UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master's Thesis

ANALYSIS OF THE CARBON FOOTPRINT EVOLUTION IN SPAIN: ECONOMIC DRIVERS

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Madrid, July 2019

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SUMMARY

There is now an almost unanimous agreement that emissions of greenhouse gases contribute in an essential way to the change of the global climate. For decades, the increasing human activity has led to more emissions. That is why most of the regulatory bodies have already taken action under this context. Several energy policies are highlighted throughout this document. Some of them include European energy policies and United Nation's agreements like Kyoto and Paris. All of them share the common objective of stimulating the reduction of greenhouse gases emissions as much as possible, deal with climate change, emissions monitoring and setting targets for the upcoming years. Spain has gradually adapted to these changes with the publication of national laws and regulations as well as the definition of national targets like the National Energy and Climate Plans (NECPs) document.

One of the most harmful gases within the greenhouse gases is carbon dioxide. CO_2 emissions evolution can be affected by various factors such as energy efficiency, the structure of the economy, fuel prices, improvements in processes or technological advances. These variables also alter the performance of the energy intensity indicator that has a close relationship with CO_2 emissions.

Because the concept of CO_2 emissions implicitly includes factors that generate opposite effects, sound conclusions could not be extracted from simply observing the trend of the historical evolution of this large aggregate magnitude. This leads to the necessity of introducing econometric analysis.

Former literature has already placed some suggestions for the study of the decomposition of environmental and energy indicators. Some of them only cover approximately until the year 2007, others did not decompose the effect into a very detailed sectoral level. Also, decomposition analysis has been applied to other environmental or energy indicators such as energy intensity.

The aim of this project is to assess how these factors have affected the evolution of CO_2 emissions in Spain from 2008 to 2016. It goes a little bit further compared to other studies by including the best level of detail possible, reasonable number of decomposition factors and update the information. This gives the opportunity of providing a national outlook of the Spanish carbon footprint. The impact the productive sectors of the economy whose information is available had in each effect is presented.

The Logarithmic Mean Divisia Index (LMDI) has been selected as the core methodology based on the evaluation of the main classification of methodologies proposed for decomposition analysis, statistical information available and the desired format for the results. It stands out for providing a perfect decomposition with no residual component, ease when computing with either in an additive or multiplicative form, consistency with

aggregation and possibility of incorporating more than two factors. The main idea behind this technique is that is able to decompose the variation of an indicator into the sum or multiplication of different effects.

As a result, the variation of CO_2 emission between two years has been decomposed into four different effects. The intrasectoral effect related to energy intensity, emission coefficient related to fewer pollutant technologies, a structural effect related to the activity mix by sub-category and activity effect associated to the change in the overall level of the activity.

If a decomposition of the trend of CO_2 emissions evolution is made from 2008 and 2016, following the application of index decomposition and considering the available statistical information, has yielded to the results represented and summarized in Table 1. It shows the impact each sector had on the aggregate indicator of Spanish CO_2 emissions measured in millions of tons of equivalent CO_2.

Table 1: Spanish CO2 emission index decomposition from 2008 to 2016 in Mton equivalent CO2. Additive decomposition

		Additive decomposition (Mton CO2)					
		INTRASEC	**COEFF EM**	**STRUCTURAL**	**ACTIVITY**	**GLOBAL**	**%**
INDUSTRY	Iron and Steel Industry+Non-ferous metal industry	1,0779	-4,4532	-2,8630	-0,2403	-6,4785	8,7%
	Chemical and Petrochemical industry	3,1779	-9,4328	3,7963	-0,3652	-2,8237	3,8%
	Non-metallic Minerals (Glass, pottery & building mat. Industry)	-2,1595	5,5542	-21,7408	-0,4658	-18,8120	25,4%
	Transport Equipment	-1,6112	-0,4364	0,2092	-0,0381	-1,8765	2,5%
	Machinery	-0,4823	-1,2549	-0,3140	-0,0443	-2,0954	2,8%
	Mining and Quarrying	3,0412	-4,9576	-1,8298	-0,0433	-3,7894	5,1%
	Food and Tabacco	0,0367	-0,8881	0,4876	-0,0698	-0,4336	0,6%
	Paper, Pulp and Print	-0,0967	-0,1262	-1,5212	-0,0754	-1,8194	2,5%
	Wood and Wood Products	0,4803	0,3363	-0,9149	-0,0241	-0,1223	0,2%
	Construction	2,0427	-2,3458	-0,9525	-0,0185	-1,2741	1,7%
	Textile and Leather	-0,1090	-0,3075	-0,2980	-0,0188	-0,7333	1,0%
	Non-specified (Industry)	-1,3557	0,8241	-0,7248	-0,0283	-1,2847	1,7%
TOTAL INDUSTRY		**4,0423**	**-17,4877**	**-26,6658**	**-1,4318**	**-41,5430**	56,0%
TRANSP ORT	Rail+Road+ Pipeline Transport	-6,2110	-5,0803	0,3379	-0,4457	-11,3991	15,4%
	International+Domestic aviation	-2,7233	2,1525	3,3974	-0,1599	2,6667	-3,6%
	Domestic Navigation	-2,6713	-0,0261	0,4644	-0,0372	-2,2703	3,1%
	Non-specified (Transport)	1,3120	-0,5335	0,1506	-0,0079	0,9212	-1,2%
TOTAL TRANSPORT		**-10,2936**	**-3,4875**	**4,3503**	**-0,6506**	**-10,0814**	13,6%
OTHER SECTORS	Services	2,5567	-14,1236	2,5298	-0,4342	-9,4713	12,8%
	Residential	-19,9760	-9,6990	18,5513	-1,1244	-12,2481	16,5%
	Agriculture / Forestry	-2,6675	1,1798	1,5625	-0,1356	-0,0609	0,1%
	Non-specified (Other)	-4,0842	3,1945	0,1306	-0,0396	-0,7987	1,1%
TOTAL OTHER SECTORS		**-24,1710**	**-19,4483**	**22,7741**	**-1,7338**	**-22,5790**	30,4%
TOTAL		**-30,4223**	**-40,4235**	**0,4586**	**-3,8162**	**-74,2034**	100,0%

The study carried out shows that emissions have decreased in -74.20 Mton between 2008 and 2016, motivated by energy efficiency and less polluting technologies according to values of intrasectoral and emission coefficient effects respectively. This change is led by the reduction of sectors like residential, services and industry. The structural effect has barely changed between years, but it can be seen that an increase in activity from the transportation and the residential sector has been compensated with a general decrease in the industry sector.

There are many reasons that explain these values. Spain is experimenting an energy transition towards a reduction of energy intensity, shifting to more energy efficient technologies, trying to replace more conventional ones. Reduction in energy intensity within the services sector is due to an improvement in energy performance in buildings, demand management, air conditioning systems, and government programs to foster efficient management of consumption. Intensification of the tourism activity has led to an increased participation in the economy of the services sector. Another possible reason that justifies these results is a process of restructuring within the sector, which is the case of the non-metallic minerals industry and the structural component. Change in prices like Brent or natural gas with almost a 60-70% reduction from 2008 values, caused an increase in economic participation of the chemical and petrochemical industry. Apart from that, a combination of incentive programs on the promotion of renewable energy sources and climate conditions of that year can change national emissions which is the case of the year 2016 (Table 5Table 1) with high participation of hydro in the electricity generation mix.

In conclusion, this document shows that economic and energy efficiency factors have a decisive importance in the Spanish emissions evolution. The regulatory area plays a fundamental role when it comes to ensure and determine the evolution of these factors. This kind of studies can help to guide regulatory bodies in the implementation of appropriate incentives to ensure the compliance of the ambitious targets to fight against climate change.

TABLE OF CONTENT

1. INTRODUCTION

With high economic development activities, more Greenhouse Gases (GHG) are being emitted, which cause global warming with negative consequences. Some examples include surface temperature increase, rise in sea level, effects on biological cycles or even floods. There is now an almost unanimous agreement that emissions of GHG contribute in an essential way to the change of the global climate. This climate change will have a far-reaching consequence for all life on Earth [1].

The most abundant GHG in the Earth's atmosphere are carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons. Their concentrations are dependent on the balance between the functions that are capable of creating and destroying these gases. Anthropogenic activities tend to increase these concentrations. Alarmingly, since the industrial revolution, the GHG levels in the atmosphere have increased significantly.

GHG come into place as follows. They are defined as a substance that can sufficiently absorb infrared radiation and emit heat. Solar radiation is partially distributed among the absorption at the Earth's surface and another portion is reflected back. If there is any presence of GHG in the atmosphere, some portions of this reflected heat are preserved within the planet. As a result, it warms the air inside but does not allow this warmed air to get out. The more these gases exist, the more heat is prevented from escaping into space and, therefore, the earth warms up. Despite naturally helping the planet maintain a stable temperature range, high concentrations of these particles can rise temperatures to unwanted levels [3].

The most harmful gases within GHG are methane and carbon dioxide. This document is focused on the latter. Burning of fossil fuels (coal, natural gas, and oil), solid waste, deforestation or the result of certain chemical reactions are the main causes that generate CO_2, which in principle should be then absorbed by oceans and plant during the process of photosynthesis. They contribute to the greenhouse effect by absorbing infrared radiation and indirectly affecting the concentration of ozone in the stratosphere.

Because of these undesirable circumstances, most of the regulatory bodies not only at a national but a worldwide level, have already taken action under this context. For instance, European energy policies in the last decades focused on developing environmental and energy efficiency policies that try to stimulate as much as possible the reduction of GHG emission. Not to mention the so-called official agreements between the United Nations member, the Kyoto protocol and the Paris Agreement. Both aimed to deal with climate change and set a variety of targets which involve, among other things, to design a plan to improve energy efficiency, increase the share of renewable energy sources in the technology mix, and of particular interest in this project, the emission reduction. This document will dedicate a specific chapter to give a brief overview of the evolution of the regulatory framework regarding GHG emissions.

Another additional example illustrating the relevance the CO_2 emissions has today is that there are specific organizations dedicated to analyze and overcome these challenges. Figure 1 gives a general overview of the CO_2 emissions balance in Spain in 2016 using a Sankey diagram elaborated by an organization whose main objective is to promote and discuss a sustainable development model for our society [2]. This figure represents the contribution and flow of various energy commodities (fuel, heat, and electricity) into the different sectors of the economy in Mt CO_2. As it could be seen, most of the main sources of energy come from pollutant technologies such as oil, gas, coal to supply the different consumption sectors.

This diagram could be subject to modifications depending on several factors. Efficiency and technology improvements are elements that directly influence emissions performance. Nevertheless, there are some other implicit and uncontrollable elements like population, Gross Domestic Product or GDP, climate conditions or international trade that also contribute to emissions. Consequently, by looking just at diagrams of CO_2 evolution, it gives very limited information on any underlying information and other factors that can affect its performance. Also, it should be compared at the same time with other direct and implicit factors so as to really understand its evolution.

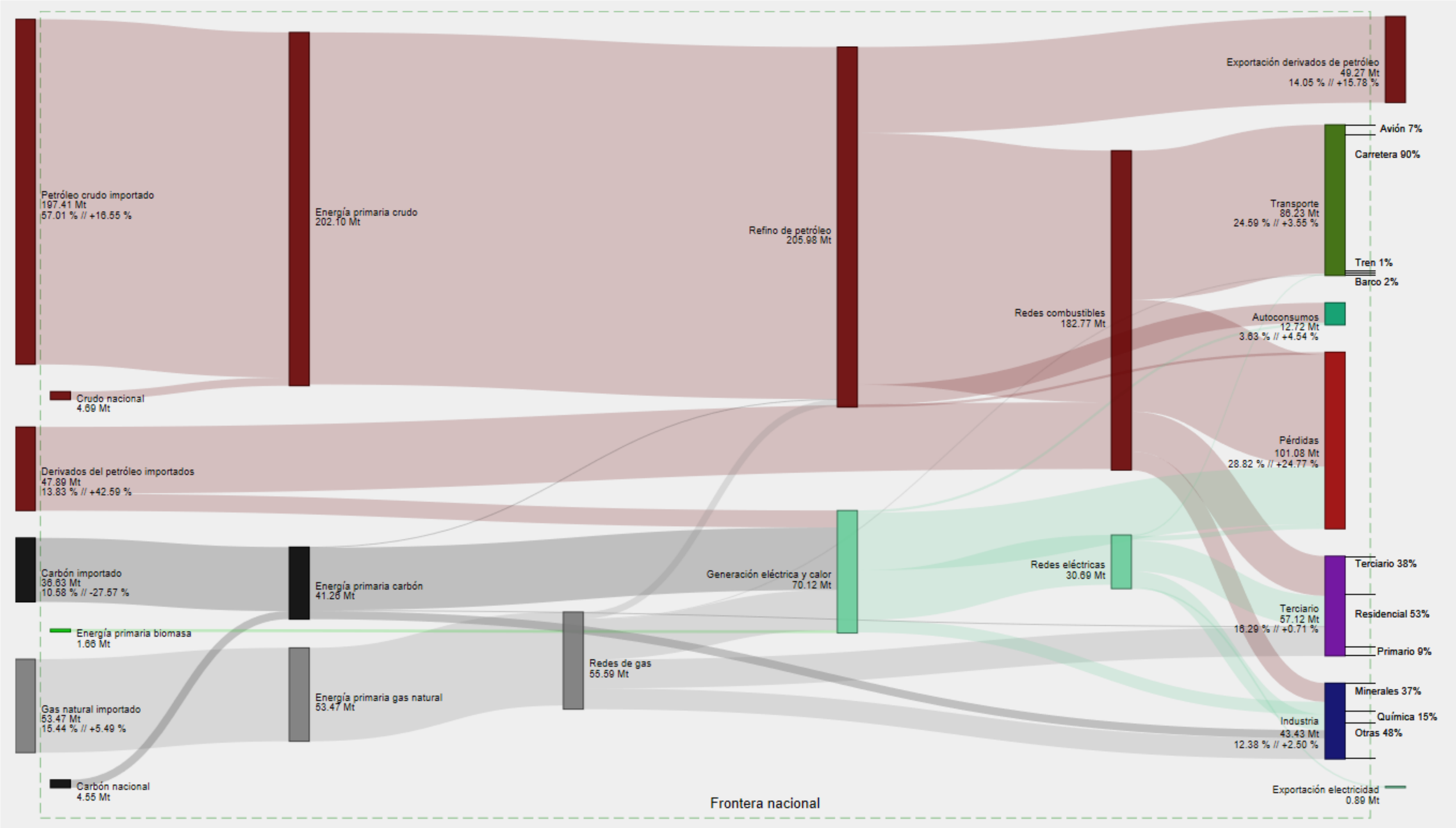


Figure 1: National emissions balance in Spain. Mton of CO2 (year 2016). Source:[41]

1.1 MOTIVATION AND OBJECTIVES

There are a variety of reasons why this project emerges. First and foremost, it will provide information to understand the evolution of Spanish CO_2 emissions. This could be owing to not only direct improvements such as efficiency or changes in technology or fuels, but also less controllable situations like economic evolution. Consequently, it arises the necessity of giving a national outlook.

This project can be summarized by the next list of objectives.

- This project will tackle the analysis of the Spanish carbon footprint across the years 2008 and 2016. This is because it is the period in which all the information required is available.

- Disaggregation of CO_2 emissions into different consumption sectors such as industry, transportation and other sectors such as services and residential. At the same time, it will also be decomposed into different technological, structural and economic effect using index decomposition. It will be provided the largest level of disaggregation possible following available statistical information.

- Identify possible responsibility sources of the performance of CO_2 emissions by analyzing each former effect.

- Understand the Spanish effectiveness when attempting to reduce CO_2 emissions across those years in order to comply with both national and international regulatory requirements.

1.2 METHODOLOGY, RESOURCES AND STRUCTURE OF THE THESIS

Firstly, if the objective is to understand and evaluate which was the role of the economy and technology at a sectoral level in the evolution of the CO_2 emission, it is necessary to cover a sufficiently long period. Despite the original target of assessing years from 2005 to 2016, due to limitations of the statistical resources, it has been reduced to 2008 and 2016.

CO_2 emission evolution, as well as GDP and Gross Value Added (GVA), are found with the best level of disaggregation by sectors in the Statistic National Institute. In order to convert the economic indicator at current prices into constant values, it has been used the World Bank's GDP deflator. Final energy consumption by sector and energy balances are obtained from the official statistical organization of Eurostat.

The methodology implemented in this study consists of gathering enough statistical parameters that are implicitly related to CO_2 emission performance. With that information, the emissions will we decomposed into different indexes following the Divisia methodology, more specifically the Logarithmic Mean Divisia Index or LMDI I.

The structure of this document will be as follows. It begins with a short introduction to the topic, defining the objectives this study wants to pursue and the methodology implemented. After that, there is a chapter dedicated to the state of art of the subject. This essentially involves describing former studies of different authors related to this field and how they propose different theories and methodologies to overcome the analysis of CO_2 emissions together with other environmental indicators. Secondly, it is interesting to provide some background about former regulatory standards in the framework of dealing with climate change and GHG reduction, at both a global level and European level. It also mentions some future European and national targets for the upcoming decades.

The next chapter is exclusively dedicated to the methodology of index decomposition. It covers introduction, some background about energy intensity, the historical development of the mathematical formulation of index decomposition and classifications. Selection of the most suitable index decomposition methodology according to the input data and the presentation of the desired results. Application of this methodology to CO_2 emissions and description of the necessary statistical information, along with limitations and adaptations to the study. Final results are presented and analyzed in detail and ending the document with final conclusions and future studies.

2. STATE OF ART

This section presents a brief background of the related subject. A survey of the literature, most of them being academic research, on the areas that are relevant to this topic are presented. It gives not only a summary of those works but also identifies gaps that this thesis tries to overcome. Also, it provides an outline of important pieces of regulation and agreements that introduce a set of commitments for the reduction of GHG emissions.

2.1 FORMER STUDIES

Several environmental and energy studies tried to analyze which are the key drivers that determine the performance in the CO_2 emissions. Some of them decompose this variable into different indexes, while others implemented alternative methodologies. According to literature, index decomposition has also been used for other environmental indicators such as energy intensity.

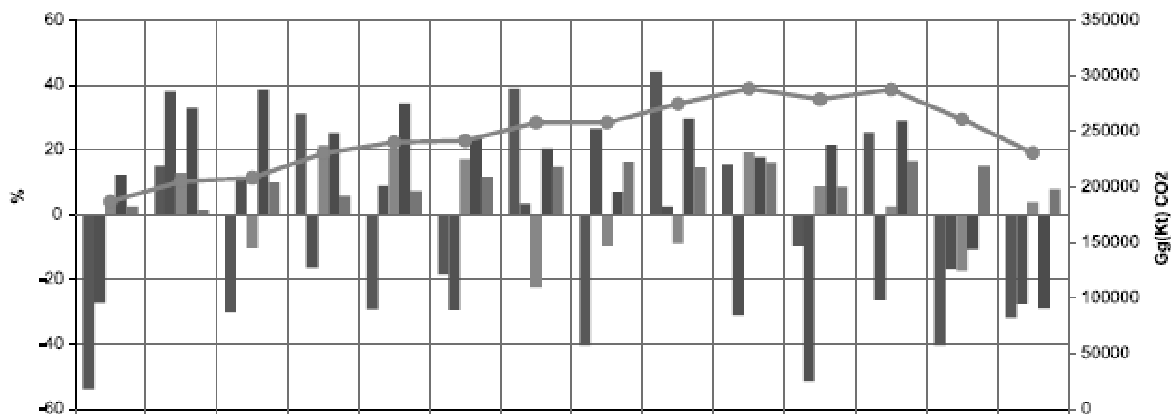
Firstly, Alcántara et al [36] assessed why the growth of GHG in Spain was far larger than the Kyoto protocol target during 1990 and 2007. In order to do so, it was implemented a factorial decomposition methodology very similar to the LMDI technique, transforming the GHG emissions variable into a carbonization effect, transformation effect, intensity effect, and scale effect. It enabled the possibility of having a first assessment on the relationship between economic, technological and GHG emissions variables. The final conclusion was that because of an increase in the production level, that is the scale effect, emissions were constantly rising. The remaining effects that should have changed the growth trend of emissions, has not moderated this increase. Table 2 displays an example of the results obtained in this study. Every year is decomposed into four effects measured in percentage over the base year. However, this study does not contemplate the option of sectoral disaggregation.

