DOCTORAL THESIS

Analysis of the main drivers of CO_2 emissions in different economies: the Spain and Chile cases

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Content

Resumen

El cambio climático (CC) es uno de los grandes desafíos de la humanidad y una de las principales amenazas para el desarrollo sostenible, con grandes consecuencias económicas, sociales y ambientales. Por esta razón, es necesario reducir las emisiones de gases de efecto invernadero (GEI) a la atmósfera, con el dióxido de carbono (CO_2) como el principal gas, y obtener una mayor eficiencia energética. Ambas acciones son clave para mitigar el cambio climático.

Para conocer con precisión las relaciones entre las variables económicas, demográficas y el volumen de emisiones de GEI que posibilitan el desacoplamiento entre el crecimiento económico y estas emisiones, es necesario medir estas interacciones. A través de estas mediciones, será posible diseñar proyectos energéticos que ayuden a cumplir los objetivos propuestos y llevar a cabo un análisis de los principales determinantes que podrían llevar a conclusiones que ayuden a establecer líneas de acción.

El objetivo de este proyecto de tesis doctoral es analizar los determinantes de las emisiones de CO_2 en dos economías; la española y la chilena. Esta elección se debe al proyecto de investigación existente entre nuestro grupo de investigación y la Universidad Autónoma de Chile. Las principales contribuciones de esta tesis pueden resumirse brevemente de la siguiente manera:

Por un lado, presentamos un análisis de los principales factores determinantes de las emisiones de CO_2 en España para el período 1995-2009. Esta investigación lleva a cabo un análisis multisectorial basado en el método Log-Mean Divisia Index (LMDI I). Los factores de descomposición utilizados representan la carbonización del mix energético (CI), la intensidad del uso de la energía (EI), la estructura económica (ES), la actividad económica (EA) y la población (P). Los principales hallazgos muestran que las fuentes de energía renovables (RES, por sus siglas en inglés) actuaron como compensador de los impulsores de las emisiones de CO_2. La tendencia positiva de la

contribución de las RES en la matriz energética de España, junto con la tendencia negativa en el uso de combustibles fósiles, nos lleva a ser optimistas.

Por otro lado, presentamos una evaluación de las emisiones de CO_2 en Chile entre 1991 y 2013 utilizando un análisis basado en el método (LMDI I) para examinar las emisiones y sus componentes. Se consideraron seis factores de descomposición: efecto intensidad de carbono (CI), efecto penetración de RES (RES), efecto intensidad de energía (EI), efecto estructura de la economía (ES), efecto ingreso (Yp) y efecto población (P). Para saber cómo estos factores podrían influirse mutuamente en el futuro, se utilizó el Innovative Accounting Approach (IAA), que incluye el análisis de la descomposición de la varianza y la función impulso-respuesta (IRF, pos sus siglas en inglés). Estas dos metodologías nos permiten identificar las causas de los cambios en las emisiones de CO_2 en el periodo (1991-2013), evaluar las medidas de política y aprender cómo estos factores podrían influirse mutuamente en el futuro, para evaluar si las medidas actuales cumplen los compromisos de París. Los resultados del análisis LMDI muestran que el factor intensidad de energía es el principal factor de compensación de las emisiones de CO_2 en Chile y el único efecto con una clara tendencia a ayudar al desacoplamiento entre crecimiento económico y emisiones de GHG. Los resultados del IAA e IFRs se comportan de manera similar y confirman que el factor intensidad de carbono reacciona a los impactos de manera más significativa en el corto plazo. La reacción a RES tiene el mismo comportamiento y opuesto a los shocks en ES y Yp, para desaparecer a largo plazo.

Estos hallazgos representan una contribución importante, no sólo para los investigadores sino también para las empresas y responsables políticos. Para nuestro conocimiento no existen análisis previos de los principales impulsores de CO_2 en estas economías. Estos resultados podrían conducir a conclusiones que ayuden a establecer líneas de acción para diseñar proyectos energéticos que ayuden a luchar eficazmente contra el cambio climático.

Abstract

Climate Change (CC) is one of the great challenges of humanity and one of the main threats to sustainable development, with great economic, social and environmental consequences. For this reason, it is necessary to reduce greenhouse gas (GHG) emissions to the atmosphere, with carbon dioxide (CO_2) the main one, and obtain greater awareness of energy efficiency. Both actions are key to mitigate climate change.

