renewable energy are less technically efficient than renewable energy laggards that are among the most technically efficient countries in Europe. However, it must be pointed out that the period of analysis and methodology used in Menegaki [49] is different from the present study.

From IRFs we can see that CO2 kWh reacts positively and significantly to shocks in the interaction between GDP squared with the share of renewable energy sources in electricity, and reacts negatively to shocks in GDP. These results show that the crossing effect between the share of renewable energy in electricity output and income is crucial to reduce the CO2 intensity of European Countries, particularly in energy supply, in what concerns increasing energy efficiency and the use of renewable energy. The GDP reacts positively to the share of renewable energy sources in the short-run, but after the fourth period the reaction is negative, which may support the conclusions of Menegaki. [49]

All these results, in particular the results reported in Model 1B, show a common pattern expected of CO2 emissions in electricity generation after the European Directive 2001/77/EC, including the first and part of the second period of the Kyoto Protocol (2005-2007 and 2008-2012). These results are relevant to identify that the share of renewable energy sources can be a potential determining driver of the difference in the emissions-income relation across European panel country level. Moreover, these results reveal the importance of the interactive impact of the share of renewable energy sources and of GDP in reducing the CO2KWh in electricity generation.

In addition, these results claim the importance of the points highlighted by the European policy (2009/28/CE directive) [62]. European policies are not only focused on market-based instruments as energy or environmental taxes/subsidies or the European Carbon Market (ECM), but also on the improvement of technology that focuses on energy efficiency and renewable energy and on the EU financial instruments supporting the achievement of political goals.

All these guidelines, especially at a domestic European level, and/or at an international one, are linked to the mitigation mechanism, which should be granted exclusively in promotion and development of clean technologies to ensure better energy efficiency.

References

[1] Olivier, J.G.J. J. Peters, G. Janssens-Maenhout and J. Wilson, 2011, Long-term trend in global CO2 emissions. 2011 Report PBL Netherlands Environmental Assessment Agency, The Hague, 2011; European Union.

[2] Commission of the European Communities, 2007, Sustainable power generation from fossil fuels: aiming for near-zero emissions from coal after 2020, Communication from the Commission to the Council and the European Parliament, Brussels, 10.1.2007, COM (2006) 843 final, http://europa.eu/legislation_summaries/energy/european_energy_policy/l27068_en.htm

[3] European Commission, 2012, Citizens' summary EU climate and energy package, http://ec.europa.eu/clima/policies/package/docs/climate_package_en.pdf

[4] European Commission Directive 2001/77/EC, of the European Parliament and of the Council of 27 September 2001, On the promotion of electricity produced from renewable energy sources in the internal electricity market, Official Journal Nº L 283, 27.10.2001, p. 33.

[5] Hettige, H., Lucas, R.E.B., Wheeler, D., 1992, The toxic intensity of industrial production: global patterns, trends, and trade policy. American Economic Review 82, 478-481.

[6] Martinez-Zarzoso I, Bengochea-Morancho A., 2004, Pooled mean group estimation of anenvironmental Kuznets curve for CO2. Economics Letters; 82: 121-126.

[7] Acaravci, A., Ozturk, I. , 2010, On the relationship between energy consumption, CO2 emissions and economic growth in Europe. Energy; 35: 5412-5420.

[8] Cropper M, Griffiths C., 1994. The interaction of population growth and environmental quality. American Economic Review; 84: 250-254.

[9] Pao H-T, Yu H-C, Yang Y-H. , 2011. Modeling CO2 emissions, energy use, and economic growth in Russia. Energy; 36: 5094-5100.

[10] Apergis N, Payne JE., 2009. CO2 emissions, energy usage, and output in Central America. Energy Policy; 37: 3282-3286.

[11] Iwata H, Okada K, Samreth S., 2011. A note on the environmental Kuznets curve for CO2: A pooled mean group approach. Applied Energy; 88: 1986-1996.

[12] Mongelli, I., Tassielli, G and Notarnicola, B., 2006. Global warming agreements, international trade and energy/carbon embodiments: an input-output approach to the Italian case. Energy Policy; 34: 88–100.

[13] Ang, J. B., 2007. CO2 emissions, energy consumption, and output in France. Energy Policy; 35: 4772-4778.

[14] Ang, J. B., 2008. Economic development, pollutant emissions and energy consumption in Malaysia. Journal of Policy Modeling; 30: 271-278.

[15] Jalil, A., Mahmud, S. F., 2009, Environment Kuznets Curve For CO2 Emissions: A Cointegration Analysis. Energy and Policy, 37(12), 5162-5172.

[16] Halicioglu, F., 2009. An econometric study of CO2 emissions, energy consumption income and foreign trade in Turkey. Energy Policy 47, 1156-1164.

[17] Alam MJ, Begum IA, Buysse J, Rahman S, Huylenbroeck GV., 2011. Dynamic modeling of causal relationship between energy consumption, CO2 emissions and economic growth in India. Renewable and Sustainable Energy Reviews; 15:3243-3251.