Table 2: Contribution of different effects into the GHG emissions in %. Source:[36]

	C/EP	*EP/EF*	*EF/Y*	*Y*	*C*
1995	-1,3	2,6	3,8	8,2	13,3
2000	-0,9	-2,1	7,5	31,7	36,2
2005	3,3	-8,7	14,8	54,1	63,5
2007	0,0	-8,3	4,3	66,7	62,6

Secondly, Naminse et al [4] investigated the relationship among economic growth, energy intensity, and CO_2 emissions in China using static, dynamic regressions and granger causality analysis with an econometric model. The results show that by comparing these values, since China is a country with a heavy reliance on coal consumption, they all had a clear relationship with CO_2 emissions. China is classified as one of the largest CO_2 emitting countries in the world. This article suggests that environmental technologies should be improved through efficiency-enhancing strategies.

The paper elaborated by Cansino et al [5] studied the role of RES in Spain as a factor to balance the driving force of CO_2 emissions. Other factors such as energy efficiency are also considered. Multisector industrial analysis based on Log- Mean Divisia Index Method (LDMI I) was conducted for the 1995 to 2009 period. Data came from the World Input-Output database. There are five factors decomposition to identify, quantify and explain the main determinants of this variation. The main factors are carbon intensity factor, energy intensity factor, structural composition of Spain's economy, the economic activity factor and population. Findings show that RES acted in detriment to the drivers of CO_2 emissions. Summary of results of this article is presented in Figure 2 in combination with an annex with tables explaining each of the industrial productive sectors.



	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
CI	-54,01	15,12	-29,94	31,25	-29,07	-18,45	39,03	-40,42	44,32	15,60	-9,53	25,47	-40,33	-31,84
EI	-27,21	37,92	11,50	-16,17	8,95	-29,26	3,37	26,57	2,51	-31,20	-51,44	-26,44	-16,62	-27,57
ES	3.95	12.81	-10.12	21.42	20.27	17.26	-22.40	-9.59	-8.78	19.25	8.70	2.59	-17.44	3.90
EA	12,30	32,85	38,53	25,29	34,37	23,33	20,52	7,13	29,82	17,77	21,64	28,86	-10,57	-28,82
P	2,53	1,30	9,91	5,87	7,33	11,70	14,67	16,29	14,58	16,17	8,69	16,64	15,03	7,86
CO2	186,848	204,897	208,314,	230,365,	240,269,	241,694,	258,020	258,016	274,868	288,531	278,846,	287,621,	260,911,	230,727,

Figure 2: Decomposition of the CO2 emissions. Source[5]

Finally, another study that it is worth mentioning is the one proposed by Mendiluce [21]. This document covers several subjects to understand the evolution of the energy intensity in Spain. It has dedicated two different sections to assess the decomposition of both energy intensity and CO_2 emissions through the period between 1995 and 2005 using the LDMI methodology. Energy intensity is broken down into structural and intrasectoral effects and it incorporates two additional effects for the analysis of GHG emissions. The level of disaggregation is limited since it is afterward compared at a European level where databases differ.

In conclusion, this thesis tries to enhance the available literature. Some of the previously mentioned work covers the analysis only until approximately the year 2007. Besides, sometimes the former articles did not decompose the effect into a very detailed sectoral level. Some of them did it at a global level, others only considered the industrial sector and very little of them consider a sensitive level of detail. This project tries to go a little further and provide even more detailed information, a reasonable number of decomposition factors and update the results and information extracted from year 2008 to 2016.

2.2 REGULATORY FRAMEWORK: CLIMATE AND ENERGY TARGETS OVERVIEW

2.2.1 UNITED NATIONS AND EUROPE

As introduced before, developed countries are principally responsible for the high levels of GHG emissions in the atmosphere as a result of more than a century of industrial activity. The creation of the United Nations Framework Convention on Climate Change (UNFCCC) in 1994, represented the first international agreement that recognized the importance of the problem and the need to seek solutions. Their aim is to prevent dangerous human interference with the climate system by stabilizing GHG concentrations in the atmosphere, ensuring food production safety and allowing economic growth in a sustainable way [6].

The first official compromise on emission limitation was the so- called Kyoto protocol which was adopted in 1998. It committed industrialized countries, including the ones in transition to a market economy listed in Annex I of this protocol, to limit their emissions according to commitments inscribed in Annex B. Article 3 stated officially that "Parties included in Annex I shall, individually or jointly, ensure their aggregate anthropogenic carbon dioxide equivalent emissions of GHG do not exceed their assigned amounts, with a view of reducing their overall emissions of such gases by at least 5% below 1990 levels in the commitment period 2008 to 2012" [8]. Parties had certain flexibility of application of such commitments, although the protocol suggests three market-based mechanisms to meet their targets. These are international emission trading, clean development mechanism and joint implementation [9]. Later on, in 2012 there was an amendment to the Kyoto protocol in Doha. It included a second period of commitment from 2013 to 2020 and a revised list of GHG to be reported by Parties.

In 2015 the UNFCCC adopted a new agreement that replaced the former Kyoto protocol, the Paris Agreement. A new legally- binding framework for an internationally coordinated effort to tackle climate change. Declares the objective of "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1,5°C above pre-industrial levels" [10]. Moreover, some other key aspects of this agreement are reaching a global peaking of GHG as soon as possible, enhancing sinks and reservoirs for GHG, strengthening national adaptation efforts. For the first time, all countries will develop plans on how to contribute to climate change mitigation and communicate their proposals and contributions to the Secretariat of the Convention [11]. Unlike the Kyoto protocol, this new agreement does not compromise each Party with a specific emission reduction target. Instead, it depends on voluntary mitigation contributions that over time should be more ambitious. Every country should submit their nationally determined contributions (NDCs) which includes requirements that all Parties report regularly on their emission and implementation efforts. It will be assessed every five years their collective progress so as to achieve the purpose of the agreement.

Following the above agreements, the European Union (EU) adopted a number of legislative and regulatory actions that will enable them to deliver on its commitments to reduce GHG. Several official documents have been published but this document will present part of them as well as key proposed targets.

EU has been at the forefront of international efforts to fight against climate change. Following the requirements for the Kyoto protocol, they established a load distribution between their members in order to achieve a global GHG reduction of 8% [7]. All EU countries, which include Spain, are required to monitor their emissions under the EU's GHG monitoring mechanism, setting internal reporting rules. The reporting covers, emissions of seven greenhouse gases, projections, policies and measures to diminish GHG emissions, national measures to adapt climate change, low-carbon strategies ..etc [12].

On top of that, EU's NDC under the Paris agreement is to reduce GHG, larger share of renewables energies and saving on projected EU final energy consumption, all of them by at least 20% by 2020 compared to 1990 under its wider 2020 climate and energy framework. However, these targets were set by EU leaders in 2007 and enacted in legislation in 2009 mainly through the implementation of an Emission Trading System. It was originated when the European Council adopted a global plan of action in the energy field for 2007-2009, which included the 2020 horizon target. In 2014, they officially published even more ambitious targets for the period from 2021 to 2030. They are at least 40% cuts in GHG, 32% share of renewable energy and 32,5% improvement in energy efficiency. The next and most recent step was taken on November 2018 when the Commission presented its strategic long-term vision for a modern, competitive and climate-neutral economy by 2050.

These targets are supported by several European energy policies, working in a number of areas to make this happen. Some of them are presented hereinafter. The European Energy policy has three main pillars which are an internal market, security of supply and environment. In developing an energy policy for Europe, the European Commission presented a set of proposals for the purpose of promoting the internal power market, known as "Third Package". In turn, in 2008 a new package on climate and energy is unveiled called "Green Package" aimed at achieving the targets set out in the 2020 strategy. It was divided into four directives aim to promote renewable energy, GHG emission trading system, GHG emissions monitoring, and carbon dioxide storage. After some years, in 2015, the Energy Union was launched. It focused on several objectives where the decarbonizing the economy is presented. After that, the European

Commission has published several packages of measures and regular reports, monitoring the implementation in order to ensure that the strategy is achieved. Finally, the most recent and as well as important piece of legislation regarding the energy field is the Clean Energy Package (2016). The EU has agreed "a comprehensive update for its energy policy framework to facilitate the transitions away from fossil fuels towards cleaner energy and to deliver on the EU's Paris Agreement commitments for reducing greenhouse gas emissions". They are divided into eight legislative acts which could be classified into energy performance in building, renewable energy, governance regulation, electricity market design, and energy efficiency. They updated the 2030 objectives of renewable participation in the energy mix and energy saving improvement to 32% and 32,5% respectively. After political agreement by the Council and the European Parliament in 2018 and early 2019, it is expected that it enters into force by summer 2019. It is necessary for EU members to transpose the new directives into national law within one or two years [14]. Also, according to the Governance regulation of the Clean Energy Package, all member states are obliged to submit an integrated National Energy and Climate plans (NEPC) for the period 2021-2030 and submit their draft plans by the end of 2018 [15].

2.2.2 SPAIN: FUTURE STRATEGY

As a member of the European Union, Spain faces strong commitments derived not only from the United Nations agreements but also for the new goals highlighted above by the European Union. In the framework of the Kyoto protocol, the European agreements allowed Spain to increase in GHG of 15% based on 1990 levels for the period from 2008 to 2012. This target was tailored to the relative wealth of each country at the time the agreement was developed. Expressed as percentages of emissions in a chosen base year and translated into an exact national cap on GHG emissions for the whole 2008-2012 period. From 2013 to 2020, in the same way as the other Member States of the European Union, the CO_2 emissions corresponding to the most electro intensive sectors when it comes to energy use (generation, refinery, iron and steel, etc.) work under the ETS under the 2003/87/CE Directive. They have to achieve a 21% GHG emission reduction for 2020 based on 2005 levels. There is no specification between Member States. The remaining emissions, in the case of Spain, have to reach a 10% reduction [16].

As previously mentioned, the Clean Energy Package demands each member state to provide a NECP for periods 2021-2030. With some months of delay, Spain was able to deliver its draft by February 2019. These documents help the European Commission to monitor the level of compliance with the European objectives as a whole. The Spanish Government states in this document that they understand their committed responsibility towards climate change and that it implies an act of responsibility through public policies, not only at a state level but also a regional level. This is the case where the Autonomous Communities have undertaken ambitious policies in terms of climate change. This document identifies long term challenges and opportunities across five Energy Union dimensions: decarbonization, energy efficiency, renewables, energy security, internal energy market and research, innovation and competitiveness. This study will try to focus on the areas of decarbonization, and energy efficiency [17].

The measures considered in the NECP allows achieving the following results by 2030. First and foremost, 21% GHG reduction based on 1990 levels. This means moving from 340,2 million tons of equivalent CO_2 in 2007 to 226,7Mton of eq-CO_2 in 2030 (see Table 3). At the same time, diffuse sector such as residential and transport contribute to a 38% emission reduction based on 2005 levels. Meanwhile, sectors subject to trade emission rights, reduce by 60% on 2005 levels. These numbers are based on technology neutrality criteria, within a cost-efficient trajectory of each technology. Note that coal plants are supposed to cease their production by 2030 at the least.

One of the other major driving forces of this plan is the presence of renewables in the transport sector. According to NECP, it is expected that they reach a 22% transport electrification (5 million electric vehicles by 2030).

Table 3: Emission evolution (thousands of tons of equivalent CO2). Source: [17]

Años	1990	2005	2015	2020*	2025*	2030*
Transporte	59.199	102.310	83.197	85.722	74.638	57.695
Generación de energía eléctrica	65.864	112.623	74.051	63.518	27.203	19.650
Sector industrial (procesos de combustión)	45.099	68.598	40.462	40.499	37.246	33.530
Sector industrial (emisiones de procesos)	28.559	31.992	21.036	21.509	22.026	22.429
Sectores residencial, comercial e institucional	17.571	31.124	28.135	26.558	23.300	19.432
Ganadería	21.885	25.726	22.854	23.247	21.216	19.184
Cultivos	12.275	10.868	11.679	11.382	11.086	10.791
Residuos	9.825	13.389	14.375	13.657	11.898	9.650
Industria del refino	10.878	13.078	11.560	12.247	11.607	10.968
Otras industrias energéticas	2.161	1.020	782	721	568	543
Otros sectores	9.082	11.729	11.991	14.169	13.701	13.259
Emisiones fugitivas	3.837	3.386	4.455	4.715	4.419	4.254
Uso de productos	1.358	1.762	1.146	1.231	1.283	1.316
Gases fluorados	64	11.465	10.086	8.267	6.152	4.037
Total	287.656	439.070	335.809	327.443	266.343	226.737

This document also considers a 42% renewables over final energy consumption. This is driven by high penetration of this technology in all economic sectors and final energy consumption reduction. Moreover, it pursues a 39,6% energy efficiency improvement and 74% renewable energy sources in the generation mix. This is done essentially due to the large expected investment in RES together with the considerable final energy consumption reduction as a result of savings and efficiency programs and measures [17].

It is more than clear that there is an objective for the European Union to decouple GHG emissions from economic growth. This is done mainly with better energy incentives, policies for transition to other forms of fuel and RES penetration. Spain has developed national strategies in order to meet the European expectations with examples such as the NECP document. This is a tool that will try to transform the Spanish energy system toward an increase in energy self-sufficiency, taking advance of renewable sources potential. This will also help to reduce the energy imports dependency subject to geopolitics and internal price volatility.

This chapter has tried to provide a brief summary of the increasing concern about climate change and the main highlights of energy and climate packages at a national and international level. That is why it is now more interesting than ever to evaluate in detail the performance of Spanish CO_2. It will help to understand if Spain is going through the right direction according to their strategies by analyzing different economic and technological effects with the index decomposition methodology.

3. ECONOMIC DRIVERS OF THE CARBON FOOTPRINT EVOLUTION IN SPAIN: INDEX DECOMPOSITION METHODOLOGY

Once it has been given an overall overview of the current situation in Spain in terms of CO_2 emissions, it has raised the necessity to analyzed in detailed the main economic drivers that are behind the CO_2 evolution. This section tries to explain the methodology implemented to reach that objective. The key tool that enables this activity is the application of the Energy Intensity through the LMDI index decomposition so as to evaluate the CO_2 evolution.

The main goal to achieve is the maximum disaggregation possible not only based on different activities of the economy (industry, transport, services ...etc.) but also into several indexes. The former is a sound technique that is one of the most preferred ones by the majority of researches. The extrapolation from the study of the Energy Intensity behavior with the index decomposition methodology helps to go in-depth into key sectors and assess which are the most suitable corrective environmental measures.

This chapter follows this next structure. The first part provides some background about the Energy Intensity, this includes definition, main factors that this parameter relies on and the relationship with the CO_2 emissions. In addition, it gives an introduction to indexes decomposition. It involves a brief classification of different alternatives and bibliographic review, concluding with an explanation stating the main reasons why it has been chosen the selected methodology. It also describes as variables definitions and mathematical formulation.

3.1ENERGY INTENSITY

3.1.1 INTRODUCTION

Nowadays, many countries consider energy consumption as a key element when designing their energy policies. Reducing energy consumption through the incorporation of more energy efficient techniques, not only helps to decrease the environmental impact but also the increase of security of supply in the most economically efficient way.

According to some resources Energy Intensity, from now on EI, is defined as a measure for the energy consumption of an economy and its energy efficiency. It is obtained as the ratio between the gross consumption of energy and gross inland domestic product or GDP. In other words, it is the inverse of energy efficiency. If the objective is to increase energy efficiency, the EI should be reduced. An extra definition is “the amount of energy required to produce a unit of wealth” [20]. The energy origin considered comes from energy sources such as coal, electricity, oil, natural gas and renewable energy sources (RES).[13]

Although the concept of using energy intensity as a proxy to energy efficiency in a country must be explained. In order to do that, there is a need for more detailed energy consumptions and activities data, like heating consumption. For example, the fact that Iceland has relatively high energy intensity is not because is not energy efficient, but because their electricity production comes from a source of very low efficiency (mainly geothermal). [22] Although, since the practice of obtaining every single efficiency factor of each technology is infeasible, it has resorted to more aggregated analysis like energy consumption of each sector divided by the Gross Value Added (GVA).

The origin of this measure is because of economic and environmental reasons. Historically, economic growth led to higher economic consumption, thus increasing the pressure exerted by energy production and consumption on the environment. The aim of this indicator is to identify to what extent there is decoupling between energy consumption and economic growth. Some of the possible scenarios are the following. It could be the case that there is a relative decoupling which occurs when energy consumption grows but not at fast as the economy. On the other hand, absolute decoupling takes place when energy consumption is constant or decreases while the GDP goes in the other direction. The most desirable situation in order to comply with environmental international standards is the latter. Absolute decoupling will definitely alleviate current environmental pressures and ease the way towards the achievement of economic and environmental goals.[13]

3.1.2 MAIN FACTORS THAT AFFECT THE EI

In principle, the economic structure of a country does not affect energy efficiency. For example, the large participation of the industrial sector in the overall economy does not influence industry consumption for a specific process. Nevertheless, the economic structure does affect the aggregated the EI, since this indicator represents all the sector aggregations with different EI. In other words, the industry sector can consume several times the energy per gross value compared to the service sector. Even within fields of the industry sector, it could appear notorious differences within unit energy consumptions. Hence, an economy with a high concentration of energy-intensive industry will present a high EI aggregated ratio compared to other tertiary activities such as services. This does not mean that this industry is inefficient, because this will depend on how far is the energy process from the optimal operation. The key problem behind these energy statistics is that they aggregate the overall energy consumption, creating a structural component in every sector. This is minimized as the level of disaggregation is increased.

Some studies evaluate from a macroeconomic perspective the relationship between several variables and the EI. They coincide in the fact that the factors that affect the EI are structural, technological changes, fuel substitution, and fuel prices [21]. It is not that clear that the saturation effect, individual preferences, and some minor ones provoke an influence in the EI.

These are several factors that directly influence the performance of the EI. The comparison between all these factors to analyze the implications of the EI is rather complicated. Finding the appropriate methodology that unifies the information and makes them suitable for a coherent comparison is a challenge. The possibility of analyzing how these parameters influence the EI that even sometimes have dissimilar implications and are difficult to quantify, making the EI interpretation diffuse.

The next paragraphs give a brief review of these factors. [21]

- **STRUCURAL CHANGES**

    The structure of the economy may change across time. For instance, in theory, it could change towards sectors of the economy whose energy demand is lower. Nevertheless, this statement is not always true. Sectors sometimes demand more energy (i.e. improvements in technical processes such as automation in the industry sector), which means that structural changes do not necessarily mean a reduction in energy consumption. It could also be the case that one sector produces indirect energy consumptions in another one as in the case of tourism in transport. However, in most general cases, the industry evolves towards less intensive industry processes but with greater gross value added.

This aforementioned scenarios of the economy do affect the aggregated EI performance since this value represents the aggregated value every sector with different EI.

- **TECHNOLOGY PROGRESS**

The evolution of new and more advanced technologies have not ceased across the economic life of a country. Some of the positive consequences they arise are the reduction in the number of materials necessary for production. Moreover, they ensure in theory that this accumulated knowledge that leads to an innovative solution will help to use the resource in a more efficient way. For instance, improvements in tools such as the Internet or social media in general, have increased exponentially over recent years. It gives the opportunity to have an even more worldwide connection and access to information which stimulates the development of production processes. Another example could be super-efficient refrigerators that can significantly reduce household's energy use per capita, but increase penetration of air-conditioning and house size increase could enlarge the energy intensity.