In order to know precisely the relationships between economic, demographic variables and the volume of GHG emissions to make possible the decoupling between economic growth and these emissions, it is necessary to develop indicators capable of analyzing these interactions. Through these indicators, it will be possible to design energy projects that help to meet the proposed objectives and carry out an analysis of the main determinants that could lead to conclusions that help to establish lines of action.

The aim of this doctoral thesis project is to analyze the determinants of CO_2 emissions in two economies: Spanish and Chilean. This choice is due to the existing research project between our research group and Universidad Autónoma de Chile. The main contributions of this thesis can be briefly summarized as follows:

On the one hand, we present an analysis of main drivers of CO_2 emissions in Spain for the 1995–2009 period. This research carries out a multisector analysis based on the Log-Mean Divisia Index Method (LMDI I). The decomposition factors used are the Carbon Intensity factor (CI), the Energy Intensity factor (EI), the structural composition of Spain's economy (Economy Structure, ES), the Economic Activity factor (EA) and Population (P), respectively. Major findings show that renewable energy sources (RES) acted as a compensating factor of the drivers of CO_2 emissions. The positive trend for the share of RES in Spain's energy matrix, together with the negative tendency in the use of fossil fuels, leads us to be optimistic.

On the second hand, we present an evaluation of the performance of Chile's CO_2 emissions between 1991 and 2013 using an analysis based on log-mean divisia index method (LMDI I) to examine emissions and their components. Six decomposition factors were considered: Carbon Intensity effect (CI), RES penetration effect (RES), Energy Intensity effect (EI), Economy Structure effect (ES), Income effect (Yp) and Population effect (P). To know how these factors could influence each other in the future, the Innovative Accounting Approach (IAA) was used, including forecast error variance decomposition and Impulse Response Functions (IRFs). These two methodologies allow us to identify the drivers of CO_2 emission changes in the past (1991–2013), test policy measures and learn how these drivers could influence each other in the future, to evaluate whether the current measures meet the Paris Agreement's commitments. The LMDI analysis results show that the Energy Intensity Factor is the main compensating factor of Chile's CO_2 emissions and the only effect with a clear trend to aid the decoupling between economic growth and GHG emissions. IAA and IFRs results react similarly and confirm that carbon intensity reacts to shocks more significantly in the short term. The reaction to RES has the same and opposite behavior to shocks in ES and Yp, to disappear in the long term.

These finding represent a major contribution, not only for researchers but also for companies and policy makers. To the best of our knowledge there are no previous analyzes of the main drivers of CO_2 in these economies. Results could lead to establish lines of action in order to design energy projects that help to fight against climate change.

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I wish to thank my friends for their joyful contributions to daily life and above all, I would like to thank my family. They have always looked out for me and offered such unfaltering support that it would be all too easy to take them for granted.

Chapter 1: Introduction

Climate change (CC) is one of the great challenges of humanity and one of the main threats to sustainable development, with great economic, social and environmental consequences. Global warming and environment problems caused by the excessive emission of greenhouse gases (GHGs), along with rapid economic development has attracted the attention of many countries and regions of the world as well as the research community.

In the literature, tests are becoming more frequent and show concern for the consequences of this problem and to create a greater social awareness and individual commitment (Blatrix et al., 2013; Day et al., 2012; Gebre et al., 2013; Hannah et al., 2018; Khetrapal, 2018; Marshall et al., 2013; Milad et al., 2011; Odell et al., 2017; Rojas et al., 2013; Schmidt et al., 2013; Sundblad et al., 2014; Thomas, 2018; Williston et al., 2018).

Reducing GHG emissions is essential to mitigate the threat of global warming. Household carbon (dioxide) emissions have been recognized as one of the most important contributors to CC, with a significant impact on both the local and global environment, and various policy instruments have been implemented by governments to bring about the reduction.

In 2013, the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report states that "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century." (IPCC Working Group I, 2013). The largest human influence has been the emission of greenhouse gases such as carbon dioxide, methane and nitrous oxide.