[18] Fodha, M., Zaghdoud, O., 2010. Economic growth and pollutant emissions in Tunisia: an empirical analysis of the environmental Kuznets curve. Energy Policy 38, 1150- 1156.

[19] Nasir M, Rehman F-U., 2011. Environmental Kuznets curve for carbon emissions in Pakistan: An empirical investigation. Energy Policy; 39: 1857-1864.

[20] Aqeel, A., Butt, S., 2001. The relationship between energy consumption and economic growth in Pakistan. Asia Pacific Development Journal, 8, 101-110.

[21] Shiu, A.,Lam, P.L., 2004. Electricity consumption and economic growth in China. Energy Policy 32, 47-54.

[22] Lee, C. C., Chang, C. P., Chen, P. F., 2008. Energy-income causality in OECD countries revisited: the key role of capital stock. Energy Economics, 30, 2359-2373.

[23] Altinay, G., Karagol, E., 2005. Electricity consumption and economic growth: evidence for Turkey. Energy Economics 27, 849-856.

[24] Yuan, J., Kang, J., Zhao, C., & Hu, Z., 2008. Energy Consumption and Economic Growth: Evidence from China at both Aggregated and Disaggregated Levels. Energy Economics, 30, 3077-3094.

[25] Halicioglu, F. 2007. Residential electricity demand dynamics in Turkey. Energy Economics, 29 (2), 199-210.

[26] Narayan, P. K., Smyth, R., 2007. Energy consumption and real GDP in G7 countries: new evidence from panel cointegration with structural breaks. Energy Economics, 30, 2331-2341.

[27] Yuan, C., Liu, S., & Xie, N. (2010). The Impact of Chinese Economic Growth and Energy Consumption of the Global Financial Crisis: An Input-Output Analysis. Energy, 1-8.

[28] Squalli, J., 2007. Electricity consumption and economic growth: bounds and causality for OPEC menbers. Energy Economics 29, 1192-1205.

[29] Mozamder, P., Marathe, A. , 2007. Causality relationship between electricity consumption and GDP in Bangladesh. Energy Policy 35, 395-402

[30] Hu, J.L., Lim, C.H., 2008. Disaggregrated energy consumption and GDP in Taiwan: a threshold cointegration analysis. Energy Economics 30, 2342-2358.

[31] Reynolds, D.B. and Kolodziej, M., 2008. Former Soviet Union oil production and GDP decline: Granger causality and the multi-cycle Hubbert curve. Energy Economics 30 (2), 271-289

[32] Sari, R., Ewing, B. T., Soytas, U., 2008. The relationship between disaggregated energy consumption and industrial production in the United States: an ARDL approach. Energy Economics, 30, 2302-2313.

[33] Akbostancı E. Turut-Asık S. and Tunç G., 2009. The relationship between income and environment in Turkey: Is there an environmental Kuznets curve? Energy Policy 37, 861–867.

[34] Dhakal, S.. 2009. Urban energy use and carbon emissions from cities in China and policy implications. Energy Policy, 37 4208–4219.

[35] Ghosh, S. & Basu, S., 2006. Coal and Gas Consumption with Economic Growth: Cointegration and Causality Evidences from India. Resources, Energy and Development, 3, 13-20.

[36] Payne, J., 2010. A survey of the electricity consumption-growth literature. Applied Energy, 87(3), 723-731.

[37] Lean, H.H., Smith, R., 2010. CO2 emissions, electricity consumption and output in ASEAN. Applied Energy 87, 1858-1864.

[38] Apergis, N. and Payne, J. E., 2010. Renewable energy consumption and growth in Eurasia. Energy Economics, 32, 1392-1397.

[39] Apergis, N. and Payne, J. E., 2010. Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. Energy Policy, 38, 656-660.

[40] Sadorsky, P., 2009. Renewable Energy Consumption and Income in Emerging Economies, Energy Policy, 37, 10, 402 1-4028.

[41] Apergis, N., Payne, J. E., 2011. The renewable energy consumption- growth nexus in Central America. Applied Energy, 88, 343–347.

[42] Apergis, N. and Payne, J. E., 2012. Renewable and non-renewable energy consumption –growth nexus: Evidence from a panel error correction model. Energy Economics, 34 (3), 733-738.

[43] Pao, H-T. and Fu, H-C. 2013. Renewable energy and non-renewable energy and economic growth in Brazil. Renewable and Sustainable Energy Reviews 25, 381-392.

[44] Al-mulali, U., Fereidouni, G.H., Lee, Y.J. and Che Sab, N.C. 2013. Examining the bi-directional long run relationship between renewable energy consumption and GDP growth. Renewable and Sustainable Energy Reviews , 209-222.

[45] Silva, S., Soares, I. and Pinho, C., 2012. The Impact of Renewable Energy Sources on Economic Growth and CO2 Emissions - a SVAR approach, European Research Studies,Volume XV, Special Issue on Energy.