However, in practice, there is no such direct relationship between EI and efficiency. It could generate new necessities and products that intensifies the energy consumption and more complex technological requirements. For instance, the elaboration of a more robust, secure and accessible telecommunication network.

- **FUEL SUBSTITUTION**

There are many different alternatives for heating up a building or fueling a vehicle. By choosing the most appropriate fuel solution, the EI could be affected. It is worth mentioning the fact that in most developed countries there is a strong incentive for the electrification of the system. Not only from a regulatory point of view but also from a technology innovation perspective. The energy content and consumed in order to produce gasoline for transportation is definitively not the same as electricity. Electricity and natural gas are defined as some of the sources of energy that give a major energy quality This situation may generate economic value to the country of interest. The assigned efficiency values for each generation technology energy may also have a significant impact on the evolution of the EI.

Figure 3 gives an illustrative example for the case of Spain. It represents the total primary energy supply from 1990-2016. It is presented fundamentally to confirm that Spain should be included in the countries that are at an incentive stage for fuel substitution. Coal energy consumption has decreased since 2008 and has been replaced for sources with better efficiency values such as natural gas and renewable energy.

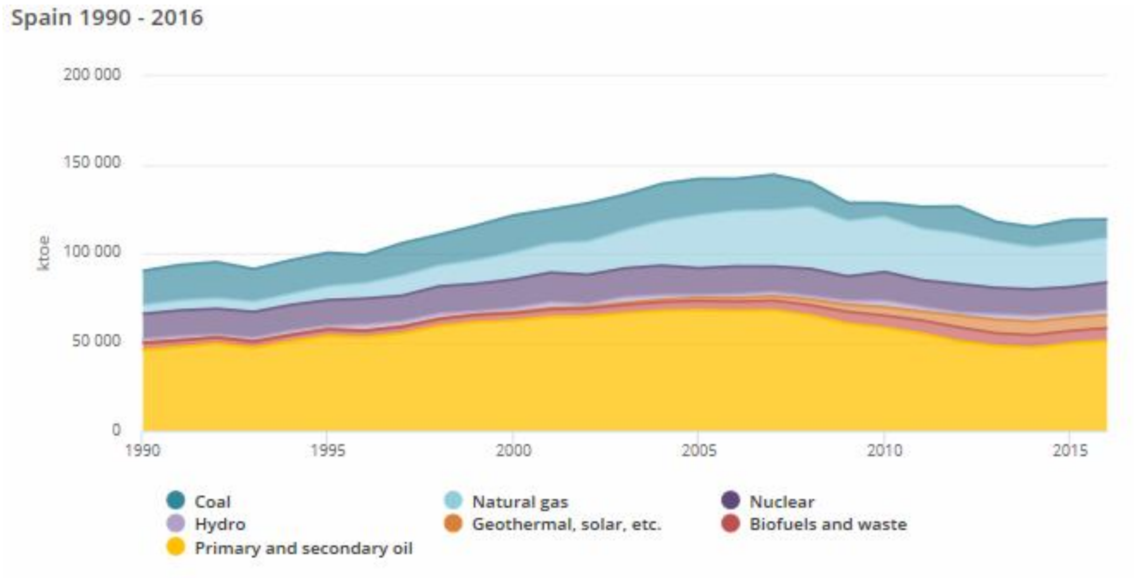


Figure 3: Total Primary Energy supply (TPES) by source. Source[18]

- **REGULATION AND PRICES**

Any regulatory reform and/or price modifications have a direct implication in the performance of a country's. For instance, if energy prices go up, implicitly it is sending a signal to promote energy savings, and therefore to lower energy-intensive activities. It is important to remember that Spain is still a very high energy dependent country. Figure 4 represents the energy dependency is Spain according to INE annual report of 2018. This parameter represents the proportionally national energy necessities that are satisfied with imports for other countries. Although energy dependency has been reduced since 2007, we still around 72% of our energy necessities relies on other countries imports.

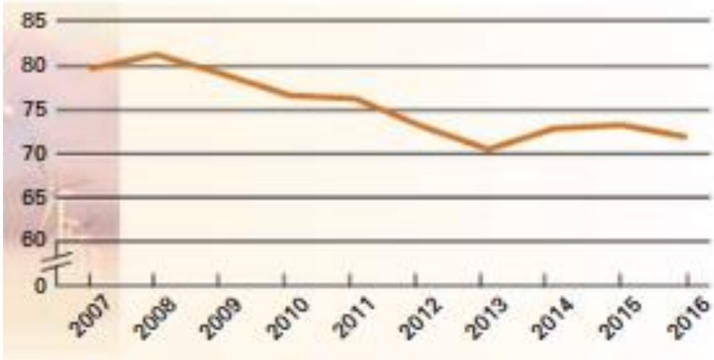


Figure 4: Energy Dependency in Spain (%). Source[20]

- **SATURATION EFFECT**

  The saturation effect is achieved when a parameter reaches a physical limit that it could no longer be increased. In the energy consumption framework, it is when the per capita income or wealth reaches an upper limit and together with a level of satisfaction. Consequently, the EI stabilizes or even decreases in the long term.

- **CONSUMER PREFERENCES**

  In most general cases, when the per capita income is limited, the user preferences when evaluating the different ways of consuming, choosing the one with the highest environmental efficiency is not a priority. In fact, it is also strongly dependent on the country's culture, personal values and again the regulation. The combination of all the previously mentioned factors determines the energy consumption preferences. Making the right political and educational decisions, a country can change their energy consumption behavior.

- **OTHER FACTORS**

  There are some other parameters that also affect the evolution of the EI. Logically, mentioning all of them exceeds the scope of this study but there are a couple of them that are worth mentioning. For example, once again the energy dependency on other countries as well as the climate conditions. The former has a considerable impact on the EI levels especially in Nordic countries that have to deal with extreme climate conditions which originate higher heating loads that are translated into higher energy consumption. Spain has an advantage over other European countries because of its Mediterranean conditions that lead to lower EI. Note that it is also important to consider if the country experiences annual fluctuations in temperature.

3.1.3 EMISSIONS AND ENERGY INTENSITY

Once it has been explaining a summary of the main factors that influence the energy intensity. the next step is to describe the relationship between national emissions and a country's EI. Across the definition of EI, it has been mentioned several times the concept of energy consumption. At the same time, this is an important factor that not only applies to IE but to emissions. The former's results highly rely on energy demand and the participation of the different sources available to supply such demand. Also, it is estimated that energy consumption is likely to be a dominant cause of carbon dioxide emission as long as we are talking about fossil fuels.

Distribution of the energy sources across a country's economy differs in many ways depending on the activity sector. It could be the case that a country has plenty of diversified energy supply portfolio coming from different sources. However, in general terms, in the transportation sector still are very much dependent on oil while in some other sectors such as transformation is very much diversified.

Apart from that, most of the above-mentioned factors are also applicable to emissions. Population, economy's activity, fuel substitution, structural and technological changes all of them conditioned by the particular sector they are evaluated, also play an important role in the behavior of CO_2 emissions.

In conclusion, in order to get a perspective on the effect of each of these sectors on the CO_2 emissions in Spain, it has to be developed an index decomposition which its background and mathematical formulation is explained in the upcoming chapter.

3.2 INDEX DECOMPOSITION METHODOLOGY

This chapter presents a general background describing the principal classification of the different methodologies for decomposition analysis designed across history. It includes variables definition as well as mathematical formulations and areas of application.

3.2.1 INTRODUCTION

The Index Decomposition Analysis is an analytical tool originated from energy studies in the late 1970s. It has since been extended to other areas including CO_2 emissions analysis, sustainable use of natural resources and environmental management. Moreover, it has been widely used to quantitatively assess the drivers leading to changes in an aggregate energy indicator over time. This is normally done with a simple single dimensional database such as industrial energy consumption by the industrial sector and extrapolated to the transportation and tertiary sector. In a single dimensional database, it will study the effect of structural change on how energy consumption is disaggregated in a particular dimension. [23]

According to some literature, after the 1973/1974 world oil crisis, energy researches began to look for ways to quantify the impact of a structural shift in industrial production on total industrial energy demand in order to have a better understanding of the mechanisms of change in energy use in the industry. They came up with several simple techniques to overcome this problem through decomposing changes in the aggregate energy intensity over time. This line of research has continued until today with more and more reported studies every year. Decomposition methodology has become a useful and popular tool not only in industrial energy demand analysis but also in energy and environmental analysis in general. [24]

Until 1985, the majority of studies corresponds to the approximation of the Laspeyres index. This is defined nowadays by Eurostat as a price index for measuring the price development of the basket of goods and services consumed in the base period. It helps to understand how much a basket bought in the base period would cost in the current period [26] But, studies like [27] prove that in some cases this methodology is still active.

After that period, these kinds of analyses start evolving towards more sophisticated techniques. It could be established two main categories of index decomposition, all of them applicable to the different areas explained above. They are the structural and index decomposition methodologies (SAD IBD respectively). They present the advantage of allowing the implementation of sectoral analysis.

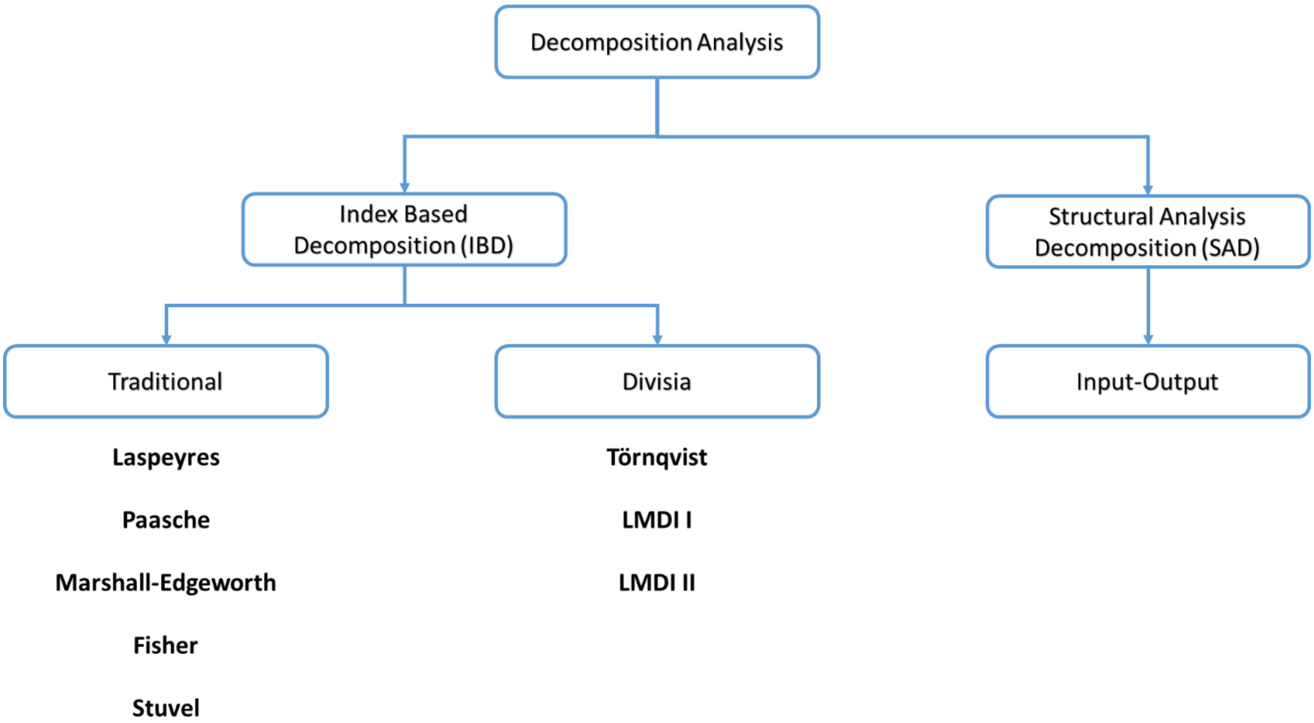


Figure 5: Index decomposition methodologies classification

- Structural analysis decomposition:
  This technique was more frequently used for decomposition studies based on input-output tables, and therefore is known for the "input-output" decomposition. It allows distinguishing a wide range of technological and final demand effect, together with indirect effects that some other decomposition techniques are not able to achieve. But this requires a great level of detail, which is translated into the necessity of a more reliable database.

- Index based decomposition:
  Their studies are initially based on sectorial information. Within this category, they cover huge methodology variations that could be subdivided into again two groups, the traditional and Divisia. The first one includes Laspeyres, Paasche, Marshall-Edgeworth, Fisher and Stuvel and the second one involves Törnqvist, Log Mean Divisia Index I and II. The decomposition could be either additive being the difference of two parameters or multiplicative being the ratio or division.[21]

In particular, the Index based decomposition is usually the most common methodology in environmental and energy studies reaching up to about hundreds of academic studies and they present some additional benefits in the face of SAD. First and foremost, it allows both additive and multiplicative decompositions make possible the decomposition for any type of aggregation (value or ratio) and requires less initial information in case of international comparison research. On the other hand, structural analysis is usually focused on additive decompositions.

After more than 30 years of application of decomposition techniques, there is not a consensus between researched that can prove which is the best methodology. Laspeyres and Divisia are the ones most implemented. The selection of the most suitable methodology needs to be assessed based on the application, theoretical fundamentals, desired results, transparency and result's reflectivity.

In practice, the best option should also depend on reliability, homogeneity, and quality of the source of the statistics. These factors are decisive when achieving acceptable results regardless of the chosen methodology.

Taking into account all the previously mentioned information, the advantages that the Index based decomposition has over the structural decomposition as well as the objectives of this project, from now it will focus essentially in the index based decomposition due to their broad experience in the environmental field.

3.2.2 VARIABLE DEFINITION

Once chosen the Index based decomposition method and setting the initial concepts, this section gives some mathematical background about the methodologies covered within these techniques. The index decomposition is capable of, in a rather simple way, identifying the weighted participation in a sector level (technological or sectoral intensity) and at the same time based on the weighted participation of each sector in the economy (structural). This is the most basic case that will be presented in this section to provide a general idea of the formulation behind the index decomposition.

To begin with, it has to be set an equation that links some factors with an aggregated one, which at first will be the energy intensity measures the consumed energy (in ktoe) divided by the GVA (euros at constant prices). It is necessary to remind once again that this methodology will be then extrapolated to evaluate the CO_2 emissions (tons of equivalent CO_2) as the aggregated factor.

The variables definitions that participate in the decomposition formulation are presented hereinafter both applied for the additive and multiplicative methodology to year *t*.

E_t= Total energy consumption at time *t*.

$E_{i,t}$= Sector *i* energy consumption at time *t*.

Y_t= Total GDP at time *t*.

$Y_{,i,t}$= Sector *i* GDP at time *t*.

$S_{i,t}$=Sector participation in the GDP at time *t* (=$Y_{,i,t}$/ Y_t).

I_t= Aggregated Energy Intensity at time *t* (=$E_{,t}$/ Y_t).

$I_{i,t}$= Sector *i* Energy Intensity at time *t* (=$E_{,i,t}$/ $Y_{i,t}$).

If the final expression is represented in a multiplicative form,

D_{tot}= Energy Intensity variation with the multiplicative methodology between timeframes *t=T* and *t=0* (=I_T/ I_0).

D_{str}= Structural effect with the multiplicative methodology between timeframes *t=T* and *t=0*.

D_{int}= Sectoral intensity effect with the multiplicative methodology between timeframes *t=T* and *t=0*.

D_{rsd}= Residual effect with the multiplicative methodology between timeframes *t=T* and *t=0*.

If I_0 is the EI at the base year *0* and I_T is EI at the time period *T*, this variation using the multiplicative method, the following equation *(1)* is obtained.

$$D_{tot} = \frac{I_t}{I_0} = D_{str} \cdot D_{int} \cdot D_{rsd} \qquad (1)$$

On the other hand, if the final expression is represented in an additive form,

I_{tot}= Energy Intensity variation with the additive methodology between timeframes *t=T* and *t=0* (=I_T - I_0).

I_{str}= Structural effect with the additive methodology between timeframes *t=T* and *t=0*.

I_{int}= Sectoral intensity effect with the additive methodology between timeframes *t=T* and *t=0*.

I_{rsd}= Residual effect with the additive methodology between timeframes *t=T* and *t=0*.

The EI variation using the additive method, the following equation *(2)* is obtained.

$$\Delta I_{tot} = I_T - I_0 = \Delta I_{str} + \Delta I_{int} + \Delta I_{rsd} \quad (2)$$

The value of the EI itself is expressed in structural productivity ($S_{i,t}$) and sectoral intensity ($I_{i,t}$) as in equation *(3)*. Note that studies seldom include the residential sector in their analyses.

$$I_t = \frac{E_t}{Y_t} = \sum_i \frac{Y_{i,t}}{Y_t} \cdot \frac{E_{i,t}}{Y_{i,t}} = \sum_i S_{i,t} \cdot I_{i,t} \quad (3)$$

As for the units, they will depend on the particularity of the study but in this specific case, usually economic values such as Gross Value Added and Gross Domestic Product are measured at the corresponding monetary value at constant prices and energy values at tons of oil equivalent (toe).

The next step is to give an overview of the fundamental decomposition methodologies classified according to Figure 5. Obviously, it will pay special attention to the selected methodology, giving extra detailed information of the mathematical formulation.

3.2.3 TRADITIONAL DECOMPOSITON METHODOLOGIES

3.2.3.1 IMPERFECT DECOMPOSITION METHODOLOGIES

This particular methodology stands out for evaluating the effect a factor has in an aggregating parameter by leaving constant the other factors. In other words, in the framework of analyzing the structural and sectorial intensity within the EI, when computing the structural effect, the sectoral intensity remains constant and vice versa.

Additionally, the traditional decomposition methodology could provide infinite solutions depending on the relevance assigned to year *0* and final year *T* by the form of weighing. This statement is reflected in equations from *(4)* to *(7)*.

$$D_{str} = \frac{\sum_i \alpha \cdot S_{i,T} \cdot I_{i,0} + \beta \cdot S_{i,T} \cdot I_{i,T}}{\sum_i \gamma \cdot S_{i,0} \cdot I_{i,0} + \lambda \cdot S_{i,0} \cdot I_{i,T}} \quad (4)$$

$$D_{int} = \frac{\sum_i \alpha \cdot S_{i,0} \cdot I_{i,T} + \beta \cdot S_{i,T} \cdot I_{i,T}}{\sum_i \gamma \cdot S_{i,0} \cdot I_{i,0} + \lambda \cdot S_{i,T} \cdot I_{i,0}} \quad (5)$$

$$D_{rsd} = \frac{D_{tot}}{D_{str} \cdot D_{int}} \quad (6)$$

where:

$$0 < \beta, \alpha, \gamma, \lambda < 1$$

$$\alpha + \beta = 1 \; and \; \gamma + \lambda = 1 \quad (7)$$

The residual term (D_{rsd}) or I_{rsd} in the case of the additive method, corresponds to the remaining part that cannot be explained with the effects that are currently under evaluation. Meaning that an acceptable decomposition will be the one that has the lowest possible residual term, resulting in a better estimation.

The above-mentioned equations are the baseline for the imperfect traditional decomposition. Depending on the selection of Laspeyres, Paasche or Marshall-Edgeworth, the decomposition will experiment slight modifications.

To begin with, the baseline for future methodologies such as Fischer or Stuvel is the Laspeyres decomposition where α=γ=1 and therefore β=λ=0. In other words, the base year of one variable remains constant and the behavior of the other variable is analyzed across time. The Laspeyres method, as indicated before, comes from the Laspeyres price index used in economics. The main drawback was that it could generate an undesired residual component due to the special importance of the base year.