The Figure 1 represents de global mean estimates based on land and ocean data from 1880 to present, with base period 1951-1980. The solid black line is the global annual mean and the solid red line is the five-year Lowess smooth. The blue uncertainty bars (95% confidence limit) account only for incomplete spatial sampling (see Hansen et al., 2010 for more information).

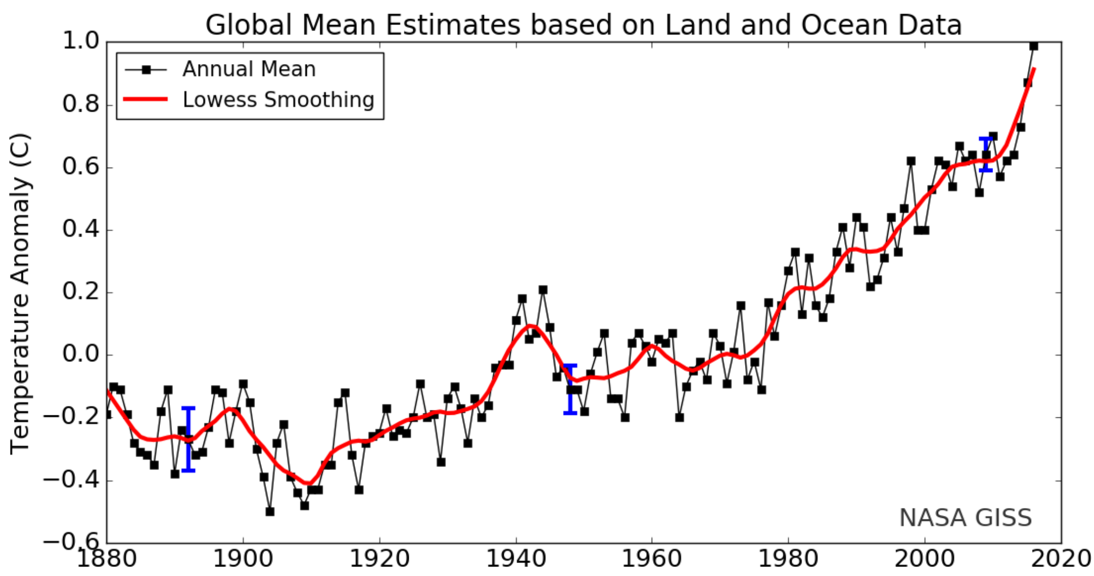

Figure 1. Global mean estimates based on land and ocean data.
Source: (NASA Goddard Institute for Space Studies, 2018).

Global emissions of greenhouse gases have increased despite global efforts to reduce them as can be observed in the figure 1. The contribution of working group I to the fifth IPCC assessment report on climate change reveals that the emission of these gases due to human activity that causes global warming has grown faster between 2000 and 2010 than in the last three previous decades (IPCC Working Group I, 2013).

More recently, the latest report from the National Oceanic and Atmospheric Administration (NOAA) published online January 2018 (NOAA, 2018), states that the year 2017 was one of the three hottest ever recorded, which is a clear sign of the consequences of climate change produced for greenhouse gases. The temperature of the terrestrial and oceanic surface of the Earth in the first eight months of the year 2017 is the second highest since 1880 (when the historical record begins), when it stood 0.88ºC above the 20th century average.