[46] Bowden N. and Payne J.E., 2010. Sectoral analysis of the causal relationship between renewable and non-renewable energy consumption and real output in the US. Energy Sources, Part B: Economics, Planning and Policy, 5(4): 400-408.

[47] Tiwari, A. K., 2011, A structural VAR analysis of renewable energy consumption, real GDP and CO2 emissions: Evidence from India, Economics Bulletin 31, 1793-1806.

[48] Menyah , K., Wolde-Rufael, Y. 2010. CO2 emissions, nuclear energy, renewable energy and economic growth in the US. Energy Policy, 38, 2911-2915.

[49] Menegaki, N.A., 2011. Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis. Energy Economics 33, 257-263.

[50] Tugcu, T.C.; Ozturk, I., Aslan, A. 2012. Renewable and non-renewable energy consumption and economic growth relationship revisited: Evidence from G7 countries. Energy Economics 34, 1942-1950.

[51] IEA, 2013, Energy Statistics, 2013 Edition. International Energy Agency, Paris.

[52] World Bank, 2013. World Development Indicators. Washington (DC): World Bank.

[53] Mahadevan, R. and Asafu-Adjaye, J., 2007. Energy consumption, economic growth and prices: a reassessment using panel VECM for developed and developing countries. Energy Policy, 35, 2481-2490.

[54] Levin, A., Lin, Chien-Fu, Chu, Chia-Shang J., 2002. Unit root tests in panel data: Asymptotic and finite-sample properties, Journal of Econometrics, 108, 1-24.

[55] Im, K. S., M. H. Pesaran, Y. Shin., 2003. Testing for unit roots in heterogeneous panels, Journal of Econometrics, 115, 53-74.

[56] Hadri, K., 2000. Testing for stationarity in heterogeneous panel data. Econometrics Journal, 3(2), 148-161.

[57] Engle, R. F. and Granger, C. W. J., 1987. Cointegration and error-correction: representation, estimation and testing. Econometrica, 55, 251-276.

[58] Pedroni P., 1999. Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxford Bulletin of Economic and Statistics; 61: 653–678.

[59] Pedroni P., 2001. Purchasing power parity tests in cointegrated panels. The Review of Economics and Statistics;83(4).

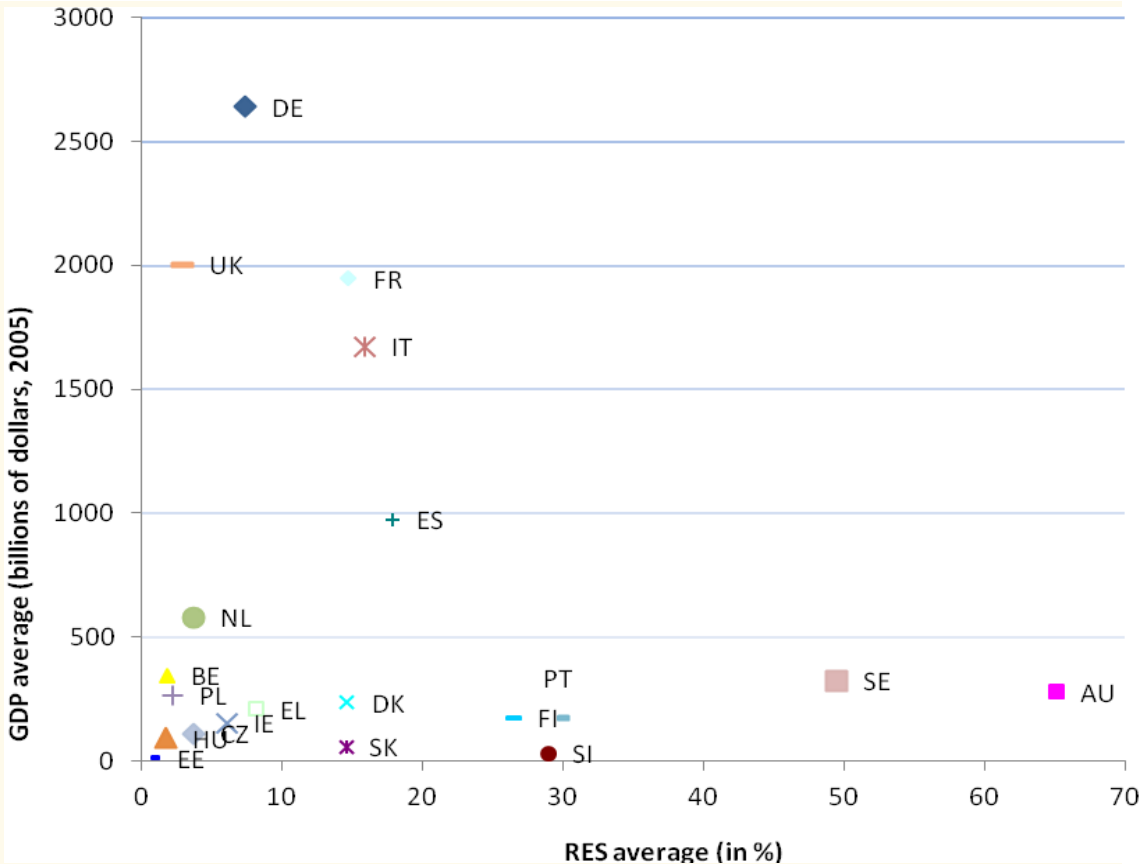
[60] Pedroni P., 2004. Panel cointegration; asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Econometric Theory; 20:597–625.