On the other hand, the Paasche decomposition goes in the opposite direction where α=γ=0 and therefore β=λ=1. Unfortunately, it is characterized from having similar drawbacks as Laspeyres but this time because of the special focus on the final year.

Finally, as a hybrid of both methodologies is the Marshall-Edgeworth decomposition where α=γ= β=λ=0.5. It gives the exact same relevance to both the base and final year [24].

3.2.3.2 PERFECT DECOMPOSITION METHODOLOGIES

It was clear that the residual term provokes a negative result to the overall decomposition. That Is why the research on the optimal decomposition continues. It started Fischer in 1922 introducing a new index that is capable to achieve a perfect decomposition. It uses both Paasche and Laspeyres multiplicative methods by a geometric mean as illustrated in the following equations including additive and multiplicative formulations.

For the multiplicative methodology,

$$D_{str} = \sqrt{S_L \cdot S_P} \tag{8}$$

$$D_{int} = \sqrt{I_L \cdot I_P} \tag{9}$$

And the additive methodology,

$$\Delta I_{str} = \sum_i I_{i,0} \cdot \Delta\, S_i + \frac{1}{2} \cdot \sum_i \Delta\, S_i \cdot \Delta I_i \tag{10}$$

$$\Delta I_{int} = \sum_i S_{i,0} \cdot \Delta\, I_i + \frac{1}{2} \cdot \sum_i \Delta\, S_i \cdot \Delta I_i \tag{11}$$

In this case, *S* and *I* represent the structural and sectorial intensity effect respectively under Laspeyres (*L*) and Paasche (*P*) methodologies. Perfect decomposition and a balanced compromise between former techniques are some of features that this decomposition has. According to the final result, it fulfills the time reversal conditions which implies that an index calculated for the future is reciprocal if it were to the past. Also, has a factor reversal property which means that the aggregated factor is determined by multiplying the individual decomposed components.

Finally, concluding with the perfect traditional decomposition methodologies was the Stuvel proposition in 1957. However, it was barely used in the economic field [21].

Compared to the Fischer method, this one considers the possibility of implementing either one of the three traditional imperfect decomposition of Laspeyres, Paasche or Marshall-Edgeworth. It also complies with time and factor reversal and is predefined to obtain a perfect decomposition. Note that this includes not only for the total variation of the variable but for each sector. These equations reflect one example of the Stuvel index decomposition for the Laspeyres case, for additive and multiplicative expressions.

The multiplicative variation is,

$$D_{str} = \left(S_L - \frac{I_L}{2}\right) + \sqrt{\left(S_L - \frac{I_L}{2}\right)^2 + \left(\frac{I_T}{I_0}\right)} \tag{12}$$

$$D_{int} = \left(I_L - \frac{S_L}{2}\right) + \sqrt{\left(I_L - \frac{S_L}{2}\right)^2 + \left(\frac{I_T}{I_0}\right)} \tag{13}$$

And the additive case,

$$\Delta I_{str} = \frac{I_T - I_0}{2} + I_0 \cdot \frac{(S_L - I_L)}{2} \tag{14}$$

$$\Delta I_{int} = \frac{I_T - I_0}{2} + I_0 \cdot \frac{(I_L - S_L)}{2} \tag{15}$$

This methodology presents some disadvantages. The before stated sectors effect does not have a direct relationship with the aggregation. Stuvel itself recognized that, as happening with the Fischer methodology as well, “there is a lack of consistency between the multiplicative analysis of each value change of the individual products and the aggregation” [30]. Logically, it generates a large inconvenient since it could not be confirmed which part of the structure effect corresponds to a specific sector. And most importantly, all of the mathematical formulation examples was considering only to effects to decompose. In case there is a need to evaluate more than one effect, the extended detailed formulation is not very operative [21].

3.2.4 DIVISIA DECOMPOSITION METHODOLOGIES

Now within the index decomposition category, this project pays special attention to Divisia index methodology. Authors such as [25] proved that Divisia index methodology verifies homogeneity, proportionality properties. The Divisia parametric decomposition methodology has been so far the most implemented one during recent years. Compared to the above mentioned decomposition proposals, when the information to analyze experiments noticeable variations across and a significant level of disaggregation, the results obtained with the Divisia decomposition are more reliable. It provides a lower residual level and a perfect decomposition in the most elaborated cases. [28]

While the traditional techniques assign to each year different weights, Divisia decomposition is based on a logarithmic mean. In other words, instead of using percentages, the change of a factor between the year is in a logarithmic base. In mathematical terms, it is expressed as follows. It is smaller than the arithmetic mean but larger than the geometric mean, except when both numbers are equal.[31]

$$L(a,b) = (a-b)/(\ln(a) - \ln(b)) \tag{16}$$

The reason behind using logarithmic mean is that it gives a symmetric change between years. Imagine for example that the energy consumption of a sector increased from 10 units in year 0 to 20 units in year T. Depending on which is the of the two years is chosen as the point of comparison, the relative difference will change. The consumption in year T is 100% larger than year 0, but year 0 is 50% lower than year T, which ends up giving an asymmetric result. However, in the case of logarithmic relative change, the results are (Ln (20/10) = 0.693= - Ln (10/20)) which are symmetric.[31]

The next stage consists of briefly describe the historical evolution of the Divisia decomposition techniques. It started with the mean arithmetic Divisia or Törnqvist (1985) which has been widely implemented since then. It introduced the logarithmic mean in the index calculation, resulting in a new symmetric and additive index.

In order to develop this new index decomposition method, it is necessary to recall equation (*3*):

$$I_t = \frac{E_t}{Y_t} = \sum_i \frac{Y_{i,t}}{Y_t} \cdot \frac{E_{i,t}}{Y_{i,t}} = \sum_i S_{i,t} \cdot I_{i,t} \tag{17}$$

The logarithm is applied at both sides of the equation and after its derivative, resulting in,

$$\begin{aligned}\frac{d}{dt}Ln(I_t) &= \frac{1}{\sum_i S_{i,t}\cdot I_{i,t}}\cdot\frac{d}{dt}\left(\sum_i S_{i,t}\cdot I_{i,t}\right)\\ &= \frac{1}{I_t}\cdot \sum_i [\left(\frac{d}{dt}S_{i,t}\right)\cdot I_{i,t} + \left(\frac{d}{dt}I_{i,t}\right)\cdot S_{i,t}]\\ &= \sum_i [\left(\frac{d}{dt}S_{i,t}\right)\cdot\left(\frac{I_{i,t}}{I_t}\right) + \left(\frac{d}{dt}I_{i,t}\right)\cdot\left(\frac{S_{i,t}}{I_t}\right)]\end{aligned} \tag{18}$$

and taking into account that,

$$\frac{d}{dt}Ln\big(f(t)\big) = \frac{1}{f(t)}\cdot\frac{d}{dt}f(t) \tag{19}$$

$$\frac{d}{dt}f(t) = \sum_i \frac{d}{dt}f(t) \tag{20}$$

$$\frac{d}{dt}\big(f(t)\cdot g(t)\big) = \left(\frac{d}{dt}f(t)\right)\cdot g(t) + \left(\frac{d}{dt}g(t)\right)\cdot f(t) \tag{21}$$

Some adjustments to equation (*18*) considering,

$$\frac{d}{dt}Ln(S_{i,t}) = \frac{1}{S_{i,t}}\cdot\left(\frac{d}{dt}S_{i,t}\right) \tag{22}$$

then,

$$\frac{d}{dt}S_{i,t} = \left(\frac{d}{dt}Ln(S_{i,t})\right)\cdot S_{i,t} \tag{23}$$

similarly,

$$\frac{d}{dt}I_{i,t} = \left(\frac{d}{dt}Ln(I_{i,t})\right) \cdot I_{i,t} \tag{24}$$

Hence, introducing the former to terms into the original equation (*18*):

$$\begin{aligned} \frac{d}{dt}Ln(I_t) &= \sum_i [\left(\frac{d}{dt}Ln(S_{i,t})\right) \cdot \left(\frac{S_{i,t} \cdot I_{i,t}}{I_t}\right) + \left(\frac{d}{dt}Ln(I_{i,t})\right) \cdot \left(\frac{I_{i,t} \cdot S_{i,t}}{I_t}\right)] \\ &= \sum_i \frac{S_{i,t\cdot} \cdot I_{i,t}}{I_t} \cdot \left[\left(\frac{d}{dt}Ln(S_{i,t})\right) + \left(\frac{d}{dt}Ln(I_{i,t})\right)\right] \end{aligned} \tag{25}$$

From now on, a new parameter called W_i represents the participation of a sector *i* respect to the global performance. Which extrapolated to this case, it is equivalent to the energy participation of sector *I* (E_{it}) on the total energy (E_T).

$$\frac{S_{i,t\cdot} \cdot I_{i,t}}{I_t} = \frac{Y_t}{E_t} \cdot \frac{Y_{i,t}}{Y_t} \cdot \frac{E_{i,t}}{Y_{i,t}} = \frac{E_{i,t}}{E_t} = W_i \tag{26}$$

Therefore equation (*25*) is now,

$$\frac{d}{dt}Ln(I_t) = \sum_i W_i \cdot \left[\left(\frac{d}{dt}Ln(S_{i,t})\right) + \left(\frac{d}{dt}Ln(I_{i,t})\right)\right] \tag{27}$$

If now an integral across times 0 and T is applied to equation (*27*),

$$\int_0^T \frac{d}{dt}Ln(I_t) \cdot dt = \int_0^T \sum_i W_i \cdot \left[\left(\frac{d}{dt}Ln(S_{i,t})\right) + \left(\frac{d}{dt}Ln(I_{i,t})\right)\right] \cdot dt \tag{28}$$

since,

$$\sum(x_i + y_i) = \sum x_i + \sum y_i \tag{29}$$

and,

$$\int_0^T \frac{d}{dt} Ln(I_T) \cdot dt = Ln(I_T) - Ln(I_0) = Ln\left(\frac{I_T}{I_0}\right) \tag{30}$$

thus,

$$\begin{aligned} Ln\left(\frac{I_T}{I_0}\right) \cdot dt = & \int_0^T \sum_i W_i \cdot \left[\left(\frac{d}{dt} Ln\big(S_{i,t}\big)\right)\right] \cdot dt \\ & + \int_0^T \sum_i W_i \cdot \left[\left(\frac{d}{dt} Ln\big(I_{i,t}\big)\right)\right] \cdot dt \end{aligned} \tag{31}$$

Finally, so as to evaluate the EI evolution between times 0 and T, it is calculated the exponential at both sides of equation (*31*).

$$\begin{aligned} & \exp\left(Ln\left(\frac{I_T}{I_0}\right) \cdot dt\right) \\ & \quad = \exp\left[\int_0^T \sum_i W_i \cdot \left[\left(\frac{d}{dt} Ln\big(S_{i,t}\big)\right)\right] \cdot dt \right. \\ & \quad \left. + \int_0^T \sum_i W_i \cdot \left[\left(\frac{d}{dt} Ln\big(I_{i,t}\big)\right)\right] \cdot dt\right] \end{aligned} \tag{32}$$

Remembering the exponential property,

$$\exp(a+b) = \exp(a) \cdot exp(b) \tag{33}$$

This is translated into equation (*31*) as,

$$\frac{I_T}{I_0} = \exp\left[\int_0^T \sum_i W_i \cdot \left(\frac{d}{dt} Ln\big(S_{i,t}\big)\right)\right] \cdot \exp\left[\int_0^T \sum_i W_i \cdot \left(\frac{d}{dt} Ln\big(I_{i,t}\big)\right)\right] \tag{34}$$

Equation (*34*) clearly looks familiar with the decomposition structure it has been discussed so far. The desired variable to analyze is decomposed into two different multiplicative indexes. In this particular case, the IE is explained through de structural effect, the first component of the equation and the sectorial intensity, being this one the second component. In the same way that former methodologies, the key element relies on how the weights are assigned to each year. Törnqvist method proposes a value of W_i' based on the arithmetic mean.

$$W_i' = \frac{1}{2}(W_{i,t} + W_{i,0}) \tag{35}$$

Hence, each of the effects to represent the decomposition of the variable (structural and sectorial intensity respectively) are obtained as,

$$D_{str} = \exp\left[\sum_i W_i' \cdot \int_0^T \left(\frac{d}{dt} Ln\left(S_{i,t}\right)\right)\right] = \exp\left[\sum_i W_i' \cdot Ln\left(\frac{S_{i,T}}{S_{i,0}}\right)\right] \tag{36}$$

$$D_{int} = \exp\left[\sum_i W_i' \cdot \int_0^T \left(\frac{d}{dt} Ln\left(I_{i,t}\right)\right)\right] = \exp\left[\sum_i W_i' \cdot Ln\left(\frac{I_{i,T}}{I_{i,0}}\right)\right] \tag{37}$$

In this first approximation there is a residual component.

$$D_{tot} = D_{str} \cdot D_{int} \cdot D_{rsd} \rightarrow D_{rsd} = D_{tot}/(D_{str} \cdot D_{int}) \tag{38}$$

Törnqvist has the advantage of reducing the residual component. Also, it gives the possibility of introducing more than two factors for the decomposition without increasing significantly the mathematical complexity. [21]

For this reason, researches try to come up with a methodology that was capable of achieving a perfect composition, without any residual component, as well as fixing problems arising from the calculation of W_i'.

There are two proposition that stand out between them which applied the logarithmic mean. The first one is called LMDI I which entails for Logarithmic Mean Divisia Index I). This decomposition uses the W_i' as the logarithmic mean of each sector's sectoral intensities divided by the logarithmic mean of the total energy intensity at both time periods. More detailed information can be found in [32].

$$W_i' = \frac{L\left(\frac{E_{i,T}}{Y_T}, \frac{E_{i,0}}{Y_0}\right)}{L\left(\frac{E_T}{Y_T}, \frac{E_0}{Y_0}\right)} \quad (39)$$

Where it is necessary to remember that L expresses the logarithmic mean as in equation (*16*).

The second one is LDMI II. This time W_i' is defined as the logarithmic mean of each sector's energy percentage over the total across times 0 and T. At the same time, it is divided by the total sum of the numerator. This methodology fulfills both time and factor reversal properties. Additional information regarding a comparison between both proposals can be found in [34].

$$W_i' = \frac{L\left(\frac{E_{i,T}}{E_T}, \frac{E_{i,0}}{E_0}\right)}{\sum_i L\left(\frac{E_{i,T}}{E_T}, \frac{E_{i,0}}{E_0}\right)} \quad (40)$$

After giving an overview of the different index decomposition methodologies, the next step it to select which of these alternatives will be most suitable for this study.

As can be seen, the main difference between both of them is the interpretation and computation of W_i'. Traditional and Törnqvist methodologies give a residual component, raising a potential disadvantage. In general, it makes the sum of the aggregated term different from the sum or multiplication of each component of the aggregation. In principle, it is desirable that the decomposition is perfect or complete, meaning that there is no deviation from the aggregated itself and the sum or multiplication of each component. With all this information, and although there is not a clear agreement of which is the optimal approach, the most convenient approach regarding the project specification will be between the LDMI I and LDMI II.

Both methodologies are the priority for many experts. Nevertheless, LDMI I method has apart from its theoretical background, some additional advantages with regard to other methods. [33][34]

- As mentioned before, the result does not generate a residual term, providing a perfect decomposition. Also, it fulfills both time and factor reversal property requirements.

- Results can be expressed in additive and multiplicative form. There is a simple mathematical relationship to link one with the other. As a result, there is no need to perform both approaches separately since one derives from the other. In the equation *x* represent the effect (structural, sectoral intensity...etc.) and *k* the sector.

$$\frac{\Delta I_{TOT}}{Ln(D_{TOT})} = \frac{\Delta I_{x,k}}{Ln(D_{x,k})} \tag{41}$$

- LMDI results are consistent with aggregation. This means that results can be evaluated at a subgroup level or aggregated at a higher level. For example, analyzing all the industrial sectors generates the same effect as if the industry as a whole is considered.

- It can incorporate without extreme complexity more than two factors only if they are properly defined in the main function.

Once the LDMI I is selected, this next chapter will try to adapt the mathematical formulation of the energy intensity to the CO_2 emission decomposition.

4. APPLICATION OF ENERGY INTENSITY TO EVALUATE CO_2 EMMISIONS IN SPAIN

4.1 METHODOLOGY FORMUALTION

In the former sections, it has been proven the importance of energy intensity and its close relationship with a country's evolution in emissions. In this part, it will be extrapolated the methodology implemented for the EI disaggregation considering some additional contributions that are relevant in the emission field. These factors will be analyzed for each productive sector. Up until now, the vast majority of the studies covering this application such as [36], limited their study by considering only the aggregation of all sectors or the industrial sector. As a result, this section will try to contribute by providing a more detailed disaggregation level into de the most relevant sectors. It will also help to identify which are the sectors that need special attention when assigning specific emission reduction measures in Spain.

The previously explained methodology is expanded into the evaluation of the CO_2 emissions by considering Figure 6.

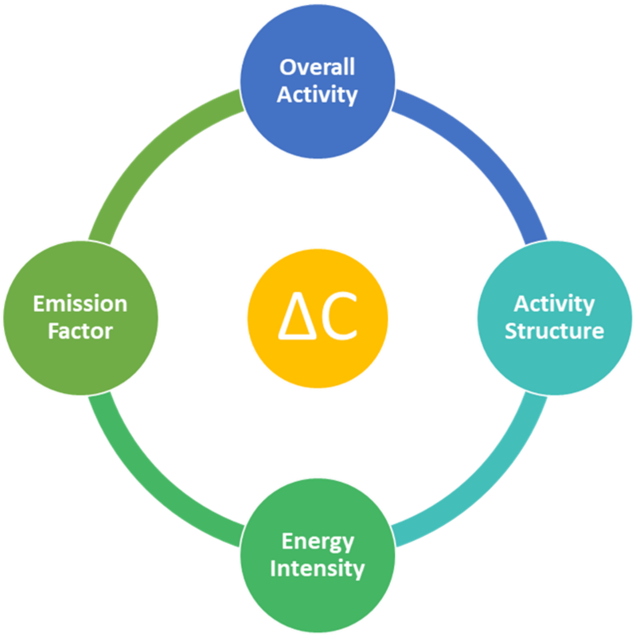


Figure 6: Emission index decomposition. Main components

- Overall activity (activity effect): The change in the aggregate associated with a change in the overall level of the activity [31].

- Activity structure (structure effect): The change in the aggregate associated with a change in the mix of the activity by sub-category.

- Sectoral energy intensity (intensity effect): The change in the aggregate associated with changes in the sub-category energy intensities.

- Emissions factor (emission factor effect): The change in the aggregated associated with changes in the sub-category emissions.

Each of these factors are mathematically formulated as follows,

$$C^T = \sum_i \frac{C_i^T}{E_t^T} \cdot \frac{E_i^T}{Y_t^T} \cdot \frac{Y_i^T}{Y^T} \cdot Y^T \tag{42}$$

Being *i* the different sectors of the economy which information is publicly available. The meaning behind these variables corresponds to,

C^T= CO_2 emissions at period *t*.

C_i^T= CO_2 emissions of sector *i* at period *t*.

E_i^T= Energy consumption of sector *i* at period *t*.

Y_i^T= Gross Value Added (GVA) of sector *i* at period *t*.

The equation above should be reconfigured in order to apply the LDMI index decomposition. Starting with the multiplicative form where the multiplication of each of these leads to the total CO_2 emissions. Resulting in,

$$C^T = \sum_i C_i^T = \sum_i I_i^T \cdot T_i^T \cdot S_i^T \cdot Y^T \tag{43}$$

Where,

I_i^T= EI of sector *i* at period *t*, representing the EI effect or intensity effect.

$$I_i^T = \frac{E_i^T}{Y_i^T} \quad (44)$$

T_i^T= CO_2 emission coefficient for by energy consumed of sector *i* at period *t*, representing the emission coefficient effect or emission factor effect.

$$I_i^T = \frac{E_i^T}{Y_i^T} \quad (45)$$

S_i^T= GVA participation of sector *i* into the total GDP at period *t*, representing the structure effect.

$$S_i^T = \frac{Y_i^T}{Y_T} \quad (46)$$

Y^T= total GDP, representing the activity effect.