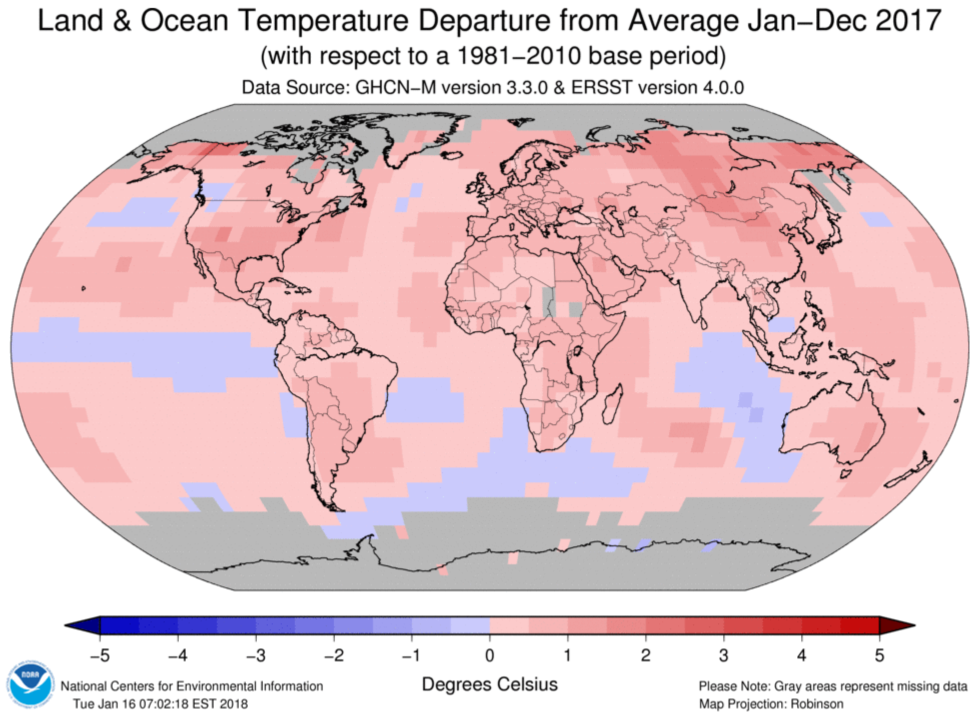

Figure 2. January–December 2017 Blended Land and Sea Surface (temperature Anomalies in degrees Celsius).
Source: (NOAA, 2018).

The year 2017 was characterized by conditions much warmer than the average in a large part of the terrestrial and oceanic surfaces of the planet. In the Figure 2, the temperature of land and ocean from January to December 2017 is showed. Record warmth was observed across parts of the western and central Pacific Ocean, western Indian Ocean, southern South America, and the southwestern contiguous U.S. and scattered across parts of the northern Atlantic Ocean, Africa, the Middle East, and eastern Asia. Averaged separately, the global land surface temperature was 1.31°C (2.36°F) above the 20th century average and also the third highest in the 138-year record, behind 2016 (warmest) and 2015 (second warmest). The global oceans also had their third warmest year since global records began in 1880 at 0.67°C (1.21°F) above the 20th century average. Only the years 2016 and 2015 were warmer (NOAA, 2018).

Due to this situation, the Intergovernmental Panel on Climate Change (IPCC) reaffirms that climate change is happening, that it is caused by human activities and that it is accelerating rapidly. Specifically, in the last decade, emissions have increased 10 gigagrams (Gg) of CO_2 equivalent, more than in any previous decade since the pre-industrial era. This increase comes mainly from the energy sector (47%), industry (30%) and transport (11%) according to the report of the IPCC working group II (2014). Experts say that low carbon technologies and improvements in energy efficiency are needed. For this reason, it is necessary to reduce greenhouse gas (GHG) emissions to the atmosphere.

After the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, in the Kyoto Protocol (Protocol, 1997), the industrialized countries committed to reduce the GHG emissions that cause global warming: carbon dioxide (CO_2), methane gas (CH_4) and nitrous oxide (N_2O), and the other three fluorinated industrial gases, hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulfur hexafluoride (SF_6).

To achieve these objectives, the Protocol proposed a series of means, including the establishment of national policies to reduce emissions. Specifically, the Kyoto Protocol implemented the objective of the UNFCCC to fight global warming by reducing greenhouse gas concentrations in the atmosphere. The Protocol is based on the principle of common but differentiated responsibilities: it puts the obligation to reduce current emissions in developed countries on the basis that they are historically responsible for the current levels of greenhouse gases in the atmosphere.

The Protocol was initially adopted in 1997 in Kyoto (Japan), but did not enter into force until 2005. The Protocol's first commitment period started in 2008 and ended in 2012. A second commitment period was agreed on in 2012, known as the Doha Amendment to the protocol, in which 37 countries have binding targets.

Negotiations were held in the framework of the yearly UNFCCC Climate Change Conferences on measures to be taken after the second commitment period ends in 2020. This resulted in the adoption of the Paris Agreement (UNFCCC, 2015) where all countries seal their commitment to care for the environment. In this new document, not only the objectives are established, but also the road map that leads them. In its original text, the 195 firms and participants designed a series of steps to reduce CO_2 emissions, make appropriate use of available resources and curb the effects of climate change. The main lines of action are the following:

- Keep temperature

The temperature increases at a very fast rate. Thus, the Paris Agreement obliges the signatory countries to fight to maintain the increase in the global average temperature well below 2°C with respect to pre-industrial levels. Over time this increase should be reduced to 1.5ºC.

