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How can Chile move away from a high carbon economy?

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A B S T R A C T

This paper quantitatively evaluates the performance of Chile's CO_2 emissions between 1991 and 2013 using a 'complete decomposition' technique to examine emissions and their components. A decomposition analysis based on log-mean divisia index method (LMDI I) was conducted. 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 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 economy's decoupling. 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.

1. Introduction

Energy related CO_2 emissions in Chile increased 178% for the 1990–2013 period, which is well above the world average (56%) for OECD-American countries (104%) and all of OECD economies (9.4%) (IEA, 2017). These emissions derived only from fuel combustion; therefore, they are associated to anthropogenic actions. Unless Chile's energy-related CO_2 emissions shares only 0.2% of total world, its percentage increased in 78.5% for the aforementioned period.

Within the global context fighting against climate change, Chile decided to become a non-Annex-I Country after once the Kyoto Protocol was approved. Chile is highly vulnerable to climate change, as it meets seven of the nine characteristics listed by the United Nations Framework Convention on Climate Change (UNFCCC), as established at the Conference of the Parties: The country has low lying coastal areas, arid and semiarid areas, forests, territories that are susceptible to natural disasters, others that are prone to drought and desertification, urban areas with atmospheric pollution and mountain ecosystems (Ministry of Environment, 2011). It has been calculated that in Chile, environmental, social and economic losses derived from climate change could amount to 1.1% of the country's GDP in 2100 (CEPAL, 2012). Growing concerns about climate change in Chile explained the formalization of the pledge made in Copenhagen by registering it in Appendix II of the Copenhagen Accord (UNFCCC, 2009). Within the framework of COP21 in Paris, Chile decided to present its Intended Nationally Determined Contribution (INDC) defining its commitment in the battle against climate change, in terms of emission intensity (tons of CO_2 equivalent per unit of Gross Domestic Product –GDP– in millions of CLP$ 2011).

Chile's commitment is based on sectorial analyses and mitigation scenarios developed with the Mitigation Actions Plans and Scenarios (MAPS) Chile project (Phase 2) (MAPs Chile, 2014), the National Greenhouse Gas Inventory results (1990–2010) and additional information provided by the Ministries of Environment, Energy, Agriculture and Finance, as well as observations received during the Public Consultation of the Intended National Contribution.

The main goal of this paper is to evaluate whether or not the measures in force to meet the Paris commitments are adequate. To do that we consider results from the two methodologies mentioned below. 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

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measures in force are well oriented towards these drivers. The analysis conducted follows four steps as is detailed below.

Firstly, the 1991–2013 decomposition of changes in CO_2 emissions is carried using a 'complete decomposition' technique to examine emissions and their components. Six decomposition factors or effects have been considered: Carbon Intensity effect (CI), Renewable Energy Sources penetration effect (RES), Energy Intensity effect (EI), Economic Structure effect (ES), Income effect (Yp) and Population effect (P). This technique consists of using one type of index decomposition analysis (IDA) known as the log-mean divisia index method –LMDI I– (Ang, 2005). LMDI I-based studies are useful to understand the evolution of energy-related CO_2 emissions, and to identify the driving forces that have impacted these changes.

Secondly, this paper offers the decomposition of changes in CO_2 emissions between 1991 and 2013 at the sectoral level; it traces changes in emissions derived from each consumption category per sector considered (energy, transport, industry, use of solvents and other products –USOP–, agriculture, and residuals and waste).

Step three researches the long-run and short-run relationships among CO_2 emissions and their determinants and how the drivers identified could influence each other in the future; this paper implemented the Innovative Accounting Approach (IAA) taking Moutinho et al. (2016) and Robaina-Alves and Moutinho (2013) as the start point. It includes the forecast error variance decomposition and Impulse Response Functions (IRFs) applied to the factors where energy-related CO_2 emissions were decomposed. Despite both tools (LMDI and IAA) being well-known, the novelty of the analysis derives from i) using the second to know how the drivers identified could influence each other in the future, ii) adding a sectoral analysis (not only to industrial sectors) and iii) evaluating the measures in force by taking into account the results of causality obtained in this relationship and information regarding how long it takes to once again attain equilibrium after the long-run relationship has been shocked. Consequently, this paper allows one to look at both current and future measures and not just the past as is customary for IDA analysis. This paper contributes to the growing body of knowledge about the transition to low carbon economies.