[61] Kao, C. and Chiang, M.H., 2000. On the estimation and Inference of a cointegrated regression in panel data. Advances in Econometrics; 15:179–222.

[62] Directive 2009/28/EC of the European Parliament and of the Council, of 23 April 2009, on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Official Journal of the European Union, Nº L 140/16, 5.6.2009.

Appendix

Figure A6.1 – Relation between GDP and RES (in average for period 2001-2010) for European countries



Country	Country Code	Country	Country Code
Germany	DE	Greece	EL
Austria	AT	Hungary	HU
Belgium	BE	Ireland	IE
Denmark	DK	Italy	IT
Slovak Republic	SK	Netherlands	NL
Slovenia	SI	Poland	PL
Spain	ES	Portugal	PT
Estonia	EE	United Kingdom	UK
Finland	FI	Czech Republic	CZ
France	FR	Sweden	SE

Source: Own elaboration with data from World Bank World Development indicators, International Financial Statistics of the IMF and Eurostat

Table A6.1 -Descriptive statistics

Variable	Period	Obs	Mean	Std. Dev.	Minimum	Maximum
CO2 kWh	2001-2010	200	430,1065	243,2643	17,46512	1085,721
Ln CO2 kWh			5,821444	0,849131	2,86	6,99
GDP	2001-2010	200	684,1233	843,9022	11,02318	2980,958
Ln GDP			5,733389	1,366776	2,4	9
GDP ^2	2001-2010	200	1175220	2214589	121,5104	8886111
RES	2001-2010	200	16,55141	15,89933	0,227638	66,68632
Ln RES			2,283056	1,153398	-1,48	4,2

Table A6.2 - Correlation matrix and Variance Inflation Factor VIF– Period 2001-2010

	Ln CO2 kWh	Ln GDP	RES	Ln RES
Ln CO2 kWh	1			
Ln GDP	-0.2187***	1		
RES	-0.6108***	-0.0063	1	
Ln RES	-0.5536***	0.1826**	0.8431***	1
VIF		4,72	-	4,72
1/VIF		0.2117	-	0.2117
Mean VIF				4,72

	CO2 kWh	GDP	RES
CO2 kWh	1		
GDP	-0.1362*	1	
RES	-0.5834***	-0.157**	1

Chapter 7

Final Remarks

7.1 Conclusions and Policy Implications

Portugal managed to meet Kyoto Target for the period 2008-2012. In 2011 it showed a level of emissions 16% higher than the 1990 level (its limit was 27%) [1]. However, the goals of reducing emissions are not restricted to this period. In 2009 a new package of environmental measures was adopted at the EU level, known as the 20-20-20 targets: by 2020 there should be a 20% reduction of Greenhouse Gases (GHG) emissions compared with 1990, 20% share of renewable energy in EU energy consumption, and energy improvement by 20%. To meet these goals, it is important to realize which variables affect GHG emissions, particularly the intensity of emissions (emissions by unit of output). It is important to understand the evolution and influence between emissions intensity, energy intensity, and the share of fossil fuels in total energy consumption.

The contributions of this thesis to the energy-related CO2 emissions at sectoral level, are threefold: first, it offers a new econometric approach for the decomposition of CO2 emissions intensity, and its progress, that can serve as a starting point for future research. Second, it presents a hybrid energy-economy mathematic and econometric model for Portugal that is based on economic theory. Third, it helps to explain the changes in CO2 emissions in important sectors of the Portuguese economy, combining normative considerations openly and explicitly with political implications at the European level, considering energy and environmental commitments.

The following conclusions summarize the findings presented in the core chapters of this thesis by answering the objective research posed in the Introduction chapter and concluding with suggestions for future research.

In this research, we observed that most of the energy used comes from fossil fuels and that this percentage is much higher in the manufacturing and energy sectors than that of the average for the Portuguese economy. This explains the relative high value of intensity of emissions in these sectors. With the analysis developed in chapter 2, we can draw conclusions about the evolution of the intensity of CO2 emissions in Portugal and what its main determinants were in the past, and also infer about the behaviour of these variables in the future. This allows us to make a more complete approach, since implementing any policy, in particular an energy or environmental policy, it is important to know not only the past context, but also in what direction the future will evolve, because it is in this timeframe that the policy will have effects. The sectors that have contributed more to reduce the intensity of emissions through the reduction of energy intensity are the manufacture of coke, refined petroleum products and construction. Yet, there are sectors that contributed to reduce energy intensity because of lower production in sectors of the economy such as agriculture, forestry and fishing, electricity, gas, steam and air-conditioning supply, the manufacturing of chemicals and chemical products, the manufacturing of rubber and plastics products, and other non-metallic mineral products, the manufacturing of wood and paper products, and printing.