- Expect adverse effects

There are factors that cause increases in temperature. To avoid this being a problem, the Paris Agreement requires countries to be able to foresee these changes. For instance, countries must promote resilience to climate so that food production is not compromised.

- Adapt economic policies

The increase in CO_2 emissions is mainly due to the use of economic and industrial models that cause more pollution. To avoid this, the signatory countries have committed themselves to carry out a policy that does not jeopardize the emission reduction objectives.

During the last years the economic literature has paid special attention to the relationship between polluting emissions, energy consumption and economic activity. For instance, De Alegría Mancisidor et al. (2009) conducted a review of the evolution of the EU energy strategy, focusing on legislation and approved programs to promote renewable energy sources and energy efficiency. The authors conclude with an analysis of the impact of these measures in Spain.

López-Peña et al. (2012) analyzed whether support for renewable energies is more effective in reducing emissions of CO_2 than the promotion of energy efficiency in sectors such as transport or buildings in Spain. Fernández López et al. (2014) investigated whether the national plans applied to reduce CO_2 emissions and energy consumption have been effective in countries such as Spain, France or Germany, among others.

Pablo-Romero and De Jesús (2016) investigated the relationship between economic growth and energy consumption using the hypothesis postulated for the Energy-Environmental Kuznets Curve for 22 Latin American and Caribbean countries. Grágeda et al. (2016) presented a review of the energy supply and demand status, planning and prospects in Chile with focus on solar photovoltaic- and solar thermal-projects.

More recently, Ito (2017) examined the linkage between CO_2 emissions, renewable and non-renewable energy consumption, and economic growth in 42 developed countries. The results suggest that non-renewable energy consumption leads to a negative impact on economic growth for developing countries and the renewable energy consumption positively contributes to economic growth in the long run.

Zhang and Wang (2017) reviewed carbon abatement measures from demand and supply-side in 144 countries. They analyzed the advantages and the disadvantages of the policies and it is found that the income level depends on the choice of policy, with high-income countries being associated with demand-side policy instruments. Low-income countries adopted less demand-side policy measures and mainly depend on supply-side policies such as targets and regulations. On the other hand, geographic location is also a key factor influencing the choice of policy instruments due to the different climates between different regions, although targets, regulations and carbon taxes are dominant GHG reduction policy measures worldwide. They suggested that, although the economic level is different, low-income countries and particularly developing countries can promote carbon abatement as well as the financial market by gradually changing from supply-side policy instruments to demand-side policies.

In summary, energy efficiency and the reduction of GHG emissions, among which CO_2 is the most important, are the key actions to mitigate climate change. Only if the relationships between the economic, demographic variables and the volume of GHG emissions are accurately known will the decoupling between economic growth and these emissions be possible. (On the concept of decoupling between economic growth and CO2 emissions can be consulted, among others, in Climent and Pardo, 2007; De Freitas and Kaneko, 2011; Diakoulaki and Mandaraka, 2007; Hák, T., Moldan, B. Dahl, 2012; Wang et al., 2013).

Therefore, it is necessary to develop indicators capable of analyzing these interactions in order to design energy projects that help meet the proposed objectives. For this reason, it is of interest to carry out an analysis of the main determinants of CO_2 that could lead to conclusions that help establish lines of action.

The remainder of the thesis proceeds as follows:

After this introduction, in chapter 2, the main objectives of this thesis are presented. Chapter 3 shows the main contributions and results obtained of the research. Finally, chapter 4 provides the main conclusions of this thesis.

Chapter 2: Objectives

In order to know precisely the relationships between economic, demographic variables and the volume of GHG emissions to make possible the decoupling between economic growth and these emissions, it is necessary to measure these interactions. Through measuring, it will be possible to design energy projects that help meet the proposed objectives and carry out an analysis of the main determinants that could lead to establish lines of action.

The aim of this doctoral thesis project is to analyze the determinants of CO_2 emissions in two economies: Spanish and Chilean. This choice is due to the existing research project between our research group and Universidad Autónoma de Chile. To do this, several techniques will be applied to the analysis of environmental and economic indicators that allow the identification, measurement and interpretation of the main determinants of said emissions.