Additionally, we do not focus on CO_2 emission intensity as the key variable due to international agreements based on carbon emission intensity commitments, which have been severely criticized. Some experts point out that CO_2 emission intensity targets are used to hide the fact that a reduction in the carbon intensity could be achieved without eliminating a continuous increase of absolute carbon dioxide emissions (Stern and Jotzo, 2010; Cansino et al., 2015). Contributions to the literature derive from applying IAA to all economic sectors considered and not only for industry. To the best of our knowledge, no previous papers have been presented that focus on Chile's economy.

By using these two methodologies, we are able to examine emissions and their components as well as analyze how these have evolved in the past. It also shows how their components are related to each other and how they can influence each other in the future.

Finally, in light of the results, the fourth and final steps allow policy measures (past and current) to be examined, as well as the impacts of relevant facts about CO_2 emissions in the energy sector. To analyze past relevant policy measures, the entire period was divided into three sub-periods based not only on climate change actions (Sanhueza and Ladrón de Guevara, 2014), but also regarding events in the energy sector and the energy policy during the period considered. Related fossil fuels combustion energy represents 74.6% of total CO_2-eq emissions up to 2010 (Ministry of Environment, 2016). The sub-periods considered are 1991–1996 (nearest to the signing of the Framework Convention at the UNFCCC summit in Rio until the beginning of massive natural gas imports from Argentina), 1997–2006 (from the relevant use of natural gas in the generation of electricity to the entry into force of the Kyoto Protocol), 2007–2013 (when Argentina decided not to export natural gas and the end of the period with available data).

Conducted research will put us in a position to evaluate if measures in force to meet the Paris commitments are adequate. The measures assessed are, for the most part, included on the long-term road map for the energy policy named Energia2050 (Ministry of Energy, 2016) and the National Climate Change Plan of Action 2017–2022 (PANCC 2017–2022 from the Spanish acronym for Plan de Acción Nacional de Cambio Climático) (Ministry of Environment, 2016).

These results are interesting not only for researchers but also for policy-makers. In fact, this paper speaks directly to the authorities of Chile and the policy agenda regarding several issues, including energy security.

The paper has been structured as follows: After the introduction, Section 2 provides details of methodology used. Dataset are exposed in Section 3. The results are presented in Section 4. In the light of our results, current political measures Paris Agreement oriented are examined in Section 5. Section 6 provides the main conclusions.

2. Methodology

2.1. LMDI analysis

There are two main decomposition techniques to identify the drivers of changes in CO_2 emissions: Structural Decomposition Analysis (SDA) (Achão and Schaeffer, 2009; Zhang et al., 2011; Ang and Su, 2016; Cansino et al., 2016) and Index Decomposition Analysis (IDA) (Hoekstra and van den Bergh, 2003; Hatzigeorgiou et al., 2008; Ma and Stern, 2008; Andreoni and Galmarini, 2016). The latest comparisons between IDA and SDA have been shown in Su and Ang (2012). Comparatively, IDA has certain advantages over SDA. IDA enables decompositions for any aggregate (value, ratio or elasticity). Also, IDA requires less data than decomposition methods based on input-output analysis and it is useful when decomposing CO_2 emission changes between its various components (Cansino et al., 2015).

This paper follows the Ang (2004) criteria that assessed the various decomposition methods. The latter concluded that LMDI I is a more recommendable method. However, it shows some limits with the proportionality test (Ang, 2004). LMDI I allows perfect decomposition (that is, without residuals) and provides a simple and direct association between the additive and the multiplicative decomposition form Ang and Liu (2007a).

The IPAT equation is the starting point for the LMDI I conducted. The Impact = Population × Affluence × Technology (IPAT) equation is used to assess the contribution of CO_2 emission drivers. Specifically, the IPAT model (Commoner et al., 1971; York et al., 2002; Brizga et al., 2013) and the 'Kaya Identity' (Kaya, 1990; Yamaji et al., 1991) are extended using IDA (Leontief and Ford, 1972; Rose and Casler, 1996) to assess the key drivers behind Chile's CO_2 emissions. Two recent papers focused on Chilean economy are due to Mundaca (2013) and Duran et al. (2015). The first conducted an interesting research using IPAT equation. The second carried out a decomposition of the energy consumption by Chilean industry but not of the CO_2 emissions as we do.

Six-factor have been proposed to identify, quantify and explain the main determinant of the variation for total energy related CO_2 eq emissions in Chile between 1991 and 2013.