CO_2 emissions variation could be disaggregated into these four effects following the LMDI I, which for the multiplicative form leads to:

$$\begin{aligned}\frac{C^T}{C^0} = \exp\left[\sum_i W_i^{T*} \cdot Ln\left(\frac{I_{i,T}}{I_{i,0}}\right)\right] \\ \cdot \exp\left[\sum_i W_i^{T*} \cdot Ln\left(\frac{T_{i,T}}{T_{i,0}}\right)\right] \\ \cdot \exp\left[\sum_i W_i^{T*} \cdot Ln\left(\frac{S_{i,T}}{S_{i,0}}\right)\right] \cdot \exp\left[\sum_i W_i^{T*} \cdot Ln\left(\frac{Y^T}{Y^0}\right)\right]\end{aligned} \quad (47)$$

The weighted factor is considered as:

$$W_i^{T*} = \frac{L(C_i^0, C_i^T)}{L(C^0\,, C^T)} = \frac{\dfrac{C_i^T - C_i^0}{\ln\left(\dfrac{C_i^T}{C_i^0}\right)}}{\dfrac{C^T - C^0}{\ln\left(\dfrac{C^T}{C^0}\right)}} \tag{48}$$

As mentioned before, this weighted factor enables the possibility of reaching a perfect and consistent decomposition.

4.2 STATISTICAL RESOURCES DESCRIPTION

After introducing the theoretical framework of CO_2 emissions in Spain and the relationship with energy intensity for the index decomposition methodology, it is required to explain the implemented resources of information and databases. In this particular case of emission evolution for Spain, and keeping in mind the last section describing each of the effects in CO_2 variation, this analysis is based on three types of data. It could be summarized by greenhouse gases emissions, energy consumption and economic data relative to Gross Domestic Product and Gross Value Added.

The information included in this database is based on a complex selection and harmonization of the limited data available. Special efforts have been made so as to solve information gaps in the original databases. The core objective is to achieve a homogeneous data.

It has only been reached to official statistical databases such as Statistics National Institute (SNI), European Statistical Office or Eurostat and International Energy Agency (IEA). Some minor additional sources of information have been included that it will be later mentioned. At the beginning of the study, the primary intention was to analyze the period cover between years 2005 and 2016, but after very limited information of one the parameters, it has finally reduced to periods from 2008 to 2016. Note that it has not gathered all the data for the year 2017, due to the fact that information presented in the platform for 2017 is at a preview stage.

- Greenhouse gases emissions:

  Several statistical resources give this variable. On the one hand, the IEA provides both worldwide and national information regarding CO_2 emissions, although with not an extended level of detailed. On the other hand, the SNI seemed the most reliable and complete source of information called "Accounts for atmospheric emissions". This platform presents atmospheric contaminant emissions, compatible with the National System Accounts having the main role of registering emitter agents breakdown into different sectors of the economy [38].

  The data is classified into several different categories. The user can select the desired activity sectors, following the CNAE (National Classification of Activities of the Economy) 2009 classification (see Annex A). It is defined as a systematization that allows grouping of different production units according to its activity in order to generate statistics. At the same time, it follows the statistical classification of economic activities in the European Community or NACE. Its mission is to provide the European Union with high-quality statistical information [37]. The relationship between CNAE and NACE is that CNAE is the national transposition of the NACE classification. Secondly, the contaminant substance which includes nitrous oxide (N_2O), methane (CH_4), Sulphur hexafluoride (SF_6), carbon dioxide (CO_2) and many others. In order to make it uniform, the larger part is provided in tons of carbon dioxide equivalent. This is a measure that represents tons of carbon footprint, the equivalent volume of that particular chemical element to a ton of carbon dioxide. This study will only evaluate the CO_2 emissions measured in tons of equivalent CO_2.

Unfortunately, from 2008 the way information is presented in the SNI platform changed. This not only includes the activity sectors, but also the substance classification where the exact value of CO_2 measured in thousands of tons of CO_2 equivalent cannot be found. Consequently, because it is not desirable that the first three years will distort the overall results of the study, years from 2005 and 2007 both included will remain out of the scope. At the present date of this document, neither SNI nor Eurostat have presented an updated version for the period before 2008.

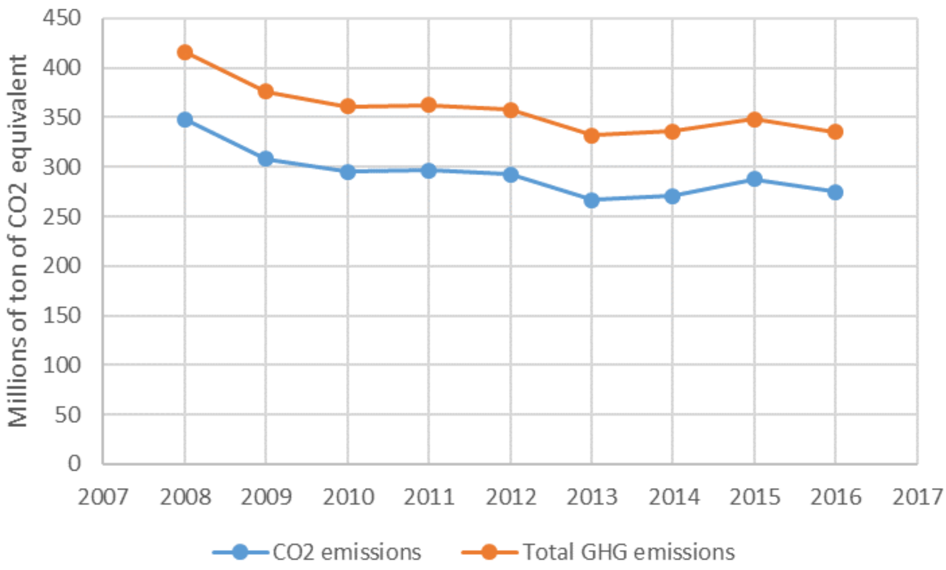


Figure 7: GHG and CO2 emission evolution in Spain from 2008-2016

It definitely looks like CO_2 emissions leads the trend of total GHG emissions in Spain, accounting for 80 and 84 percent participation in the global performance.

- Energy consumption:

  Again, general information regarding energy consumption in Spain could be found in IEA. For every country member of the European Union, the energy consumption is given though energy balances. Also, a very common visual tool to express the energy flows from generation to final energy consumption into the different sectors are the Sankey diagrams. Figure 8 gives an illustrative example of the Spanish energy flows in 2016. It could be seen that final consumption classification is divided into only four main categories. Nevertheless, the most level of detailed found for final energy consumption for Spain was in both energy balances at IDAE and Eurostat measures in *ktoe* (thousands of ton of oil equivalent) [39] [40]. The conversion of physical units into *toe* is done based on the lower calorific value of each energy sources considered. It is important to emphasize the fact that this study will evaluate the final energy consumption, not including transformation sectors. In summary, they are considered final energy consumption including industry, transport and other sectors as services. It is not included the final non-energy consumption. They are not analyzed because usually they are not implemented for energy production.

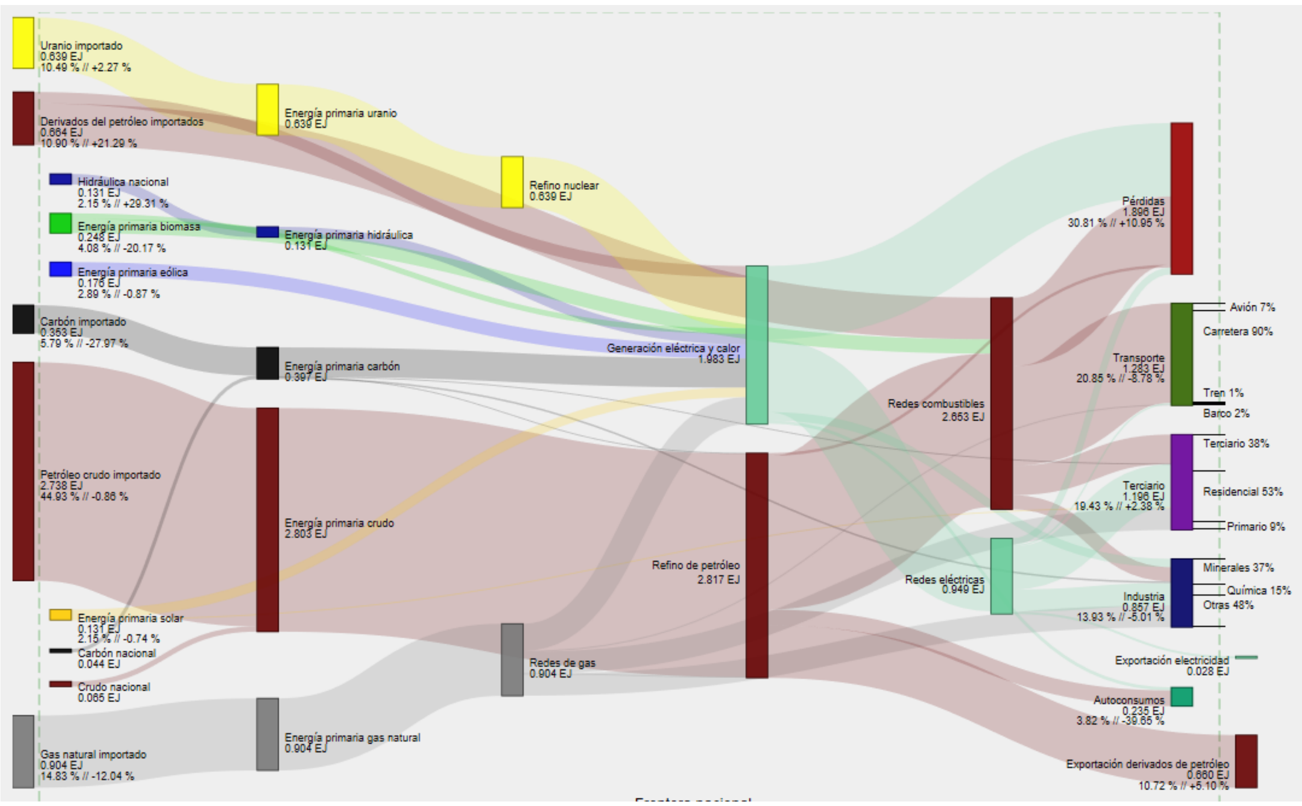


Figure 8:Energy consumption in Spain 2016. Sankey diagram. Source [41]

This classification introduces some limitations: They arise because the breakdown level of the published energy balances is very low compared to the emissions platform by SNI. Table 4 shows the relationship for the adjustment of categories for the energy consumption (energy balances by Eurostat) and SNI national accounts for emission evolution and gross value added which will be explained later on. It has been aggregated the SNI classification into the Eurostat since it is simpler than the other way round. Otherwise, the level of complexity and error will have been much higher.

Table 4: Relationship between energy consumption information (Eurostat) and CO_2 emissions and GVA (SNI)

	Aggretated Activities (Eurostat classification)	Detailed Activities (SIN/NACE classification)
INDUSTRY	Iron and Steel Industry+Non-ferous metal industry	24; 25; 35(%)
	Chemical and Petrochemical industry	19; 20; 21; 22; 35(%)
	Non-metallic Minerals (Glass, pottery & building mat. Industry)	23; 35(%)
	Transport Equipment	29; 30; 35(%)
	Machinery	26; 27; 28; 35(%)
	Mining and Quarrying	05-09; 35(%)
	Food and Tabacco	10-12; 35(%)
	Paper, Pulp and Print	17; 18; 35(%)
	Wood and Wood Products	16; 35(%)
	Construction	35(%); 41-43
	Textile and Leather	13-15; 35(%)
	Non-specified (Industry)	31-32; 35(%)
TRANS PORT	Rail+Road+ Pipeline Transport	35(%); 49
	International+Domestic aviation	35(%); 51
	Domestic Navigation	35(%); 50
	Non-specified (Transport)	35(%); 52
OTHER SECTORS	Services	33; 35(%); 36; 37-39; 45; 46; 47; 53; 55-56; 58; 59-60; 61; 62-63; 64; 65; 66; 68; 69-70; 71; 72; 73; 74-75; 77; 78; 79; 80-82; 85; 86; 87-88; 90-92; 93; 94; 95; 96
	Residential	97-98; 35(%)
	Agriculture / Forestry	1; 2; 35(%)
	Non-specified (Other)	35(%); 84

The standardization of both databases was implemented with the Eurostat's guidelines document This document is entitled to provide support for the construction of energy balances [42]. Sometimes it provided the relationships between NACE classification and Eurostat. Non-specified transport accounts for quantities of fuels used for transport activities not included elsewhere. Includes fuels used by airplanes for their road vehicles and fuels used in ports for ships' unloaders, various types of cranes. Non-specified other it is referred to military fuel use for all mobile and stationary consumption (e.g. ships, aircraft) regardless of whether the fuel delivered is for the military of that country or for the military of another country. For these two categories, it was especially difficult to assign a NACE category. After, reading the guidelines set by Eurostat it has been allocated to categories 52 and 84 respectively.

Some additional special assumptions are worth mentioning. All Eurostat categories have a “35%” category. This is the one for electricity, gas, steam and air conditioning supply. It is obvious that every category is an electricity consumer, and therefore category 35 has been proportionally distributed according to the electricity consumption of each Eurostat category. For example, chemical and petrochemical industry consumes 945,73 *ktoe* (4,31%) of total final electricity consumption (21934,13 *ktoe*). As a result, a 4,31% of the total emissions associated with electricity, gas and steam supply will be assigned to chemical and petrochemical industry. Another assumption was that fishing sector was excluded from the study since at some periods there was no information available related to energy consumption and thus to avoid any possible noise in the statistical computation.

- Gross value added (GVA) and Gross domestic product (GDP):

  In a similar fashion as in the case of CO_2 emissions, the GVA separated into the different sectors of the economy is found at SNI. However, the information at the SNI platform is rather incomplete for our study [43]. Some years ago, the data regarding GVA was given both at current and constant values, now it is only given at current values without any base year. This makes the requirement of making an extra adjustment for the current values, selecting a baseline year, and translating these values into constant. If this step is skipped, these current values will include undesired noise related to inflation.

  To perform this modification, a deflator should be defined. The deflator is an economic metric that accounts for inflation by converting output measured current prices into constant-dollar. This deflator shows how much a change in the base year’s GDP relies upon changes in the price level [44].

  The first option that was analyzed as a possibility which is very common is the Consumer Price Index (CPI) as deflator [45]. This is calculated by dividing the current value by one plus the CPI variation between that year and baseline year. The selected baseline year for this study is 2008. However, this alternative is not the most appropriate one owing to the fact that CPI only affects final consumer prices.

The final deflator used in this the GDP deflator proposed by the World Bank [46]. Figure 9 shows a relative comparison between the two possibilities for a deflator. The selection of one or the other option will drastically change the finals statistic results. The PCI as deflator would have led to lower GDP if used instead of the World Bank deflator.

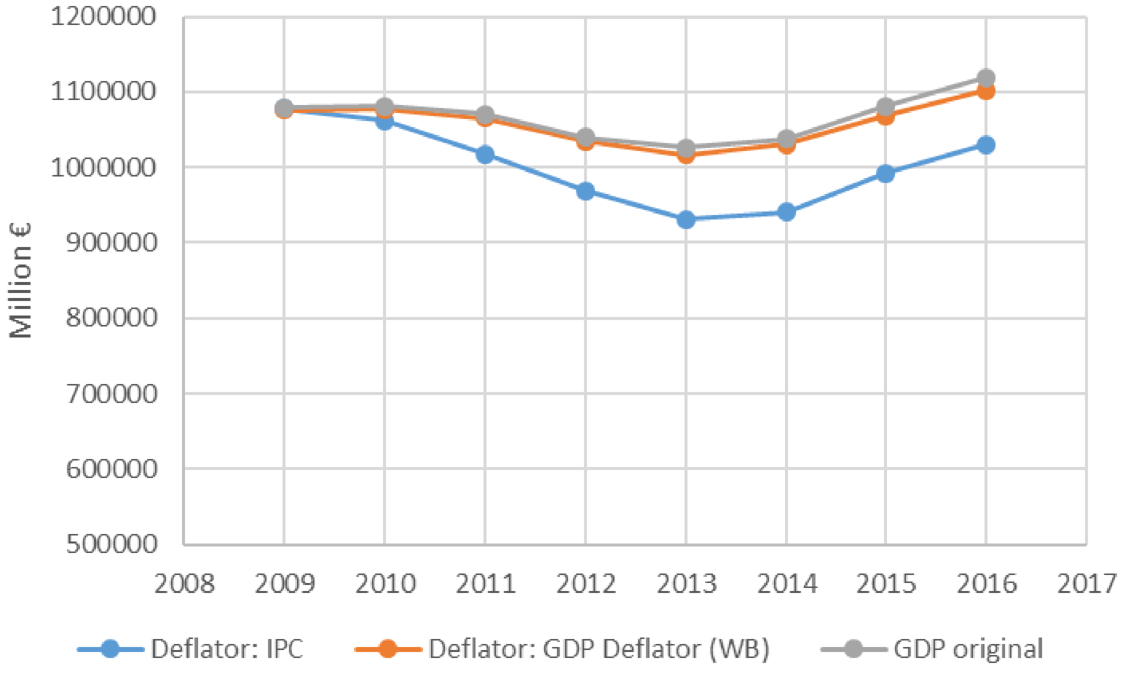


Figure 9: Comparison between deflator alternatives: PCI and World Bank GDP Deflator

The reason why there is not much difference between the GDP at current values and at constant values using the GDP deflator by World Bank is illustrated in Figure 10. Particularly the years of evaluation (2008-2016) the GDP deflator barely changes if the baseline year is 2008.