The results obtained will allow a diagnosis of the relationship between economic, technological and demographic variables and CO_2 emissions, as well as the determination of the degree of responsibility of the factors considered in the variation of emissions.

The main contributions of the thesis are two journal papers that are encompassed under the topic of environmental economics research. Specifically, they are the following journal papers:

- Driving forces of Spain's CO_2 emissions: a LMDI decomposition approach (Cansino et al., 2015).

The aim of this paper is to analyze the determinants of emissions CO_2 in Spain from burning fossil fuels for energy required by industrial processes and the use of commercial transportation (except for the residential sector). For this, a decomposition analysis based on Divisia indices is carried out. This technique allows the identification, measurement and interpretation of the main determinants of CO_2 emissions. The results obtained will allow a diagnosis of the relationship between economic, technological and demographic variables and CO_2 emissions, as well as determine the degree of responsibility of the factors considered in the variation of emissions during the 1995-2009 period.

- How can Chile move away from a high carbon economy? (Cansino et al., 2018).

The main goal of this paper is to evaluate whether or not the measures in force to meet the Paris commitments are adequate in Chile. To do that we consider results from the two methodologies. These results allow us to identify past (1991-2013) drivers of changes in CO_2 emissions and test policy measures in that period. Together with this and regarding the main objective of the paper, the results also allow us to know how the identified drivers could influence each other in the future and if the measures in force are well oriented towards these drivers.

Chapter 3: Results and Discussion

In this chapter, we will analyze the main determinants of CO_2 emissions in different economies: Spanish and Chilean. To do this, it is important to choose the right method to conduct the research and achieve the objectives.

Decomposition analysis has been widely used to quantify the sources of change over time for a wide range of variables. Particularly, prolific has been its application in the identification of the determining factors of the variations in the levels of GDP, energy consumption or volume of imports.

The two most used methodological approaches for the analysis of decomposition in the literature are the analysis of structural decomposition (Structural Decomposition Analysis or SDA) and the analysis of decomposition in indexes (Index Decomposition Analysis or IDA). Both allow decomposing the variation experienced by an indicator (environmental, socioeconomic, economic or labor, among others) among its determining factors. These techniques have been developed independently and are frequently applied to analyze variations in energy consumption and CO_2 emissions.

The IDA analysis is the most common in environmental and energy studies to have a better understanding of energy consumption in a specific sector. SDA analysis is used by researchers who use extended input-output analysis to study changes in energy consumption or emissions. Ang and Zhang (2000) and Ang (2004) offer a comprehensive review of IDA methods. In the case of SDA, Rose and Casler (1996) and Ronald (2011) presented very complete reviews.

The traditional methods of SDA have limitations because they do not lead to a single distribution of the contributions of the explanatory variables. In practice, these methods do not give an exact decomposition, that is, the results include a residual term that complicate their interpretation. Betts (1989) presented two methods of exact structural decomposition. From this study, other authors follow the same idea

(Jacobsen, 2000; Wier and Hasler, 1999). However, the methods of decomposition proposed for these authors are not ideal, i.e., the results of the decomposition depend on the sequence of the factors in the product.

Since the 1980s, literature on decomposition based on Divisia type indices has been extremely prolific (Albrecht et al., 2002; Ang, 2005; Ang and Lee, 1994; Boyd et al., 1987; Choi and Ang, 2012; Fernández and Fernández, 2008; Liu et al., 1992; Su and Ang, 2012; Törnqvist et al., 1985). These papers performed studies based on Divisia methods and have proven practical applications. De Freitas and Kaneko (2011) offered an overview of decomposition studies from the seminal paper by Grossman and Kruege (1991).

There are differences and similarities between both analyzes. Hoekstra and van den Bergh (2003) conducted the first study comparing the IDA and the SDA and provided a review of both methods until 2001. A more recent study that reviews the SDA and performences a comparison with the IDA is the one conducted by Su and Ang (2012). Comparatively, the IDA analysis has some advantages over the SDA. The IDA analysis allows decompositions for any type of aggregate (value, ratio or elasticity). In addition, the analysis of decomposition based on indexes requires less data than decomposition methods based on input-output tables and can be very useful when decomposing energy intensity changes between its different components.