Applying the decomposition proposed to six productive sectors, the total CO_2 emissions may be decomposed as follows:

$$CO_2 = \sum_{i=1}^{6} CI_i \cdot RES_i \cdot EI_i \cdot ES_i \cdot Yp \cdot P = \sum_{i=1}^{6} \frac{CO_{2i}}{FF_i} \cdot \frac{FF_i}{E_i} \cdot \frac{E_i}{Y_i} \cdot \frac{Y_i}{Y} \cdot \frac{Y}{P} \cdot P \qquad (1)$$

CO_{2i} represents the energy related CO_2 emissions of sector i; FF_i denotes the share of fossil fuels of sector i; E_i denotes the energy consumption of sector i; Y_i represents the output of sector i; Y denotes the total output for the entire economy the same as in CO_2, and P represents the population.

Changes in CO_2 emissions may be assessed by implementing additive or multiplicative decomposition. In this paper, an additive LMDI I analysis is carried out. The overall ratio of change in CO_2 emissions during the period 0 and t is decomposed as follows:

$$\Delta CO_2 = CO_{2t} - CO_{20} = \Delta CI + \Delta RES + \Delta EI + \Delta ES + \Delta Y\text{p} + \Delta P \qquad (2)$$

ΔCO_2 represents changes in aggregate CO_2 emissions in the economy from one period to another, being the right-hand side variables the representatives of the various contributing determinants as previously defined but now being referred to as changes. By considering the additive decomposition identity, the LMDI formula is calculated as Table 1 shows for each effect:

The term $w_i\ (t)$ is the estimated weight for the additive LMDI I method and is defined as Ang (2005):

$$w_i(t) = \frac{CO_{2i,t} - CO_{2i,0}}{\ln CO_{2i,t} - \ln CO_{2i,0}} \qquad (9)$$

Eq. (3) captures the Carbon Intensity effect (CI). Variable ΔCI shows the changes in CO_2 emissions from fossil fuels consumption in sector i $(= CO_{2i}/FF_i)$, between the periods t and 0, respectively. Available statistical information does not offer fossil fuels consumption broken down by type of fuels so FF_i is total fossil fuels by sector without distinction by different fuels. The CI factor captures the quality of fossil fuels and may also be used to evaluate the substitution between fossil fuels. We assume that the better a fossil fuel is, the less CO_2 it emits.

Eq. (4) shows the RES penetration effect (RES). Variable ΔRES shows the share of fossil fuel consumption with respect to the total primary energy required in sector i $(= FF_i/E_i)$, between periods t and 0, respectively. The RES factor captures the Renewable Energy Source share in total primary energy matrix in each sector.

A specific comment regarding RES needs to be made to better understand their link with CO_2 emission data. By carrying out a decomposition analysis, we could research the role of RES in Chile's energy matrix. However, one problem must be solved, which is linked to the fact that RES technologies are free or almost free of CO_2 emissions and we observe this as a crucial variable. To bridge this lack of information, we observed the evolution of the ratio between total fossil fuel consumption for total primary energy consumption. O'Mahony (2013) explained that theoretically the carbon emissions from renewables are zero as fossil fuels are not combusted during the generation of electricity (when used in energy supply) or in the delivering of energy services (when used in final consumption). As E_i denotes the final energy consumption of sector i measured in Tera calories it needs to be considered that not all of the primary energy sources use to generate final energy are fossil fuels. Rest of the total final energy consumption is generated by RES or nuclear plants. Being that nuclear energy in Chile is not part of the energy matrix, the role played by RES on CO_2 emissions trend can be derived from RES effect (IEA, 2017). This is why if the ratio FF_i/E_i is considered in the decomposition analysis to capture the penetration of RES into the Chilean energy matrix. A decline in values for the ratio of total fossil use on total energy use might show a higher share of RES in Chile's energy matrix (mainly hydropower). In other words, higher (lesser) values would mean lesser (higher) levels of RES penetration in the Chilean energy matrix.

Table 1
Formulae for each effect in the additive decomposition.