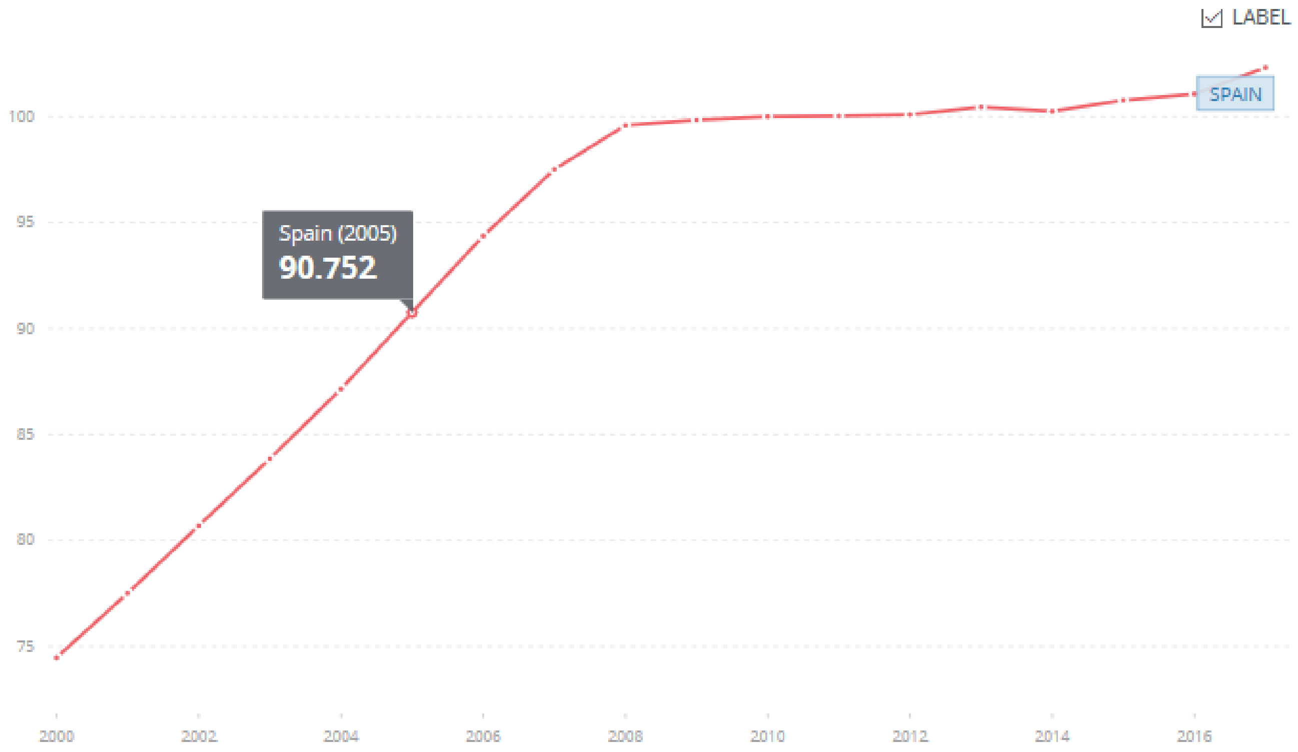


Figure 10: GDP Deflator. Source: World Bank[46]

4.3 RESULTS ANALYSIS

Once it has been gathered all the mathematical background, defined and adapted the selected methodology and at the same time adjusted the statistical data, it can be computed the evolution of the CO_2 emissions in Spain across years 2008 and 2016. The aim of this section is to identify to what extent which sectors have contributed to its evolution in intrasectoral, emissions coefficient, structural and activity terms.

First and foremost, before entering into detail about the implication of each of the individual sectors, it is interesting to illustrate the global performance of the four indexes decomposition in the multiplicative form (see Figure 11). That way it can be seen the influence of each one of them.

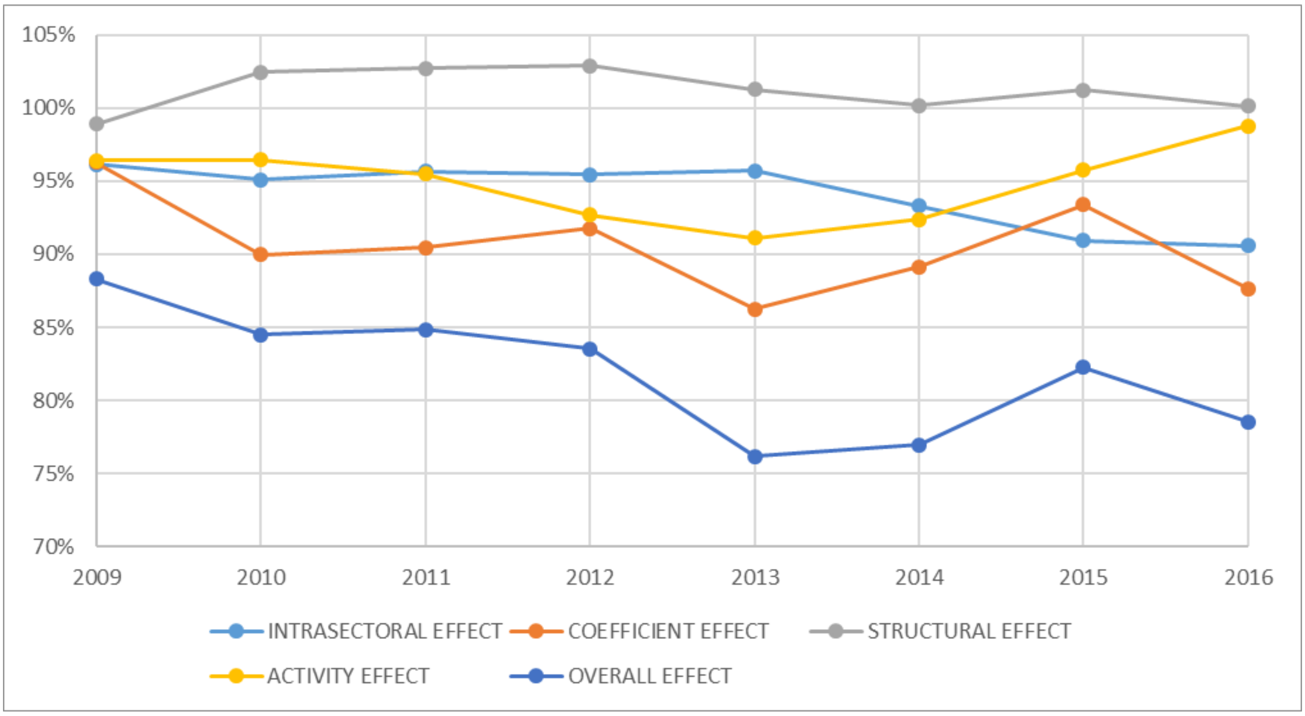


Figure 11: CO2 emission index decomposition from 2008 to 2016. Baseline year 2008

This figure should be interpreted in the following way. Year 2008 has been selected as the base one for all the consecutive years. It shows the relative performance of each indicator compare to the base year. Total CO_2 variation at one year (overall effect) arises from the result from multiplication of the intrasectoral, activity, coefficient and structural effects. It is relevant to point out the fact that if a different baseline year is chosen, results from Figure 11 will be different.

All indexes seemed to have a decreasing trend, resulting in a lower overall effect and therefore reducing the overall CO_2 emissions in Spain. They do not experiment a dramatic change in trend or variation, since most of them oscillate between a 10% compared to the baseline year. There is the only exception of the coefficient effect at some point in time that goes below 90%. Once again, in order to actually understand what is behind those indexes, the should be divided into the different subsectors of the economy.

Table 5 illustrates the Spanish CO_2 emissions evolution disaggregated into different indexes between 2008 and 2016 for the sectors whose information is currently available. It has been chosen to represent these two years owing to the fact that they are the ones located at the extremes under the evaluated period (see Annex B for additional information regarding other years, similar information can be extracted). To facilitate the analysis, results have been converted into the additive methodology. In other words, now the CO_2 emissions growth in Spain is the sum of all the emissions of each sector (global factor) which at the same time is the individual sum of intrasectoral, coefficient, structural and activity effects.

Table 5: CO2 emission decomposition in Spain between 2008 and 2016 (Million tons of equivalent CO2)

		Additive decomposition (Mton CO2)					
		INTRASEC	COEFF EM	STRUCTURAL	ACTIVITY	GLOBAL	%
INDUSTRY	Iron and Steel Industry+Non-ferous metal industry	1,0779	-4,4532	-2,8630	-0,2403	-6,4785	8,7%
	Chemical and Petrochemical industry	3,1779	-9,4328	3,7963	-0,3652	-2,8237	3,8%
	Non-metallic Minerals (Glass, pottery & building mat. Industry)	-2,1595	5,5542	-21,7408	-0,4658	-18,8120	25,4%
	Transport Equipment	-1,6112	-0,4364	0,2092	-0,0381	-1,8765	2,5%
	Machinery	-0,4823	-1,2549	-0,3140	-0,0443	-2,0954	2,8%
	Mining and Quarrying	3,0412	-4,9576	-1,8298	-0,0433	-3,7894	5,1%
	Food and Tabacco	0,0367	-0,8881	0,4876	-0,0698	-0,4336	0,6%
	Paper, Pulp and Print	-0,0967	-0,1262	-1,5212	-0,0754	-1,8194	2,5%
	Wood and Wood Products	0,4803	0,3363	-0,9149	-0,0241	-0,1223	0,2%
	Construction	2,0427	-2,3458	-0,9525	-0,0185	-1,2741	1,7%
	Textile and Leather	-0,1090	-0,3075	-0,2980	-0,0188	-0,7333	1,0%
	Non-specified (Industry)	-1,3557	0,8241	-0,7248	-0,0283	-1,2847	1,7%
TOTAL INDUSTRY		**4,0423**	**-17,4877**	**-26,6658**	**-1,4318**	**-41,5430**	56,0%
TRANSPORT	Rail+Road+ Pipeline Transport	-6,2110	-5,0803	0,3379	-0,4457	-11,3991	15,4%
	International+Domestic aviation	-2,7233	2,1525	3,3974	-0,1599	2,6667	-3,6%
	Domestic Navigation	-2,6713	-0,0261	0,4644	-0,0372	-2,2703	3,1%
	Non-specified (Transport)	1,3120	-0,5335	0,1506	-0,0079	0,9212	-1,2%
TOTAL TRANSPORT		**-10,2936**	**-3,4875**	**4,3503**	**-0,6506**	**-10,0814**	13,6%
OTHER SECTORS	Services	2,5567	-14,1236	2,5298	-0,4342	-9,4713	12,8%
	Residential	-19,9760	-9,6990	18,5513	-1,1244	-12,2481	16,5%
	Agriculture / Forestry	-2,6675	1,1798	1,5625	-0,1356	-0,0609	0,1%
	Non-specified (Other)	-4,0842	3,1945	0,1306	-0,0396	-0,7987	1,1%
TOTAL OTHER SECTORS		**-24,1710**	**-19,4483**	**22,7741**	**-1,7338**	**-22,5790**	30,4%
TOTAL		**-30,4223**	**-40,4235**	**0,4586**	**-3,8162**	**-74,2034**	100,0%

It is important to keep in mind during all the process the meaning behind each of those effects. If each component is analyzed separately, CO_2 emission reduction is essentially due to a decrease in energy intensity (-30,42 Mton CO_2), that is the intrasectoral effect and a transition towards lower polluting fuels with the emissions coefficient (-40,42 Mton CO_2). The leading role of the high contribution in reducing CO_2 emissions because of energy intensity are the other sectors that are neither transport or industry, which is mostly because of the residential sector (-19,98 Mton CO_2) and the transportation sector (-10,29 Mton CO_2). The emission coefficient reduction in comparison with 2008 was because of essentially other sectors such as services (-14,12 Mton CO_2), and residential (-9,69 Mton CO_2). Meanwhile, for the industry (-17,48 Mton CO_2) is more of less evenly distributed among sectors, being the chemical and petrochemical industry the one with the highest value.

Apparently, the structural effect has remained almost steady between these two years, although thanks to the detailed level of disaggregation, it can be seen that there is an important reason hidden. Increased participation on the GDP activity from other sectors like residential (18,55 Mton CO_2) and transportation (4,35 Mton CO_2), has been compensated with a decrease in general in the industry sector (-26,66 Mton CO_2).

Spain's total GDP at constant prices has barely increased in comparison with 2008, that is the activity effect, and therefore had very limited contribution to total CO_2 emission reduction. More specifically, it only represents a 5% contribution of the global performance.

Additionally, almost every sector of the economy has reduced their energy intensity (intrasectoral effect), with some exceptions. Chemical and petrochemical industry (3,17 Mton CO_2), mining (3,04 Mton CO_2), services (2,55 Mton CO_2) and construction (2,04 3,04 Mton CO_2) are the ones that have, yet very low, positive contributions to the intensification of energy intensity. The construction sector is subject to a sector restructuring after the economic crisis due to market contraction [47]. It seems that Spain is experimenting an energy transition towards a reduction of energy intensity. Table 6 illustrates some values for the efficiency of conversion of primary energy into electricity. They would slightly change depending on the specific type of technology, the objective of this table is to provide just a level of magnitude. This means that there is the technology mix is shifting to more energy efficient technologies such as wind and solar, trying to replace more conventional technologies as in the case of coal which induce to a greater level of energy intensity. This activity is not only implemented at a national level in Spain, but at least at a European scale. Nevertheless, when the generation mix is diversified, meaning that technologies with different efficiency factors contribute to energy supply, the interpretation of the overall energy intensity is distorted.

Table 6: Efficiency factors for electricity production. Source ***¡Error! No se encuentra el origen de la referencia.***

	Efficiency factors for electricity production (%)
Coal	36
Oil derivatives	40
Nuclear	33
Gas	56
Hydro	100
Wind and Solar	100
Biomass	33

On the other hand, emission coefficient presents a similar trend as the intrasectoral factor or the one related to energy intensity, although with slight differentiations. Services sector present an emission reduction of -14,12 Mton CO_2. This situation takes place because there is a sector limitation when it comes to decarbonization, because its energy supply comes primarily from electricity. This reduction is explained by an improvement in energy performance in buildings, demand management and air conditioning systems. This argument could be also applicable to the residential sector with a -9,69 Mton CO_2 contribution. Also, it looks like the chemical and petrochemical industry provides a -9,43 Mton CO_2 reduction, which means that it changed its energy sources. Something that is unusual as well as unexpected.

Another possible way of analyzing Table 5 results its by evaluating each sector individually. To begin with the industrial sector, iron and steel with chemical and petrochemical industry are usually classified within the most electro intensive industry sectors. Regardless of that circumstances, the keep reducing their energy intensities by 1,07 Mton CO_2 and 3,17 Mton CO_2 respectively. The main reason behind these values could be because they want to evolve and incorporate measures to improve their energy efficiency. For instance, the purpose of replacing conventional fuels with electricity. Non-metallic minerals industry is the area that has by far the largest participation with 81% in the decrease of the structural effect, meaning the mix in the economic activity. One possible reason could be due to a reshaping of this industry after the crisis, since it incorporates manufacturing processes related to construction like building materials. The remaining industrial sectors also decrease their participation with a lesser extent than non- metallic minerals, but with one exception. Chemical and petroquemical industry increase its participation in the economy with 3,79 Mton CO_2. Figure 12 and Figure 13 gives an historical chart of Brent (Europe) crude oil prices measured in $ per barrel over the last ten years and Henry Hub natural gas prices in U.S dollars. It can be confirmed base on both figures that the increase in participation in the chemical and petroquemical industry unlike some other industrial sectors, is because prices very low compared to 2008 values, especially at the beginning of 2016. By the end of 2008, crude oil prices were around 90$ per barrel and in 2016 they decreased to even 30$ barrel. In the case of natural gas, the change was even more severe. Prices decrease from 12-14$ to 3$, almost a 77% decline.

Figure 12: Brent Crude Oil prices. 10 year daily chart. Source own elaboration from [49]

Figure 13: Natural Gas prices. Historical data. Source [48]

From the transportation point of view, they all have increased their structural component. Improvements in infrastructure as well as freight transport, may be some of the reasons behind these changes. Besides, this sector improved the energy intensity by 33% in the total contribution to reduce this index in Spain. Consequently, it resulted in a -10,29 Mton CO_2 emission reduction. In a lesser extent, they provided a reduction of the emission coefficient with -3,48 Mton CO_2. Both of these reductions are mainly because an enhancement to more energy efficient technologies and less pollutant fuels, particularly in vehicles for freight and people transportation (rail, road and pipeline transport). However, it is complicated to assign these achievements to one specific sector within the transportation area. It is still a diffuse sector where it is not subject to very strict political restrictions and/or regulation.

Finally, the other sectors classification need as well special individual analysis. Services sector increased their structural contribution to the economy with 2,53 Mton CO_2, because of an intensification of the tourism activity according to Figure 14. There was an 32% increase in tourism activity in 2016, reaching a record of a total expenditure of 77.000 million euros [53].

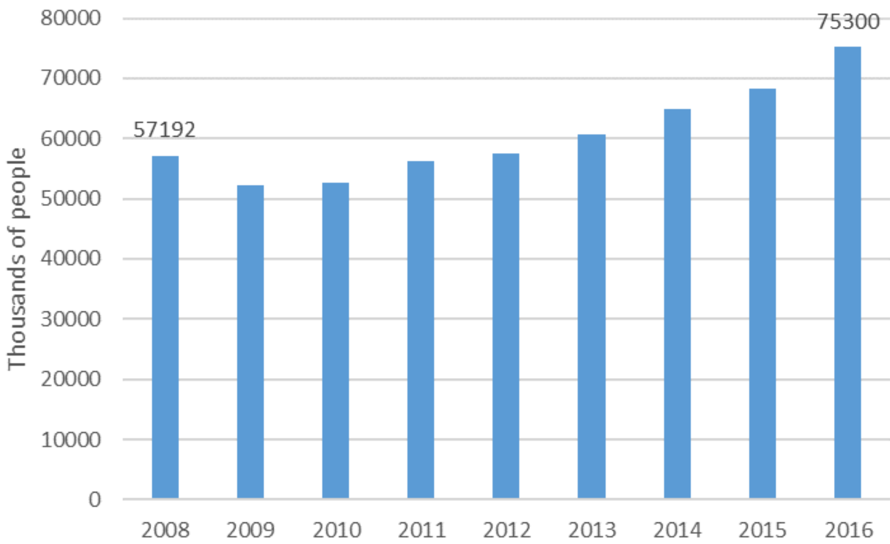


Figure 14: Number of international tourist received in Spain. Own elaboration from FRONTUR:[52]

The residential sector turned out to be one of the sectors with the largest increase in participation in the economy with 18,55 Mton CO_2.that at the same time is capable of improving energy intensity with -19,97 Mton CO_2 and moving towards less pollutant fuels with -9,69 Mton CO_2 emission reduction contribution. On top of that, there are government programs with commercial campaigns so as to foster and efficient management of energy consumption.

These activities are encouraged by incentive programs on renewable energy generation in order to attract new investments. At that moment, it required substantial investment costs compared to the present time of this document. Renewable energy sources (RES) are characterized for being sources of energy that emit little to no greenhouse gases or pollutants into the air, resulting in a positive impact to the natural environment. Introduction of RES leads to a reduction of both intrasectoral and emission coefficient. Apart from that, between these particular years, there was a change in the electricity generation mix according to Figure 15 and Figure 16. They represent the electricity generation balance by source or technology. Year 2016 is defined by the outstanding role of hydro and renewable generation, primarily wind generation, replacing coal and combined cycle. This is a key driving force that could help explain the behavior behind the effects regarding the residential sector and it can be extrapolated to other sectors such as services since most of their energy consumption comes from electricity. Note that some other years could have a different electricity generation mix and emissions can change.