The methodology for this research is based on Divisia type indices. More specifically, it is used the LMDI-I (Log-mean Divisia Index Method) method proposed initially by Ang and Choi (1997) and reviewed by Ang et al. (1998) and Ang and Liu (2001). The LMDI-I is a refined approach based on Divisia indexes of non-parametric nature, with logarithmic mean-type weights. A practical guide of this method is reported in Ang (2005).

Our choice is based in the criterion of Ang (2004) who performed an assessment of several methods of decomposition. This author concluded that the LMDI-I method is the most recommendable for its theoretical basis and for the set of properties that it satisfies in the case of the decomposition of index numbers. An additional argument for choosing the LMDI-I is that it allows a perfect decomposition (i.e. without residues), and provides a simple and direct association between the form of additive and multiplicative decomposition (Ang and Liu, 2007). In the first case, the effects are the result of the factorization of an index, being therefore dimensionless. In the second case, the effects are quantified in the units of measurement in which the variable to be decomposed is expressed.

This methodology has been complemented with the Innovative Accounting Approach (IAA) to know the long-run and short-run relationships between the decomposition factors and identify how they could influence each other in the future. IAA includes forecast error variance decomposition and Impulse Response Functions (IRFs). The IAA approach analyzes the causal dynamic relationship between various time series. One of the advantages of this method over other approaches used in the literature is that it allows us to incorporate an analysis for a forwards period, i.e. perform predictions of the behavioral relationships between time series from the selected sample period.

The main results of this doctoral thesis are presented in Cansino et al. (2015) and Cansino et al. (2018).

Chapter 4: Conclusions

In this thesis, we have been concerned with identifying, quantifying and interpreting the impact of the factors that influence such important environmental aggregates as CO_2 emissions.

To achieve our goal, the methodology has been based mainly on index decomposition analysis (IDA). IDA method has been widely applied to analyze the influencing factors of the growth of energy consumption and its CO_2 emissions. In the literature, the Logarithmic Mean Divisia Index I (LMDI) method is the recommended method because it is robust and convenient for many applications. Our results have been presented and discussed in two well differentiated parts based on our published journal papers.

In chapter 3 based in journal paper, **Driving forces of Spain's CO_2 emissions: a LMDI decomposition approach**, an extended version of the IPAT model and the 'Kaya identity' is used to assess the contribution of drivers of CO_2 emissions in Spain for the 1995-2009 period. The study carries out a multisector analysis based on the Log-Mean Divisia Index Method (LMDI I). The decomposition factors used are the Carbon Intensity factor (CI), the Energy Intensity factor (EI), the structural composition of Spain's economy (Economy Structure, ES), the Economic Activity factor (EA) and Population (P), respectively.

The results show that RES acted in detriment to the drivers of CO_2 emissions. This may be stated for the last few years under consideration. The positive trend for the share of RES in Spain's energy matrix, together with the negative tendency in the use of fossil fuels, leads us to be optimistic. Spain's carbon intensity reflects a step forward on the path towards independence from fossil fuels with the development of its energy-economy system. It may be said that Spain's economy is moving towards a low carbon economy. The estimated energy intensity provides an indication of greater efficiency in

Spain’s energy-economy system when compared to previous years. The statistics show a “decoupling” trend between environmental impacts and economic growth.

In accordance with the results obtained, two types of energy policy recommendations should be developed. Firstly, and focusing on the Power Sector, although a very intense development of solar-electrical technology is not expected, wind power seems to have reached grid-parity and is likely to continue increasing its share in Spain’s electricity mix; this will help reduce the sector’s energy intensity.

Secondly, energy efficiency improvements in the industrial sector as a whole will encourage the installation of new cogeneration plants at industrial sites. Renewal by substituting high-intensity generation equipment and vehicles for lower consumption machinery must form part of this strategy. In this regard, public support with the acquisition of new, more efficient machinery should be limited to guaranteed energy efficient goods. It could be useful to insert tax benefits into the Spain’s energy efficiency improvement programmes for those companies demonstrating reductions in their energy intensity ratios.