$\Delta CI = \sum_{i=1}^{6} w_i(t) \cdot \ln\left(\frac{CI_{i,t}}{CI_{i,0}}\right) \qquad (3)$	$\Delta RES = \sum_{i=1}^{6} w_i(t) \cdot \ln\left(\frac{RES_{i,t}}{RES_{i,0}}\right) \qquad (4)$
$\Delta EI = \sum_{i=1}^{6} w_i(t) \cdot \ln\left(\frac{EI_{i,t}}{EI_{i,0}}\right) \qquad (5)$	$\Delta ES = \sum_{i=1}^{6} w_i(t) \cdot \ln\left(\frac{ES_{i,t}}{ES_{i,0}}\right) \qquad (6)$
$\Delta Yp = \sum_{i=1}^{6} w_i(t) \cdot \ln\left(\frac{Yp_t}{Yp_0}\right) \qquad (7)$	$\Delta P = \sum_{i=1}^{6} w_i(t) \cdot \ln\left(\frac{P_t}{P_0}\right) \qquad (8)$

Eq. (5) presents the Energy Intensity effect (EI). Variable ΔEI shows the total primary energy required in comparison to the output in sector i $(= E_i/Y_i)$, between periods t and 0, respectively. EI factor is often used as a measure or aggregate proxy of the energy efficiency or technology level of a country's economy. It may be seen as a signal indicating the efficiency of the energy system and investments for energy saving (Goldemberg and Johansson, 2004; Voigt et al., 2014).

Eq. (6) is the Economic mix or Economic Structure effect (ES). Variable ΔES shows the sectoral structure of Chile's economy between period t and 0, respectively. The ES factor indicates the relative weight of each sectoral output within the total output of the overall economy; it incorporates the relative impact of structural changes on Chile's economy in terms of CO_2 emissions for a given year included into the analysis.

Eq. (7) is the Income effect (Yp). Variable ΔYp is the output per capita between period t and 0, respectively. Yp factor captures the income effect on CO_2 emission changes from energy consumption.

Eq. (8) shows the Population effect (P). Variable ΔP shows the total population between period t and 0, respectively. The P factor allows the effects of population growth as a determinant for energy demand to be analyzed.

To accommodate cases of zero value, Ang and Choi (1997), Ang and Liu (2007a), and Ang et al. (1998) analyzed and proposed that the best way to handle this situation is by substituting zeros for a δ value between 10^{-10} and 10^{-20}. This is known as the small value (SV) strategy. Ang and Liu (2007b) also showed that the SV strategy is robust when an appropriate value is used, and that it would provide satisfactory results even for highly extreme cases.

2.2. The Innovative Accounting Approach (IAA)

Following Moutinho et al. (2016), different approaches have been used previously to account for decomposition effects. They highlight that Zhang and Cheng (2009) used in the VAR Granger Causality and Generalized Impulse Response to examine the causality among urban population, economic growth, energy consumption and CO_2 emissions. In a similar way, Lee and Chien (2010) applied the IAA to examine the relationship between energy consumption, capital stock and real income in G-7 countries. A more extended review of the literature is offered by Robaina-Alves and Moutinho (2013).

The generalized forecast variance decompositions measure the contribution of each type of shock to the forecast error variance over different time horizons and estimates the simultaneous shocks stemming from other variables. This technique can also provide a rough analysis of how long it takes for a variable to revert back to equilibrium after the long run relationship has been shocked.

IRFs show the dynamic responses of time series to a one-period standard deviation shock, and indicate the direction of the response to each of the shocks (Maghyereh, 2004; Park and Ratti, 2008; Ozkan and Ozkan, 2012; Shahbaz et al., 2013). Thus, a random shock in one standard deviation establishes a chain reaction over time in all VAR variables. IFR's calculate these chain reactions (Moutinho et al., 2016).

Both computations are useful in assessing how shocks to economic variables reverberate through a system.This technique can also provide a rough analysis of how long it takes for a variable to revert back to equilibrium after the long run relationship has been shocked. IRFs show the dynamic responses of time series to a one-period standard deviation shock, and indicate the direction of the response to each of the shocks (Maghyereh, 2004; Park and Ratti, 2008, Ozkan and Ozkan, 2012;

Shahbaz et al., 2013). Thus, a random shock in one standard deviation establishes a chain reaction over time in all VAR variables. IFR's calculate these chain reactions (Moutinho et al., 2016).

We have implemented the IAA to know the long-run and short-run relationships between CO_2 emissions drivers 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.