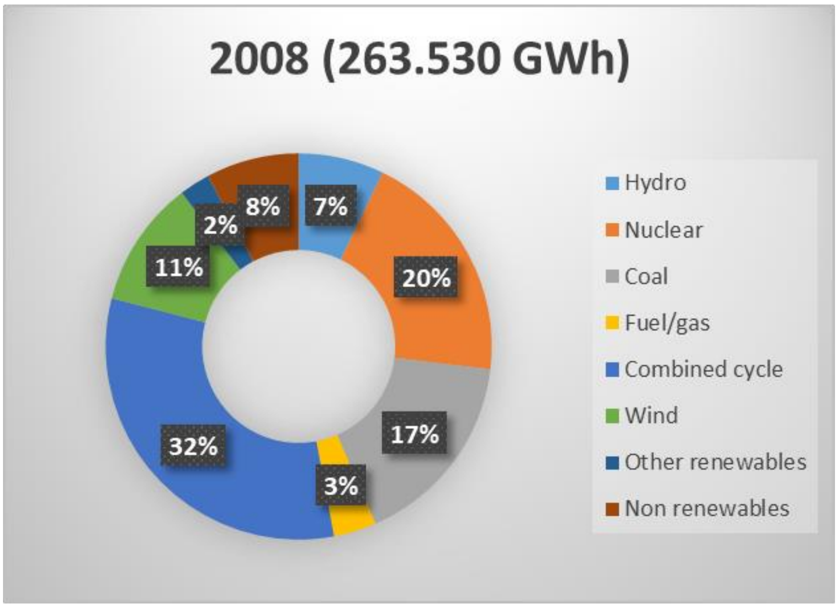


Figure 15: Spanish electricity generation balance in 2008. Source: [50]

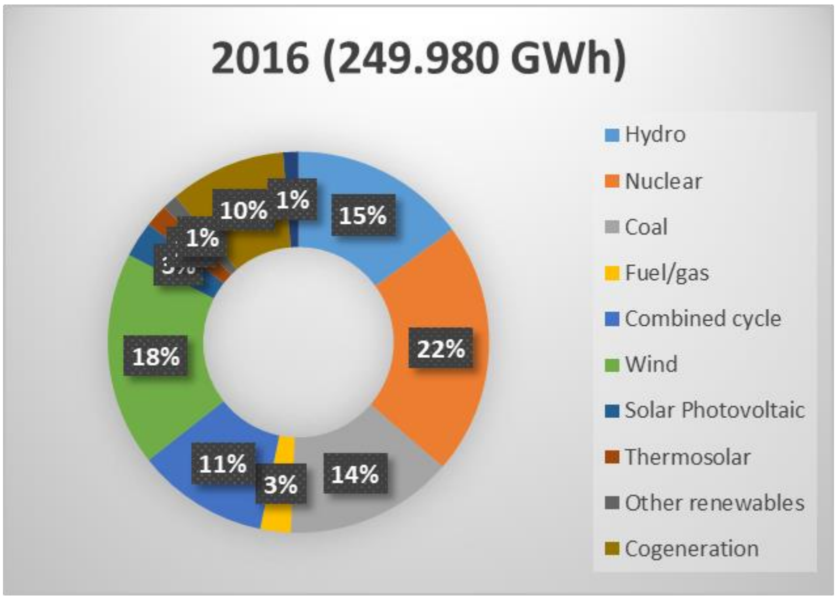


Figure 16: Spanish electricity generation balance in 2016. Source: [51]

5. CONCLUSIONS

This Master Thesis tried to understand and analyze any direct and/or implicit drivers behind the evolution of CO_2 emissions in Spain. It began with an introductory chapter dedicated to highlighting the fact that there is now an almost unanimous agreement that emissions of GHG contribute in an essential way to the change of the global climate. After more than a century of industrial activity in developed countries, human activity is one of the main responsibility sources of some undesirable consequences derived from GHG emissions. That is why several institutions such as the UNFCCC were created. Moreover, it has been provided an overview of the regulatory framework at a national and international level, regarding the fight against climate change. Some examples are presented like international targets, commitments and national strategies for the upcoming decades. Some of them require Member States to monitor their GHG emissions. The possibility of measuring the impact of human activity on climate with GHG emissions, it encouraged government initiatives to stabilize those emissions at the right level that keeps increasing temperatures under control.

Carbon dioxide is one of the most abundant elements within GHG emissions. Most of the official reports present the CO_2 historical evolution as an aggregated variable, making it difficult to extract any valuable information. As a result, the aim of this project was to provide detail analysis of possible economic and technological drivers behind the performance of CO_2 emissions. While the total CO_2 emission change is a highly aggregate indicator, it can be decomposed so as to evaluate the underlying effects. This indicator was disaggregated by sectors of final energy consumption and into different effects by index decomposition. Because global CO_2 variations could be owing to direct improvements such as energy efficiency, technology or uncontrollable situations like economic growth.

In the beginning, it was interesting to introduce the definition of energy intensity and its relationship with CO_2 emissions. They both have several things in common. Their performance can be affected by other implicit variables such as economic structure, technology innovation, regulation, prices...etc.

Apart from some limitations that later on will be mentioned, the generated analysis showed that CO_2 emissions were reduced from 2008 to 2016 by 21,45% mainly driven by changes in energy intensity (-30,42 Mton CO_2) and emissions coefficient (-40,42 Mton CO_2). These two terms represent a technological improvement from more energy efficient and fewer pollutant technologies. Increased participation in the GDP activity from the residential sector and transportation, was compensated by the decrease in general in the industry sector (mainly in the non-metallic minerals industry).

These results are due to several reasons, some of them are mentioned. Spain is experimenting with an energy transition towards a reduction of energy intensity, increasing the share of fewer pollutant technologies such as renewable energies with a larger efficiency factor for electricity than some other conventional sources of energy. On the other hand, some sectors are experimenting a sector restructuring after the crisis, resulting in a decrease in their economic activity which is the case of the non-metallic minerals industry. Meanwhile, because of a decrease in input prices (i.e. Crude oil, Brent), some sectors have increased their activity in the economy. Most importantly, there are strong incentives on renewable energy generation. Particularly in the year 2016 because of climate consequences, the participation of hydro and wind generation was intensified compared to 2008 which lead to emission reduction.

This document shows that energy efficiency and economic factors have a decisive importance in the GHG emission evolution. The regulatory area still plays a fundamental role when it comes to determining the evolution of these factors. Spain is one of the countries with very ambitious targets for the next decades. With the appropriate incentives and knowing the information behind the evolution of CO_2 emissions, trends can change in order to ensure the compliance of current and future targets.

It is expected that the outcome of this project has successfully contributed the best way possible to help the society towards a more sustainable future where there is a clear incentive for non-pollutant technology innovation. There is a worldwide energy transition defined among other attributes, by the increased participation of new emerging energy forms that contribute to a de-carbonized, decentralized and digitalized world where detailed CO_2 emission analysis could facilitate the evolution of this transition in a more efficient way.

6. DIFFICULTIES AND FUTURE STUDIES

This analysis presents some limitations, especially because there was a lack of homogeneity between the databases available. Energy consumption data published by Eurostat had very low detailed information compared to the CO_2 emissions, GVA, and GDP classified by sector published by SNI. Consequently, there was an additional effort made to make both statistics uniform. Some sectors of the economy such as fishing did not have data available for those specific years. At the beginning, it included some noise into results. To avoid it, it ended up being excluded from the scope of this study. Also, up to 2008, the way information was provided by the SNI was completely different as it is from 2008. Hence, the period of evaluation was reduced from 2008 to 2016 instead of 2005-2016 which was the original objective.

Future studies could arise from this project. It could be interesting to assess the underlying effects in the GHG emission evolution from an international trade perspective as a complementary study to the national outlook just presented. Note that the methodology to implement for international trade depends on how statistical data is provided since it is not that accessible in comparison to national energy consumption or GVA. Another possible study is if the information is displayed as an input- output table, a structural analysis decomposition can give extra conclusions by showing the relationship between sectors.

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8. Annex A: NACE classification

01	Crop and animal production, hunting and related service activities
02	Forestry and logging
05-09	Mining and Quarrying
10-12	Manufacturing
13-15	Manufacture of textiles, wearing apparel, leather and related products
16	Manufacture of wood and products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
17	Manufacture of paper and paper products
18	Printing and reproduction of recorded media
19	Manufacture of coke and refined petroleum products
20	Manufacture of chemicals and chemical products
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
22	Manufacture of rubber and plastic products
23	Manufacture of other non-metallic mineral products
24	Manufacture of basic metals
25	Manufacture of fabricated metal products, except machinery and equipment
26	Manufacture of computer, electronic and optical products
27	Manufacture of electrical equipment
28	Manufacture of machinery and equipment n.e.c
29	Manufacture of motor vehicles, trailers and semi-trailers
30	Manufacture of other transport equipment
31-32	Manufacture of furniture and other manufacturing
33	Repair and installation of machinery and equipment
35	Electricity, gas, steam and air conditioning supply
36	Water collection, treatment and supply
37-39	Sewerage, waste collection, treatment and disposal activities, materials recovery and remediation activities and other waste management services
41-43	Construction of buildings, civil engineering, specialized construction activities
45	Wholesale and retail trade and repair of motor vehicles and motorcycles
46	Wholesale trade, except of motor vehicles and motorcycles
47	Retail trade, except of motor vehicles and motorcycles
49	Land transport and transport via pipelines
50	Water transport
51	Air transport

52	Warehousing and support activities for transportation
53	Postal and courier activities
55-56	Accommodation and food and beverage service activities
58	Publishing activities
59-60	Motion picture, video and television programme production, sound recording and music publishing activities
61	Telecommunications
62-63	Computer programming, consultancy and related activities, information service activities
64	Financial service activities, except insurance and pension funding
65	Insurance, reinsurance and pension funding, except compulsory social security
66	Activities auxiliary to financial services and insurance activities
68	Retail estate activities
69-70	Logal and accounting activities, activities of head offices, management consultancy activities
71	Architectural and engineering activities; technical and testing analysis
72	Scientific research and development
73	Advertising and market research
74-75	Other professional, scientific and technical activities, veterinary activities
77	Rental and leasing activities
78	Employment activities
79	Travel agency, tour operator reservation service and related activities
80-82	Security and investigation activities, services to buildings and landscape activities, office administrative, office support and other business support activities
84	Public administration and defense; compulsory social security
85	Education
86	Human health activities
87-88	Residential care activities, social work activities without accommodation
90-92	Creative, arts and entertainment activities, libraries, archives, museums and other cultural activities, gambling and betting activities
93	Sports activities and amusement and recreation activities
94	Activities of membership organizations
95	Repair of computers and personal and household goods
96	Other personal service activities
97-98	Activities of households as employers of domestic personnel, undifferentiated goods and services-producing activities of private households for own use

9. Annex B: Additional years of CO_2 emissions decomposition in Spain

Table 8: CO2 emission decomposition in Spain between 2008 and 2009 (Million tons of equivalent CO2)

		ADITIVE (Mton CO2)					
		INTRASEC	COEFF EM	STRUCTURAL	ACTIVITY	CONJUNTO	%
INDUSTRY	Iron and Steel Industry+Non-ferous metal industry	-0,4035	0,4058	-3,7700	-0,7405	-4,5083	11,1%
	Chemical and Petrochemical industry	-1,8780	1,0559	-1,8173	-1,0492	-3,6885	9,1%
	Non-metallic Minerals (Glass, pottery & building mat. Industry)	-1,5222	2,5573	-10,9964	-1,5118	-11,4732	28,4%
	Transport Equipment	-0,6184	0,3863	-0,2676	-0,1368	-0,6365	1,6%
	Machinery	0,3576	-0,8722	-0,3633	-0,1517	-1,0296	2,5%
	Mining and Quarrying	0,3204	-0,4502	-0,8508	-0,1856	-1,1662	2,9%
	Food and Tabacco	-0,1571	-0,5627	0,2068	-0,1986	-0,7115	1,8%
	Paper, Pulp and Print	-0,1222	0,2040	-0,4470	-0,2435	-0,6086	1,5%
	Wood and Wood Products	0,0166	0,1105	-0,4581	-0,0651	-0,3961	1,0%
	Construction	0,8348	-1,1306	-0,0534	-0,0724	-0,4216	1,0%
	Textile and Leather	0,3179	-0,4248	-0,1676	-0,0629	-0,3374	0,8%
	Non-specified (Industry)	0,2220	-0,9562	-0,2772	-0,0867	-1,0980	2,7%
TOTAL INDUSTRY		**-2,6322**	**0,3232**	**-19,2618**	**-4,5048**	**-26,0755**	64,5%
TRANSP ORT	Rail+Road+ Pipeline Transport	-1,5767	-2,0098	0,7093	-1,4389	-4,3161	10,7%
	International+Domestic aviation	-0,9600	-0,5238	0,3553	-0,3915	-1,5200	3,8%
	Domestic Navigation	-0,7914	0,0413	0,2015	-0,1421	-0,6907	1,7%
	Non-specified (Transport)	0,0707	-0,0704	0,0110	-0,0102	0,0011	0,0%
TOTAL TRANSPORT		**-3,2574**	**-2,5627**	**1,2771**	**-1,9827**	**-6,5257**	16,1%
OTHER SECTOR S	Services	0,5846	-2,8299	1,2681	-1,4033	-2,3806	5,9%
	Residential	-7,4944	-7,0004	13,4920	-3,4277	-4,4305	11,0%
	Agriculture / Forestry	-0,4233	0,8461	-0,6024	-0,3865	-0,5661	1,4%
	Non-specified (Other)	0,5181	-1,1515	0,2897	-0,1221	-0,4658	1,2%
TOTAL OTHER SECTORS		**-6,8150**	**-10,1358**	**14,4474**	**-5,3396**	**-7,8430**	19,4%
TOTAL		**-12,7045**	**-12,3753**	**-3,5373**	**-11,8271**	**-40,4442**	100,0%

Table 7: CO2 emission decomposition in Spain between 2008 and 2010 (Millions of tons of equivalent CO2)

		ADITIVE (Mton CO2)					
		INTRASEC	COEFF EM	STRUCTURAL	ACTIVITY	CONJUNTO	%
INDUSTRY	Iron and Steel Industry+Non-ferous metal industry	0,8379	-1,3228	-2,8382	-0,7462	-4,0693	7,6%
	Chemical and Petrochemical industry	-1,7299	0,3954	-1,0567	-1,0498	-3,4411	6,4%
	Non-metallic Minerals (Glass, pottery & building mat. Industry)	3,9384	0,5898	-15,6364	-1,4836	-12,5918	23,5%
	Transport Equipment	-1,0434	0,7049	-0,4524	-0,1307	-0,9216	1,7%
	Machinery	0,2666	-1,4533	-0,4733	-0,1354	-1,7955	3,4%
	Mining and Quarrying	-0,1471	0,2119	-0,6114	-0,1931	-0,7397	1,4%
	Food and Tabacco	-0,0983	-1,3070	0,3084	-0,1867	-1,2836	2,4%
	Paper, Pulp and Print	-2,0178	0,7607	-0,3106	-0,2198	-1,7875	3,3%
	Wood and Wood Products	0,0865	0,0571	-0,5651	-0,0631	-0,4846	0,9%
	Construction	0,5948	-0,9153	-0,4007	-0,0648	-0,7860	1,5%
	Textile and Leather	0,0707	-0,1434	-0,2094	-0,0625	-0,3445	0,6%
	Non-specified (Industry)	0,8178	-1,8554	-0,4658	-0,0755	-1,5790	2,9%
TOTAL INDUSTRY		**1,5761**	**-4,2775**	**-22,7116**	**-4,4112**	**-29,8242**	55,7%
TRANSP ORT	Rail+Road+ Pipeline Transport	-3,0555	-2,7939	1,2207	-1,4009	-6,0296	11,3%
	International+Domestic aviation	-1,4744	-0,7003	1,0989	-0,3910	-1,4668	2,7%
	Domestic Navigation	-1,5337	0,0043	0,8039	-0,1382	-0,8637	1,6%
	Non-specified (Transport)	0,0464	-0,0428	0,0351	-0,0106	0,0281	-0,1%
TOTAL TRANSPORT		**-6,0172**	**-3,5326**	**3,1585**	**-1,9407**	**-8,3320**	15,6%
OTHER SECTOR S	Services	1,7295	-7,5752	1,5418	-1,3366	-5,6406	10,5%
	Residential	-13,7598	-16,7791	25,1897	-3,3355	-8,6847	16,2%
	Agriculture / Forestry	-1,6337	0,7876	0,0978	-0,3747	-1,1229	2,1%
	Non-specified (Other)	2,0571	-2,2486	0,3822	-0,1313	0,0594	-0,1%
TOTAL OTHER SECTORS		**-11,6068**	**-25,8153**	**27,2115**	**-5,1781**	**-15,3888**	28,7%
TOTAL		**-16,0479**	**-33,6254**	**7,6584**	**-11,5301**	**-53,5450**	100,0%

Table 9: CO2 emission decomposition in Spain between 2008 and 2011 (Millions of tons of equivalent CO2)

		ADITIVE (Mton CO2)					
		INTRASEC	COEFF EM	STRUCTURAL	ACTIVITY	CONJUNTO	%
INDUSTRY	Iron and Steel Industry+Non-ferous metal industry	2,5517	-1,4378	-3,1584	-0,9785	-3,0229	5,8%
	Chemical and Petrochemical industry	1,8656	-3,4348	0,1815	-1,3572	-2,7449	5,2%
	Non-metallic Minerals (Glass, pottery & building mat. Industry)	8,1803	-3,3553	-18,2201	-1,8258	-15,2209	29,1%
	Transport Equipment	-0,8041	-0,0788	-0,2147	-0,1583	-1,2559	2,4%
	Machinery	0,2806	-1,5465	-0,4878	-0,1694	-1,9232	3,7%
	Mining and Quarrying	0,3901	-2,3942	-0,3832	-0,1983	-2,5856	4,9%
	Food and Tabacco	-1,2874	-0,2805	0,5643	-0,2395	-1,2431	2,4%
	Paper, Pulp and Print	-1,0799	0,8357	-0,3680	-0,3023	-0,9145	1,7%
	Wood and Wood Products	0,3555	-0,2810	-0,6601	-0,0759	-0,6616	1,3%
	Construction	0,8061	-0,8442	-0,6800	-0,0823	-0,8003	1,5%
	Textile and Leather	-0,1294	-0,2456	-0,0437	-0,0760	-0,4947	0,9%
	Non-specified (Industry)	-0,2405	-0,3248	-0,5807	-0,1060	-1,2520	2,4%
TOTAL INDUSTRY		**10,8888**	**-13,3879**	**-24,0509**	**-5,5696**	**-32,1196**	61,4%
TRANSP ORT	Rail+Road+ Pipeline Transport	-4,4771	-2,6078	1,2540	-1,7507	-7,5816	14,5%
	International+Domestic aviation	-0,1857	-0,5701	0,6245	-0,5188	-0,6501	1,2%
	Domestic Navigation	-1,6224	-0,0239	0,1793	-0,1566	-1,6236	3,1%
	Non-specified (Transport)	0,8096	-0,3088	0,1201	-0,0241	0,5967	-1,1%
TOTAL TRANSPORT		**-5,4756**	**-3,5106**	**2,1779**	**-2,4502**	**-9,2586**	17,7%
OTHER SECTOR S	Services	2,8078	-4,5916	2,6678	-1,8189	-0,9349	1,8%
	Residential	-22,5605	-10,2086	27,5805	-4,2413	-9,4299	18,0%
	Agriculture / Forestry	-0,4982	0,6952	-0,2372	-0,4924	-0,5326	1,0%
	Non-specified (Other)	0,7529	-1,0373	0,3801	-0,1647	-0,0691	0,1%
TOTAL OTHER SECTORS		**-19,4980**	**-15,1423**	**30,3912**	**-6,7173**	**-10,9664**	21,0%
TOTAL		**-14,0848**	**-32,0408**	**8,5182**	**-14,7371**	**-52,3446**	100,0%

Table 10: CO2 emission decomposition in Spain between 2008 and 2012 (Millions of tons of equivalent CO2)