In chapter 3 based in journal paper, **How can Chile move away from a high carbon economy?,** the performance of Chile's CO_2 emissions between 1991 and 2013 is quantitatively evaluated using a decomposition analysis based on log-mean Divisia index method (LMDI I) was conducted. This decomposition is a complete decomposition technique to examine emissions and their components. Six decomposition factors were considered: Carbon Intensity effect (CI), RES penetration effect (RES), Energy Intensity effect (EI), Economy Structure effect (ES), Income effect (Yp) and Population effect (P). Additionally, to know how these factors could influence each other in the future, the Innovative Accounting Approach (IAA) was used, including forecast error variance decomposition and Impulse Response Functions (IRFs).

These two methodologies allow us to identify the drivers of CO_2 emission changes in the past (1991–2013), test policy measures and learn how these drivers could influence each other in the future, to evaluate whether the current measures meet the Paris commitments.

The results obtained from LMDI analysis provide useful policy guidance for Chilean authorities. Upon analyzing the results, these recommend acting on RES penetration and enhancing energy efficiency as the two main factors that can help meet the decoupling between economic growth and energy related CO_2-eq emissions. The IAA analysis supported these results and allowed one to examine policy measures related with the battle against climate change. The results from forecast error variance decomposition and impulse response functions show the importance of the mix level resource efficiency that may mitigate CO_2 emissions and energy consumption without compromising economic growth and change of population.

In light of the results obtained, it can be concluded that main measures in force regarding energy and Climate Change policies in Chile are adequate in terms of the country's Paris Agreement commitments. Focus is on measures that directly impact on the main drivers of CO_2 emissions in recent years. Additionally, the main measures are oriented towards influencing factors that showed the correct causality on others. Such are the cases of measures oriented towards promoting NCRES deployment and improving energy efficiency.

In terms of the development of distributed generation systems, the difficulties behind its implementation have proven that it must be taken into consideration. In addition to this, improvements in energy storage systems must favor development. Considering Chile's lithium resources and the use of hydrogen batteries, national authorities could include measures to promote their use as well as electric vehicles.

On the other hand, measures focusing on improving energy efficiency are adequate and in terms of sectors, are well oriented. Energy intense sectors and with an important weight in Chile's GDP will favor international competitiveness while at the same time contribute to attaining its commitments with the Paris Agreement. Moreover, the energy efficiency measures focusing on the residential sector must contribute to compensating the role of income and population as traditional drivers of CO_2 emissions in Chile.

Concerning actions focusing on the sequestration of CO_2, Chile's priority continues to be its forestry sector. Finally, the educational actions in place are also adequate and correctly oriented towards impacting on income and population factors.

Some more general conclusions from analysis of the results of the two investigations, that could serve the competent authorities to define the lines of energy and environmental performance in the territories analyzed, are deducted:

The factors of decomposition RES penetration effect and energy efficiency effect are those that more contribute to the improvement of the efficiency at the level of CO_2 emissions and are the two main factors that can help meet the decoupling between economic growth and energy related CO_2-eq emissions. On the other hand, population growth, GDP and structural change have been under pressure, increasing the level of CO_2 emissions.

A general recommendation that seems to be inferred from our results is that in order to achieve sustainable development, policies aimed at favoring a better use of technologies must be adopted, as well as the substitution of energy by other, less polluting and higher quality technologies and the adaptation of new ones. The lines of action that affect these aspects could be not only sufficient, but also necessary to globally compensate the possible adverse impacts of other effects.

Currently, governments are aware of the need to fight against climate change as well as the long-term effects on economic and human development. However, there are drawbacks to advance sustainable development and achieve decoupling between economic growth and greenhouse gases. The weakness of the prices of solid fuels is undermining the attractiveness of investments in clean energy technology. The decline in resources directed at investment in energy infrastructure threaten the access of the poorest households to electricity and other forms of modern energy. The financial difficulties prevent some economically viable projects, lacking credit, can be carried out. To fight against climate change and energy insecurity, governments should try to solve these problems and act together.

The integration of existing key technologies would make it possible to reduce dependence on imported fossil fuels and limited national resources, as well as to have low-carbon electricity, improve energy efficiency and reduce emissions in the sectors of energy production, industry, transport and buildings. This would slow the vertiginous growth of energy demand, reduce imports, strengthen national economies and, over time, reduce greenhouse gas emissions.

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