In chapter 3, the convergence analysis stochastic differences, in the long-term, between industrial sectors, means that accumulated random differences in the short-term constitute an explanation to see if the shocks on those series persist over time. This same evidence is of interest to energy policy makers because, evidence of a random shock can reverse the direction wanted to those variables, among others, those that promote productive efficiency in these sectors with the use of new cleaner technologies. In what concerns sigma convergence, emissions and energy intensity, sectors tend to have similar behaviour, even these similarities are bigger for a sub group of 5 industries of the most polluting manufacturing sectors. There is also convergence in the economic structure which is higher for the aggregated group of 16 manufacturing industries . Therefore, for the intensity of emissions and for energy intensity, there is a trend towards harmonization of sectors for the whole period, which is most evident in the group of 5 industries of the most polluting manufacturing sectors. For emissions by fossil fuel and the structure of the economy there is more harmonization in the group of 16 industries manufacturing sectors.

This is important to understand, specially for Portugal, concerning the progressive increase of regulatory incentives in the industrial sectors of energy, particularly in terms of incentives and public policies that promote such investments to producers operating in those industries. On the other hand, if there is evidence of differences in the long term of being deterministic, this means that the deterministic random components of the series, over time, are diluted. In this case, policy makers do not need to intervene in a certain moment of time, since the same series follows the desired evolution.

Chapter 4 focuses on the effects of the determinants of emissions intensity in theTourism Industry, in six tourism activities: Wholesale and retail trade, Repair of motor vehicles and motorcycles, Transportation and storage, Accommodation and food service activities, Telecommunications, arts, entertainment and Recreation and others services. There is a general convergence of all decomposed effects; the carbon intensity (emissions/consumption of fossil fuels) is the effect that converges more. This means that all sectors became more similar in terms of the mix of fossil fuel used. In the group of Wholesale and retail trade, Transportation and storage, Accommodation and food service activities, the convergence effect is even more stable, which means that in these sectors that directly affect tourism, the evolution of the determinants of emissions are very similar across sectors. This may require more specific and targeted policies for these subsectors included in group activities: Transportation, accommodation and food service activities. The exception is on carbon intensity, which contrary to what happened in the group, all six activities present periods of great divergence (even checking the global convergence in the period). This means that the sectors in this group have a different behaviour, bearing in mind the mix of fossil fuels used, which is related to the most appropriate fuel type to the different economic activities.

In the group of activities that affect tourism in a more indirect way there is convergence in general for all the effects, but most clearly in energy intensity and carbon intensity.

The similarity of behaviour between tourism subsectors towards emissions intensity and their determinant effects (particularly between sectors including hotels, restaurants and transports, or trade in general, that affect the tourism activity directly) could imply equal treatment, although specific to each activity, in relation to energy and environmental policies.

In chapter 5, we used the 'complete decomposition' technique to examine GHG emissions intensity and its components, for the agriculture sector in the 1995-2008 period, for a set of European countries. It is shown that NA effect and LVA effect were the ones that had a greater contribution to the variation of EI. This means that the use of Nitrogen per cultivated area is an important factor of CO_2 emissions and that in those countries where labour productivity increases, emissions intensity tends to decrease.

These results imply that the way to reduce emissions in agriculture would be to provide better training of agricultural workers to increase their productivity, which would lead to a less need for energy and use of Nitrogen. On the other hand, there may be an exaggerated focus on the use of fossil fuels as a source of emissions, while this study shows that the use of Nitrogen represents a more important role in determining emissions than the use of fossil energy.

In chapter 6, we examines the long and short-run causality of the share of renewable energy sources (RES) in the relation between Carbon Dioxide emissions of electricity generation (CO_2 kWh) and real income (GDP) for 20 European countries over the 2001-2010 period. We used Cointegration Analysis and the Innovative Accounting Approach that includes Forecast Error Variance Decomposition and Impulse Response Functions (IRFs). Our results provide supportive evidence for the validity of the Environmental Kuznets Curve (EKC) and suggest that renewable energy can be a potential determining driver of the difference in the emissions-income relations across European countries and a significant way of reducing CO2 kWh. Moreover, the share of renewable energy in electricity output will have significant influence on the shape of the EKC, which will shift downward as RES increases, suggesting lower (environmental) costs of development. These results have important implications. Among others, the significant evidence that the share of renewable energy in electricity output is a potential driver for reducing the carbon emissions in electricity, tends to be large at the early stage of European economic development. With the obtained estimates, we can see that as countries invest more in renewable energy, they can grow without compromising the environment too much, or as they become richer, they don't need to increase proportionally the share of renewable energy to reduce emissions. We can illustrate this with countries with lower income on average for this period, such as Austria or Sweden that made a strong investment in renewable energy and were able to grow without too many emissions. Richer countries, such as Germany, United Kingdom and France, did not need to significantly increase their share of renewable energy in the period 2000-2010, to reduce emissions. If the income level of the country is already very high, a higher percentage of renewable energy will enhance the ease of economic growth without compromising the environment otherwise we do not need to increase renewable energy significantly to reduce emissions.