		ADITIVE (Mton CO2)					
		INTRASEC	COEFF EM	STRUCTURAL	ACTIVITY	CONJUNTO	%
INDUSTRY	Iron and Steel Industry+Non-ferous metal industry	1,5924	-0,1751	-3,6987	-1,5732	-3,8545	6,8%
	Chemical and Petrochemical industry	7,8528	-6,5285	-0,4891	-2,2791	-1,4439	2,5%
	Non-metallic Minerals (Glass, pottery & building mat. Industry)	5,1325	1,5008	-21,5870	-2,8827	-17,8363	31,4%
	Transport Equipment	-1,0383	0,2646	-0,3666	-0,2540	-1,3943	2,5%
	Machinery	-1,2691	-0,0116	-0,3505	-0,2788	-1,9100	3,4%
	Mining and Quarrying	1,0832	-2,7441	-0,6256	-0,3244	-2,6109	4,6%
	Food and Tabacco	-0,6004	-0,5474	0,6847	-0,4083	-0,8714	1,5%
	Paper, Pulp and Print	0,2679	0,3920	-0,8216	-0,5062	-0,6678	1,2%
	Wood and Wood Products	0,3703	0,2718	-0,8475	-0,1380	-0,3434	0,6%
	Construction	2,6255	-2,4124	-0,8938	-0,1345	-0,8152	1,4%
	Textile and Leather	-0,0469	-0,0577	-0,1915	-0,1277	-0,4239	0,7%
	Non-specified (Industry)	-0,5103	0,0478	-0,5044	-0,1788	-1,1457	2,0%
TOTAL INDUSTRY		**15,4596**	**-9,9997**	**-29,6916**	**-9,0857**	**-33,3173**	58,6%
TRANSPORT	Rail+Road+ Pipeline Transport	-8,0792	-1,1818	1,8933	-2,7692	-10,1368	17,8%
	International+Domestic aviation	-0,7498	0,1998	0,8651	-0,8560	-0,5410	1,0%
	Domestic Navigation	-1,0599	-0,0334	-0,1728	-0,2614	-1,5275	2,7%
	Non-specified (Transport)	1,7186	-1,1518	0,1210	-0,0410	0,6468	-1,1%
TOTAL TRANSPORT		**-8,1703**	**-2,1672**	**2,7066**	**-3,9276**	**-11,5585**	20,3%
OTHER SECTORS	Services	2,5591	-3,7621	3,4906	-2,9952	-0,7077	1,2%
	Residential	-25,2284	-10,9552	32,3158	-6,9107	-10,7785	18,9%
	Agriculture / Forestry	0,8512	-0,1165	-0,1124	-0,8214	-0,1990	0,3%
	Non-specified (Other)	-0,2018	-0,1399	0,2793	-0,2607	-0,3231	0,6%
TOTAL OTHER SECTORS		**-22,0199**	**-14,9737**	**35,9734**	**-10,9879**	**-12,0082**	21,1%
TOTAL		**-14,7306**	**-27,1406**	**8,9884**	**-24,0013**	**-56,8840**	100,0%

Table 11: CO2 emission decomposition in Spain between 2008 and 2013 (Millions of tons of equivalent CO2)

		ADITIVO (Mton CO2)					
		INTRASEC	COEFF EM	STRUCTURAL	ACTIVITY	CONJUNTO	%
INDUSTRY	Iron and Steel Industry+Non-ferous metal industry	2,8988	-3,4537	-3,9411	-1,8049	-6,3010	7,7%
	Chemical and Petrochemical industry	7,6659	-7,6767	-0,0525	-2,7306	-2,7939	3,4%
	Non-metallic Minerals (Glass, pottery & building mat. Industry)	3,6061	1,5785	-23,0380	-3,3467	-21,2001	25,7%
	Transport Equipment	-1,4774	-0,3251	0,0935	-0,2781	-1,9871	2,4%
	Machinery	-0,0668	-1,5196	-0,2366	-0,3282	-2,1512	2,6%
	Mining and Quarrying	3,1226	-3,8352	-1,3813	-0,4043	-2,4982	3,0%
	Food and Tabacco	-0,1947	-1,5147	0,6275	-0,4665	-1,5485	1,9%
	Paper, Pulp and Print	0,4873	0,0408	-0,9492	-0,6034	-1,0245	1,2%
	Wood and Wood Products	0,5362	0,3912	-0,9584	-0,1760	-0,2069	0,3%
	Construction	2,7774	-2,7170	-1,0336	-0,1475	-1,1207	1,4%
	Textile and Leather	-0,2469	-0,0509	-0,1801	-0,1462	-0,6240	0,8%
	Non-specified (Industry)	-0,4499	-0,6971	-0,5721	-0,1742	-1,8933	2,3%
TOTAL INDUSTRY		**18,6586**	**-19,7795**	**-31,6219**	**-10,6066**	**-43,3494**	52,6%
TRANSPORT	Rail+Road+ Pipeline Transport	-7,3617	-0,4294	1,1568	-3,4012	-10,0355	12,2%
	International+Domestic aviation	-2,2315	0,9857	1,9384	-1,0581	-0,3655	0,4%
	Domestic Navigation	-2,1722	0,0292	-0,2242	-0,2556	-2,6228	3,2%
	Non-specified (Transport)	1,4757	-0,7729	0,1159	-0,0540	0,7647	-0,9%
TOTAL TRANSPORT		**-10,2896**	**-0,1874**	**2,9868**	**-4,7689**	**-12,2591**	14,9%
OTHER SECTORS	Services	1,1706	-11,0371	3,2183	-3,2243	-9,8725	12,0%
	Residential	-23,3294	-12,4447	27,9895	-8,2189	-16,0035	19,4%
	Agriculture / Forestry	0,3712	-0,3812	0,8519	-1,0088	-0,1669	0,2%
	Non-specified (Other)	0,1509	-0,9007	0,3595	-0,3015	-0,6919	0,8%
TOTAL OTHER SECTORS		**-21,6367**	**-24,7638**	**32,4193**	**-12,7536**	**-26,7348**	32,5%
TOTAL		**-13,2677**	**-44,7306**	**3,7842**	**-28,1291**	**-82,3432**	100,0%

Table 12: CO2 emission decomposition in Spain between 2008 and 2014 (Millions of tons of equivalent CO2)

		ADITIVO (Mton CO2)					
		INTRASEC	COEFF EM	STRUCTURAL	ACTIVITY	CONJUNTO	%
INDUSTRY	Iron and Steel Industry+Non-ferous metal industry	-0,2008	-1,0340	-3,1188	-1,5568	-5,9104	7,4%
	Chemical and Petrochemical industry	7,0165	-8,2848	0,6655	-2,3236	-2,9264	3,7%
	Non-metallic Minerals (Glass, pottery & building mat. Industry)	1,6340	3,8119	-22,6216	-2,9087	-20,0844	25,2%
	Transport Equipment	-1,4062	-0,7116	0,2839	-0,2332	-2,0671	2,6%
	Machinery	-0,8277	-1,0149	-0,1697	-0,2733	-2,2856	2,9%
	Mining and Quarrying	3,5668	-4,1784	-1,7592	-0,3346	-2,7054	3,4%
	Food and Tabacco	-0,0496	-1,2610	0,6581	-0,4186	-1,0712	1,3%
	Paper, Pulp and Print	0,6564	-0,3398	-1,3410	-0,4937	-1,5181	1,9%
	Wood and Wood Products	0,4227	0,5238	-1,0157	-0,1496	-0,2188	0,3%
	Construction	2,6989	-2,7272	-1,0451	-0,1219	-1,1954	1,5%
	Textile and Leather	-0,2787	-0,1215	-0,2249	-0,1191	-0,7442	0,9%
	Non-specified (Industry)	-0,5655	-0,6916	-0,5827	-0,1433	-1,9830	2,5%
TOTAL INDUSTRY		**12,6668**	**-16,0292**	**-30,2711**	**-9,0765**	**-42,7101**	53,6%
TRANSPORT	Rail+Road+ Pipeline Transport	-8,4370	-0,8580	2,1693	-2,9014	-10,0272	12,6%
	International+Domestic aviation	-2,4583	1,3838	2,3455	-0,9306	0,3404	-0,4%
	Domestic Navigation	-2,8828	0,0058	-0,1516	-0,1822	-3,2107	4,0%
	Non-specified (Transport)	1,3782	-0,6534	0,1441	-0,0476	0,8213	-1,0%
TOTAL TRANSPORT		**-12,3999**	**-0,1218**	**4,5074**	**-4,0618**	**-12,0762**	15,2%
OTHER SECTORS	Services	-1,9602	-9,0752	2,9746	-2,7106	-10,7715	13,5%
	Residential	-20,0902	-9,6549	22,5374	-7,0825	-14,2902	17,9%
	Agriculture / Forestry	0,2509	0,4874	0,4355	-0,8788	0,2950	-0,4%
	Non-specified (Other)	0,4123	-0,6479	0,3709	-0,2799	-0,1447	0,2%
TOTAL OTHER SECTORS		**-21,3872**	**-18,8905**	**26,3183**	**-10,9518**	**-24,9113**	31,3%
TOTAL		**-21,1204**	**-35,0416**	**0,5545**	**-24,0901**	**-79,6976**	100,0%

Table 13: CO2 emission decomposition in Spain between 2008 and 2015 (Millions of tons of equivalent CO2)

		ADITIVE (Mton CO2)					
		INTRASEC	COEFF EM	STRUCTURAL	ACTIVITY	CONJUNTO	%
INDUSTRY	Iron and Steel Industry+Non-ferous metal industry	1,0671	-1,5036	-3,2958	-0,8867	-4,6190	7,5%
	Chemical and Petrochemical industry	4,7078	-8,0513	2,8765	-1,3033	-1,7703	2,9%
	Non-metallic Minerals (Glass, pottery & building mat. Industry)	0,4770	4,8901	-22,6280	-1,6303	-18,8912	30,8%
	Transport Equipment	-1,5320	-0,4365	0,2440	-0,1339	-1,8584	3,0%
	Machinery	-0,4243	-0,9774	-0,2979	-0,1616	-1,8612	3,0%
	Mining and Quarrying	2,8146	-4,6873	-1,8104	-0,1503	-3,8335	6,3%
	Food and Tabacco	-0,0378	-0,1448	0,4725	-0,2551	0,0349	-0,1%
	Paper, Pulp and Print	0,1581	0,0366	-1,4759	-0,2706	-1,5517	2,5%
	Wood and Wood Products	0,2016	0,6960	-0,9389	-0,0843	-0,1256	0,2%
	Construction	2,1258	-2,1908	-1,0409	-0,0677	-1,1736	1,9%
	Textile and Leather	-0,3131	0,0509	-0,2936	-0,0685	-0,6243	1,0%
	Non-specified (Industry)	-0,8879	0,9538	-0,7854	-0,1108	-0,8302	1,4%
TOTAL INDUSTRY		**8,3568**	**-11,3641**	**-28,9737**	**-5,1231**	**-37,1041**	60,6%
TRANSPORT	Rail+Road+ Pipeline Transport	-8,8493	-0,0191	2,8326	-1,6505	-7,6862	12,5%
	International+Domestic aviation	-2,6468	1,6060	2,8548	-0,5317	1,2823	-2,1%
	Domestic Navigation	-2,8199	-0,0760	0,1356	-0,1119	-2,8723	4,7%
	Non-specified (Transport)	1,1928	-0,4026	0,1714	-0,0278	0,9338	-1,5%
TOTAL TRANSPORT		**-13,1233**	**1,1084**	**5,9944**	**-2,3218**	**-8,3424**	13,6%
OTHER SECTORS	Services	1,6060	-8,0917	2,7835	-1,6188	-5,3210	8,7%
	Residential	-22,2135	-6,3302	22,4840	-3,9904	-10,0501	16,4%
	Agriculture / Forestry	-2,6927	2,0552	1,2823	-0,4803	0,1646	-0,3%
	Non-specified (Other)	-1,8076	1,1159	0,2261	-0,1433	-0,6089	1,0%
TOTAL OTHER SECTORS		**-25,1077**	**-11,2508**	**26,7759**	**-6,2327**	**-15,8152**	25,8%
TOTAL		**-29,8741**	**-21,5065**	**3,7966**	**-13,6777**	**-61,2617**	100,0%

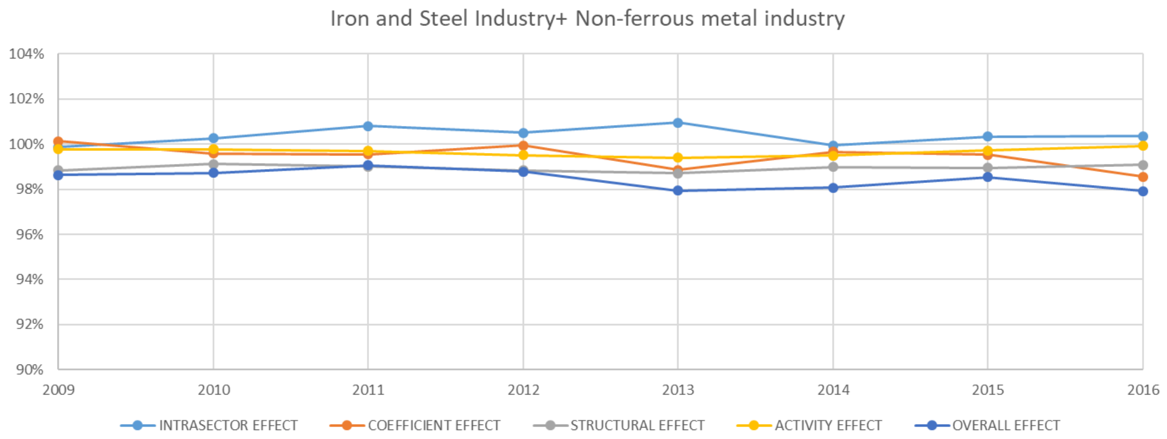

Figure 17: Evolution of CO2 emission index decomposition in IIron and Steel Industry. Multiplicative form

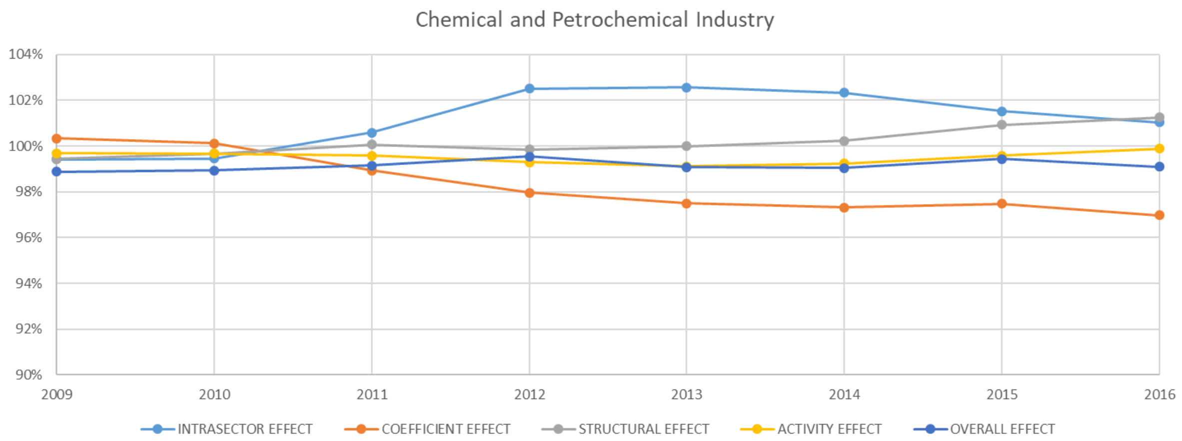

Figure 18: Evolution of CO2 emission index decomposition in Chemical and Petrochemical Industry. Multiplicative form

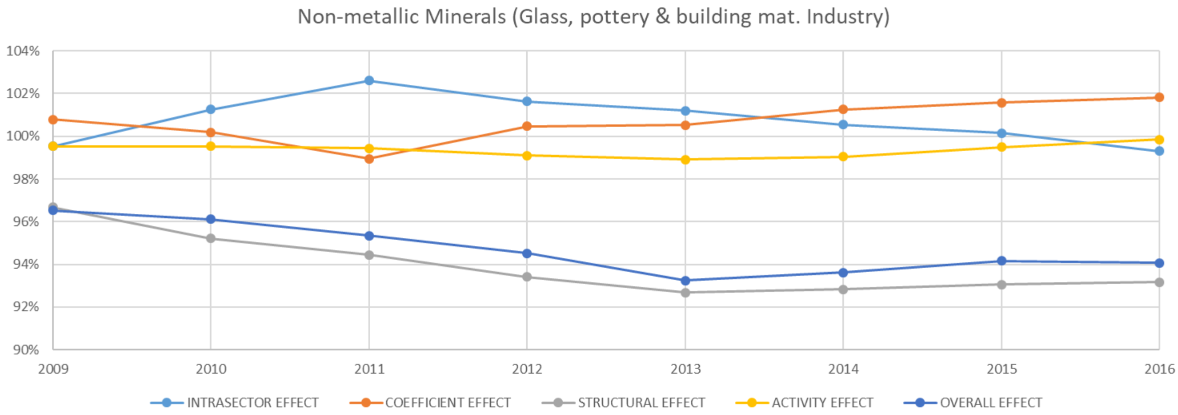

Figure 19: Evolution of CO2 emission index decomposition in Non-metallic Mineral Industry. Multiplicative form

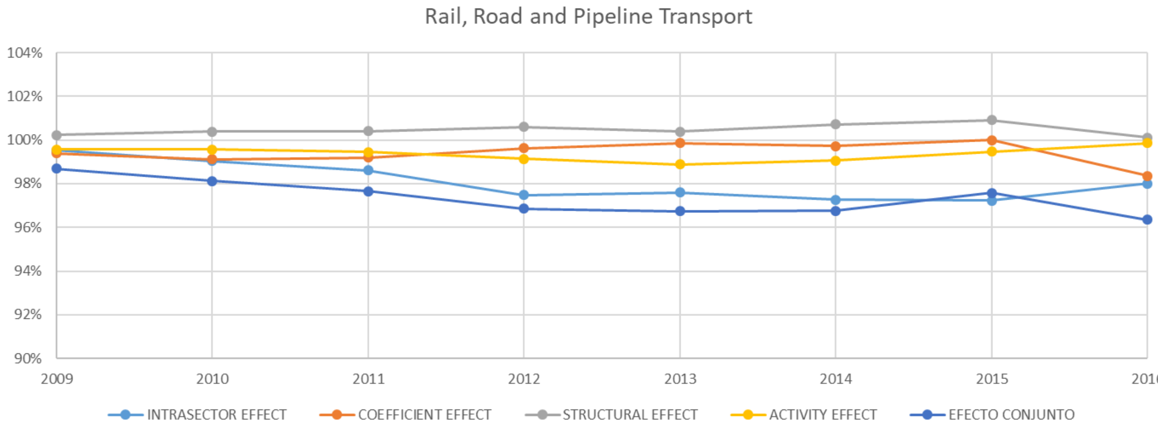

Figure 20: Evolution of CO2 emission index decomposition in Rail, road and pipeline transport. Multiplicative form

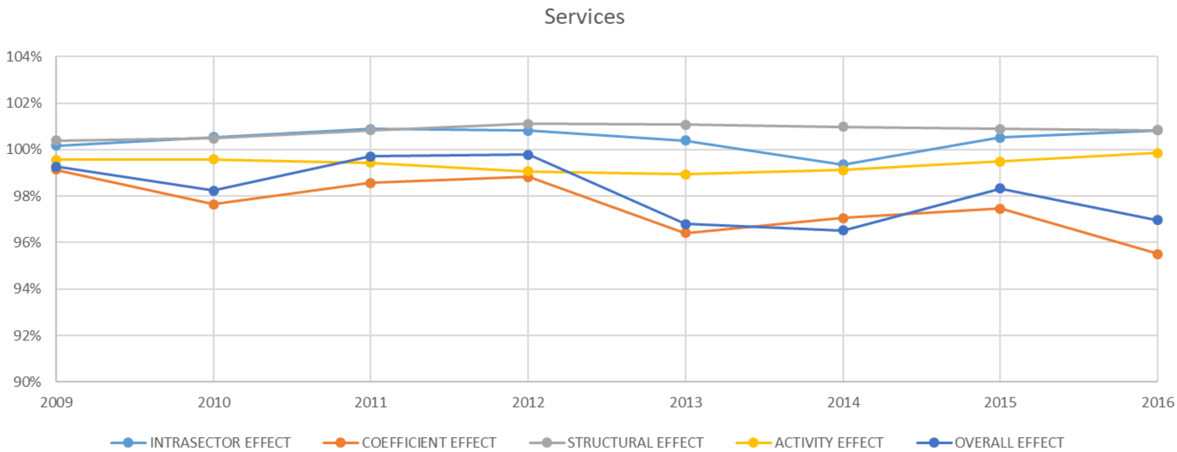

Figure 21: Evolution of CO2 emission index decomposition in the Services sector. Multiplicative form

Figure 22: Evolution of CO2 emission index decomposition in the Residential sector. Multiplicative form