In this paper, the generalized forecast variance decomposition approach estimates simultaneous shocks effects, which is determined from the estimation of the VAR model to test the strength of casual relationships between the determining factors of total CO_2 emissions, CI effect, RES effect, EI effect, ES effect, Yp effect and P effect. For instance, if the CI effect explains more of the forecast error variance of the RES effect, then we deduce that there is a unidirectional causality from the CI to the RES effect. The bidirectional causality exists if shocks in the RES effect also affect the CI effect in a significant way. If shocks happen in both series they do not have any impact on the changes in the CI and in the RES effects, then there is no causality between the variables. On the other hand, the relation among these six factors is analyzed with the IRFs. We determined how each decomposition factor of CO_2 emissions responds due to its shock and to shocks in other factors. Results from IFRs offer a rough analysis of how long it takes for the variable to go back to equilibrium after the long-run relationship has been shocked.

3. Database

The emission data for CO_2-eq stem from the official emission inventories that the government of Chile has sent to the UNFCCC (2016). The most recent year for which information is available is 2013. This data has been supplied by the Ministry of the Environment for this research. Energy consumption data –either for fossil fuels as for energy consumption- has been taken from the energy balances published by the Ministry of Energy (CNE, 2015). All energy consumption data are measured in Teracalories. Energy balances available at Energia2050 were also considered (Ministry of Energy, 2016).

Unfortunately, there are not time series of Gross Value Added available so Gross Domestic Product (GDP) data was used. GDP data come from National Accounting drafted by the Central Bank. All data used corresponds to real GDP data at constant prices for 2008 (BCC, 2016a). These GDP series, in real terms, have been built using the annual GDP deflator per activity class and the exchange rates for deflator values as of the linked series included in the databases within the aforementioned Central Bank National Accounting (BCC, 2016b). Total Chilean economy was grouped into the following six sectors: Energy, Transport, Industry, use of solvents and other products (USOP), Agriculture and Waste. Because of its relevance it might be noted that mining sector is included into the industrial sector. The criteria for grouping productive activities into these six sectors were twofold. First, to match official emission inventories information, energy balances and GDP data. Secondly, being near to sectors included in Chilean's INDC submitted to Paris in 2015. Finally, population data has been taken from the Central Bank of Chile (BCC, 2016c). Main figures of sectoral GDP are offered in Annex 1.

Regarding Chile's commitments derived from Paris Agreement, when later changed to Use of the Land and Forestry sector (LULUCF) is excluded, the official document by the Chilean government defined two carbon intensity measures in its INDC, depending on whether it received international financing or not. The exact commitments were:

a) By 2030, Chile is committed to reducing its CO_2 emissions per GDP unit by 30% below its 2007 levels, considering a future economic growth which allows the implementation of adequate measures to reach this commitment. This commitment considers an economic growth rate similar to the country's in the last decade, except for the most critical years of the international financial crisis (2008–2009). The commitment affects the following sector included in the National Greenhouse Gas Inventory (1990–2010): Energy, which includes the generation and distribution of electricity, transportation, industry, mining, housing, among other fossil fuel consuming sectors, industrial processes, use of solvents and other products (USOP), agriculture, including the livestock sector and waste.
b) Additionally, and subject to a grant from international cooperation, the country is committed to reducing its CO_2 emission per GDP unit by 2030 until it reaches a 35% to 45% reduction with respect to 2007 levels, considering, in turn, a future economic growth which allows the implementation of adequate measures to achieve such a commitment. The official document specifies that for the purposes of this commitment, an international monetary grant shall be deemed any grants which allow the implementation of actions having direct effects on greenhouse gas emissions within adequate time frames. Table 2 provides a quantified sample of Chile's commitments.

4. Results

4.1. Decomposition analysis

The LMDI analysis results allow Chile's policy measures in force during the period under consideration to be examined. There are strong energy policy decisions which directly impact on some decomposition factors as CI. These are the cases of massive imports of natural gas from Argentina, but also decisions oriented to replacing such an energy source by coal when imports are interrupted. In an indirect way, these types of strong energy policy decisions also affect other factors, as is the case of population. When electricity is generated by thermal plants powered by coal, an increase of demand because of a higher population explains its role as a driver of CO_2 emissions. Another strong energy policy measure is the progressive elimination of leaded gasoline, which directly influences CI but in an indirect way on income and population factors when people go to gas stations and this fuel option is not available. Environmental stress (CO_2-eq emissions) through income and population factors decreases when the quality of fuels increases. Related with this, a relevant question about energy and environmental policies is if they can act on income and population factors. It can be thought that those factors are beyond the control of such policies depending on the business cycle, income distribution patterns or demographic issues. However, there are many relevant measures acting on those two factors. For example, when, after 2007, it became mandatory for refrigerators and light bulbs to indicate their level of energy efficiency, consumers accessed a clear information that could change residential consumption levels, also modifying the EI trend. This type of 'ecolabelling' policy is also relevant when it is regarded from the income factor perspective, as the better the level of

Table 2
Chile's Intended Nationally Determined Contribution sent to COP21.
Source: Government of Chile (2015).