All that results show a common pattern expected of CO2 emissions in electricity generation after the European Directive 2001/77/EC, and reveal the importance of the interactive impact of renewable energy sources and GDP to reduce the CO2 emissions in electricity generation.

7.1.1 Policy Implications

The results specially on decomposition analysis and econometric decomposition approach show that these ratios are crucial to reducing the CO2 intensity of Portuguese sectors, especially in the industries listed in Group B, particularly in what concerns increasing energy efficiency and the use of renewable energy. Both points focused on European policy (2009/28/CE directive) [2]. European policies are not only focused on market-based instruments (mainly taxes, subsidies and the CO_2 emissions market), but also on the development of energy technologies (especially technologies dedicated to energy efficiency and renewable energy, or technologies for low-carbon) and on the EU financial instruments supporting the achievement of political goals.

On the other hand, a few European Directives were aimed at improving the performance of uncovered sectors by EUETS, for instance, agriculture, transports, tourism and other service activities. As examples we can mention the European Energy Performance in Buildings Directive (EPBD), the Ecodesign Directive, the Biofuels Directive and the Energy Services Directive. However, the sectors mentioned in this study as having greater relevance in determining the emissions intensity and its components are sectors that are already regulated.

In Portugal, the Tourism Industry has made a significant contribution to the economy and involves the transportation and hosting of tourism consumers. The specific characteristics of the tourism industry point towards many energy consumption sources and carbon dioxide emissions channels, such as food services and accommodation, travelling and transportation, shopping and recreation: all of them consume energy and fossil fuels and produce carbon emissions. These tourism activities motivated the research of the relationships between the energy consumption, share of fossil fuel consumption and dioxide emissions.

Energy mix and Energy intensity effects appear as a secondary influence on CO_2 emmissions. This can be related once more with the enterprise structure of portuguese tourism sector. According Beccali et al. [3], Taylor et al. [4], Teng et al. [5], among others, energy use in accommodation and services varies according to the differentiation of the type of accommodation, so that the levels of power consumption will be linked to that housing structure. This indicates that the potential CO_2 emissions are higher in the type of accommodation with higher levels of energy consumption, which is reinforced by the evidence referred by Gossling [6], Warnken et al. [7] and, more recently, Tsai et al. [8], that the energy used per tourist per night is higher in typologies of accommodation and services in which dominate the highest levels of quality, and consequently higher levels of tourist consumption.

On the other hand, the importance of Energy Mix effect in some years, showing the possible substitution between fossil fuels in favor of less polluting ones, can reveal the demand for more sustainable solutions in energy, even in these small installations. Wang and Huang [9] reinforce the idea that factors such as the amount and type of facilities, accommodation services, type of air conditioning system and its configuration, the thermostat temperature and cooling are key factors for the increase in energy consumption and consequently can be the drivers explaining the changes in carbon emissions.

On what concerns policy implication of all the tourism activities, only recently the aviation sector was included in the EU ETS. All other activities were excluded from this market. The aviation sector was brought into the EU ETS on 1 January 2012 through Directive 2008/101/EC [10]. For 2012 the cap on aviation allowances was set at a level equivalent to 97% of aviation emissions in the 2004-2006 reference period and 85% of allowances were given to aircraft operators for free.

The European Commission is taking the first steps to reduce the GHG emissions from the maritime transport industry. The proposed legislation (only for 2018) will oblige owners of large ships using EU ports to monitor and report the ships' annual CO2 emissions, as well as to provide information about the ships' energy efficiency.

An agreement between the European Parliament, Council and European Commission on a further reduction in CO2 emissions from cars is expected to reduce average CO2 emissions from new cars to 95g per kilometre from 2020 (European Commission [11] 2012). This represents a 40% reduction from the mandatory 2015 target of 130g/km. The target is an average for each manufacturer's new car fleet; some models will emit less than the average and some will emit more.

On the other hand, dealing with the energy consumed in the building stock, in particular for heating and cooling purposes, the EU adopted a revised EPBD in 2010. The Member States have to apply minimum energy performance requirements for new and existing buildings, and ensure that by 2021 all new buildings are "nearly zero-energy buildings." (European commission [12] 2013).
All these guidelines, especially at a domestic European level and, or at an international one, are linked to the mitigation mechanism, both in the area of subsidies, which should be granted exclusively in the promotion and development of clean technologies to ensure better energy efficiency, whether in the area of licence trading or shares.

James [13] (2009) supported the premise that currently many countries subsidize some activities or economic sectors activities that emit GHG through the subsidization of fossil fuel prices, which when removed would also work as encouragements to the decrease of pollutant gas emissions. For Thomas and Callan [14] (2010), the negotiation of the GHG limits should be implemented based on the use of the mechanism of tradable emission shares, to ensure the minimization of the difference in marginal cost of mitigation between countries, since the international trade of emission share alone would only decrease the cost of meeting the national emissions limits.

Following these two orientations and taking into account the results found in our study by the explanatory determinants of the CO2 variations at the level of pollution sectors but not part of mitigation plan of the first and second phase of the Kyoto Protocol, namely at the level of tourism industry and agriculture.

All these results, in particular the results reported in Chapter 6, show a common pattern expected of CO2 emissions in electricity generation after the European Directive 2001/77/EC, including the first and part of the second period of the Kyoto Protocol (2005-2007 and 2008-2012). These results are relevant to identify that the share of renewable energy sources can be a potential determining driver of the difference in the emissions-income relation across European panel country level. Other hand, these results claim the importance of the points highlighted by the European policy (2009/28/CE directive) [62]. European policies are not only focused on market-based instruments as energy or environmental taxes/subsidies or the European Carbon Market (ECM), but also on the improvement of technology that focuses on energy efficiency and renewable energy and on the EU financial instruments supporting the achievement of political goals.

All these guidelines, especially at a domestic European level, and/or at an international one, are linked to the mitigation mechanism, which should be granted exclusively in promotion and development of clean technologies to ensure better energy efficiency. It seems appropriate to suggest that the success of national mitigation policies will arguably require the normalization between different marginal abatement costs at the level of those very same levels of economic activity in the countries enrolled in the agreement, based on cost effectiveness which could be achieved through market based instruments, a solution found for the activity sectors which are members of the agreement.

If countries agree to adopt the same level of taxation in these polluter sectors (sectorial level harmonized fees), the marginal costs of abatement would tend to equalize between countries at a sectoral level, in line with the international policy instruments of emissions mitigation in force, which would require greater commitment and responsibilities among countries.

7.1.2 Limitations

Energy security and environmental challenges are forcing many economic sectors to find energy alternatives to fossil fuels. Both renewable and nuclear energy sources are believed to provide some solutions to the problems of energy security and environmental degradation (Vaillancourt et al.[15] (2008); Adamantiades and Kessides, [16] (2009).)

Nuclear energy plays an important role not only in meeting the energy needs of many countries, but also in mitigating emissions. The use of non-hydro emerging renewable energy sources (wind, solar, geothermal, tidal, wave, and bio-energy) exhibits the fastest rate of increase, with most of the increase in power generation, (Tolon-Becerra et al, [17]).

For this purpose, the access to information of non-hydro emerging renewable energy sources at sectoral level in Portugal and in Europe for the period of 1995-2009 was not available to study the role of energy-related CO2 emissions and their policies implications in Europe, and particularly in Portugal. The requirements imposed by our methodology (Decomposition analysis, Convergence analysis and econometric decomposition approach) which require data about energy-related CO2 emissions and their decomposed drivers, could not be met.

7.1.3 Suggestions for future research

Based on the findings of this thesis, the following suggestions are avenues for future research concentrated on refining the mathematic/econometric methods for realizing an assessment of energy-related CO2 emissions.

(1) Examining the energy-related CO2 emissions intensity in Tourism over 2000-2008 in Portugal: Decomposition Analysis

The objective of this work is to identify the effects in which the intensity of CO2 (carbon dioxide) emissions (A) in tourism can be broken down and analysed, as well as their evolution and which of them has more importance in determining the intensity of emissions. For that, we used the 'complete decomposition' technique in the 2000-2008 period, for seven tourism categories in Portugal: (i) Accommodation services; (ii) Restaurants and similar; (iii) Transport; (iv) Travel agencies and similar and (v) Cultural, sports and recreational services. The change of CO2 emissions can be decomposed into six effects for each tourism subsector *i*, and for each year *t* of the studied period: (i) the changes in CO2 emissions compared to fossil fuels consumption, that is, carbon intensity (CI effect), (ii) the changes in fossil fuels consumption towards total energy consumption, that is, energy mix (EM effect), (iii) the consumption of energy by tourism consumption on the economic territory, that is, energy intensity (EI effect), (iv) The tourism consumption by the value added generated by tourism

(VA effect), (v) the value added generated by tourism subsectors divided by total value added generated by tourism (ES effect), and (vi) Value added generated by tourism (TA effect).

The analysis of the first three effects allows us to evaluate aspects such as: the fossil fuel quality, the substitution between fossil fuels, the installation of abatement technologies, the substitution of fossil fuel for renewable energy sources, the energy efficiency of tourism activities as well as technology choices, energy conservation techniques and investments for energy saving. The last three effects give us signals about: the influence of relative tourism demand face to national tourism supply, on the CO_2 emissions; the diversification of tourist products among the various subsectors analyzed and the preferences of the consumer; the evolution of Portuguese tourism production and its impacts on the environment.

(2) A new frontier approach to model the relationships among Production, Carbon Dioxide Emissions, Fossil Fuels Consumption, Capital and Labour in European Countries

European economies are presently facing serious environmental problems, related in part with the emissions of greenhouse gases (GHG), in particular Carbon Dioxide (CO_2). This environmental conscience together with the alleged commitments to adjust the present course has lead to the implementation of policies that change the harmful environmental behaviour, in several European countries. The Kyoto Protocol and the 20-20-20 strategy are examples of such policies.