	Carbon intensity per GDP (CLP$ 2011)
Base Year: 2007	1.02 tCO_2-eq/million CLP$
Target Year: 2030 (conditioned to economic growth)	0.71 tCO_2-eq/million CLP$
Target Year: 2030 (conditioned to an international grant and economic growth)	0.56–0.66 tCO_2-eq/million CLP$

energy efficiency, the higher the price of the device. A final example of energy policy measures altering the population factor is mentioned when referring to the Netbilling Act (Law no. 20.571), allowing self-consumption of electricity from a small RES system installed at home and selling back part of this electricity to the grid.

Focus is placed on those measures that could impact on decomposition factor values. A richer discussion could be held if the whole period were broken down into sub-period separated by relevant events based on what happened in the energy sector and the energy policy during the period of time considered and regarding the main climate change actions (Sanhueza and Ladrón de Guevara, 2014). The sub-periods considered were 1991–1996, 1997–2006 and 2007–2013.

Fig. 1 and Table 3 show the main results of the LMDI analysis for the 1991–2013 period; a complete database has been drafted for all of the factors considered. Positive values imply that the factor or effect acts as a driver of CO_2 emissions (measured in gigatons –GT– in Fig. 1). When its sign is negative, this reveals that it works as a compensating factor. The specific analysis for each sector is carried out below. Results are presented by sub-periods.

4.2. From 1991 to 1996

This period is nearest to the signing the Framework Convention at the UNFCCC summit in Rio and runs up to the beginning of massive imports of natural gas from Argentina for power. On average, Tapio's index for this sub-period is equal to 0.58 (Tapio, 2005). In keeping with Vehmas et al. (2007) and Wang et al. (2016), this implies a weak decoupling between economic growth and CO_2 emissions. For this sub-period, the only factors that work as compensators for the increase in CO_2 emissions are CI and ES, but without surpassing absolute values for the rest of the factors that act as emission drivers. However, with the results obtained, we must be cautious because LMDI does not always capture the changes in energy consumption attributed to the energy consumption structure between sectors. We assume that these remain unchanged (Han et al., 2012).

The carbon intensity factor –CI– was the most important inhibitory factor for the increase of CO_2 emissions. This showed a clear pattern for the sub-period evaluated; it seems to show that the energy matrix in Chile moved towards de-carbonization. When performing a sector analysis of the CI effect (Table 3a), it shows that for the energy sector, this factor had a negative sign, thus working against CO_2 emissions. The energy, USOP, Agriculture and waste sectors all acted as compensating sectors for CO_2 emissions. Transport and Industry sectors drove CO_2 emissions. The role of Transport sector could be partly explained because authorities created the Oil and Fuel Price Stabilisation Funds in 1991 (Law 19.030) and 2005 (Law 20.493) to avoid a negative impact of high crude oil prices (Mundaca, 2013). The industrial process sector registered a behavior that was similar to that of the transportation sector, but lesser in absolute terms.

The explanation behind the positive sign of RES (Table 3b) is found in the behavior of the Energy sector. Between 1991 and 1996, the RES factor in this sector showed a quantitatively positive sign that was larger than the other sectors. For the same time span, the Agriculture and Industry sectors also worked to favor the increase in CO_2 emissions.

For this sub-period, the EI factor failed to show a compensating effect on CO_2 emissions (Table 3c). Sanhueza and Ladrón de Guevara (2014) pointed out that in 1992, Chile received funding from the Global Environmental Facilities (GEF) for a project to deal with promoting the installation of services supporting efficient energy use, by using Energy Service Companies, through pilot projects in the country's copper mining sector. The 'pilot' nature of this project might explain that despite the fact that it was correctly oriented in sectoral terms, it was not enough to have a strong impact on Chile's energy efficiency.