Economic activities use production factors as energy resources, labour and capital to produce desirable goods and services, but simultaneously produce undesirable outputs, such as CO_2 emissions. According to IPCC report (2007), the energy consumption of fossil fuels such as coal, oil and natural gas is the major contributor towards the increase of GHG emissions including CO_2. Thus, if the energy is used inefficiently, this will lead to higher emission levels. Therefore, the efficiency in energy use becomes of greater importance, coupled with rising prices of fossil energy resources. It becomes necessary to base the economic, energy and environmental policies in the efficient use of resources, in particular in energy efficiency.

Thus, this study aims to evaluate the resource and environment efficiency problem of European countries. We specify a new stochastic frontier model where Gross Domestic Product (GDP) is considered as the desirable output and CO2 emissions as the undesirable output. Fossil fuel consumption, Capital and Labour are regarded as inputs. GDP is maximized given the values of the other three variables. The study is divided into two distinct periods: 1995-2004 and 2004-2011. This division is related to the implementation of Kyoto Protocol in 2005, and will allow us to evaluate the difference between the levels of efficiency before and after the establishment of environmental targets. In the second period we will do a sensitivity analysis by simulating the levels of efficiency with the real levels of CO2 and the levels intended by the Protocol for each country.

Since stochastic frontier models are typically ill-posed, many researchers claim the urgent need to develop robust estimation techniques. Recently, maximum entropy estimators are used in the literature as powerful alternatives to traditional estimators, such as the maximum likelihood or the corrected ordinary least squares, in the estimation of stochastic frontier models. In this proposed study, a parametric stochastic frontier approach using some maximum entropy estimators, namely the generalized maximum entropy and the generalized cross-entropy, is proposed as an alternative to the Kaya identity. A novel maximum entropy approach to assess technical efficiency, which combines information from the data envelopment analysis and the structure of composed error from the stochastic frontier approach without requiring distributional assumptions, is presented in this work.

References

[1] Portuguese Environmental Agency. Portuguese National Invert Report on Greenhouse Gases 1990-2011. Submitted under the United Nations Framework convention on Climate change and the Kyoto; 2013.

[2] EU Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing directives 2001/77/EC and 2003/30/EC; 2009.

[3] Beccali, M., La Gennusa, M., Lo Coco, L., & Rizzo, G. An empirical approach for ranking environmental and energy saving measures in the hotel sector. Renewable Energy 2009; 34: 82-90.

[4] Taylor, S., Peacock, A., Banfill, P., & Shao, L. Reduction of greenhouse gas emissions from UK hotels in 2030. Building and Environment 2010; 45: 1389-1400.

[5] Teng, C. C., Horng, J. S., Hu, M. L., Chien, L. H., & Shen, Y. C. Developing energy conservation and carbon reduction indicators for the hotel industry in Taiwan. International Journal of Hospitality Management 2012; 31: 199-208.

[6] Gössling, S. (2002). Global environmental consequences of tourism. *Global Environmental Change, 12 (4)*, 283-302.

[7] Warnken, J., Bradley, M., & Guilding, C. Eco-resorts vs. mainstream accommodation providers: an investigation of the viability of benchmarking environmental performance. Tourism Management 2005; 26: 367-379.

[8] Tsai K-T., Lin, T-P., Hwang, R-L. & Huang, Y-J. (2014). Carbon dioxide emissions generated by energy consumption of hotels and homestay facilities in Taiwan. *Tourism Management, 42,*13-21.

[9] Wang, J. & Huang K. (2013). Energy consumption characteristics of hotel´s marketing preference for guests from regions perspective. *Energy, 52,* 173-184.

[10] EU Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amends Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community.

[11] European Commission (2012). 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the regions', *Cars*

2020: Action Plan for a competitive and sustainable automotive industry in Europe, COM 2012/636 final, Brussels.

[12] European Commission (2013). 'Green Paper', *A 2030 framework for climate and energy policies*, COM 2013/169 final, Brussels.

[14] Thomas, J. M, Callan, S. J. (2010). *Environmental Economics and Management: Theory, Policy, and Applications. 5th edition* (5th ed.). Mason, OH: South-Western, part of Cengage Learning.- ISBN-13: 9781439080634.

[15] Vaillancourt, K., Labriet, M., Loulou, R., Waaub, J.-P., 2008. The role of nuclear energy in long-term climate scenarios: an analysis with the World-TIMES model. Energy Policy 36 (7), 2296–2307.

[16] Adamantiades, A.& Kessides, I., 2009. Nuclear power for sustainable development: Current status and future prospects, Energy Policy, 37: (12) , 5149-5166.

[17] Tolon-Becerra A, Lastra-Bravo X, Bienvenido-Barcena F. Proposal for territorial distribution of the EU 2020 political renewable energy goal. Renew Energy 2011;36:2067e77 (13)