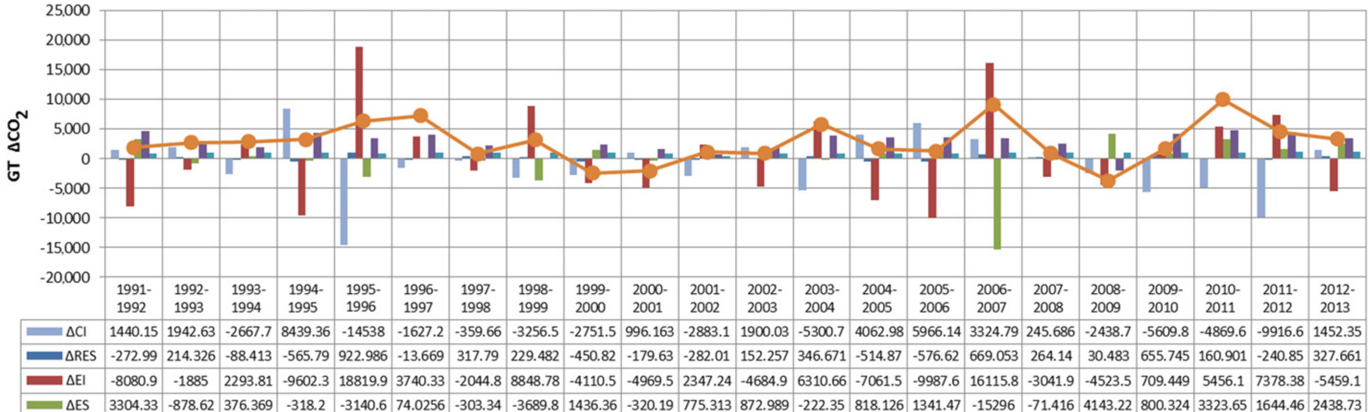
Together with this pilot project and from the perspective of the domestic governance in the fight against climate change, it must be pointed out that a National Advisory Committee on Global Change was set up in 1996. Nevertheless, it only began to operate on a regular basis at the beginning of 1998.

The ES factor acted as a compensating factor of CO_2 emissions. From 1991 to 1996, the weight of the Agriculture sector on Chile's GDP at constant prices reduced by 14.5%. This is coherent with its role as a compensating sector, shown on Table 3d. Other emitter sectors also reduced their weight in total GDP, such as mining, non-metallic and Pulp sectors (−8.51%), all of them included in the industry sector of Table 3d, and the Chemical sector, included in USOP sector. Detailed analysis is based on National Accounts provided by BCC (2016b).

As was expected, the results for Income effect show a clear coupling between economic growth and emissions (Table 3 e and f). The population increase also works as a driver for CO_2 emissions. This result is in line with, for example, Hatzigeorgiou et al. (2010) and Cansino et al. (2015). From the sectoral perspective and similar to what happens with the Yp factor, the sectors where greater absolute values take on this factor are energy, transportation and agriculture.

4.3. From 1996 to 2006

The sub-period begins with an important change in Chile's primary energy and in the electricity generation matrix. This is a consequence



	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013
ΔCI	1440.15	1942.63	-2667.7	8439.36	-14538	-1627.2	-359.66	-3256.5	-2751.5	996.163	-2883.1	1900.03	-5300.7	4062.98	5966.14	3324.79	245.686	-2438.7	-5609.8	-4869.6	-9916.6	1452.35
ΔRES	-272.99	214.326	-88.413	-565.79	922.986	-13.669	317.79	229.482	-450.82	-179.63	-282.01	152.257	346.671	-514.87	-576.62	669.053	264.14	30.483	655.745	160.901	-240.85	327.661
ΔEI	-8080.9	-1885	2293.81	-9602.3	18819.9	3740.33	-2044.8	8848.78	-4110.5	-4969.5	2347.24	-4684.9	6310.66	-7061.5	-9987.6	16115.8	-3041.9	-4523.5	709.449	5456.1	7378.38	-5459.1
ΔES	3304.33	-878.62	376.369	-318.2	-3140.6	74.0256	-303.34	-3689.8	1436.36	-320.19	775.313	872.989	-222.35	818.126	1341.47	-15296	-71.416	4143.22	800.324	3323.65	1644.46	2438.73
ΔYp	4568.25	2356.12	1933	4268.75	3420.63	4070.07	2183.79	12.6036	2390.93	1590.08	693.075	1860.13	3836.85	3523.71	3641.18	3384.36	2472.12	-2005.8	4110.47	4821.39	4515.54	3400.88
ΔP	912.008	936.132	967.604	1002.48	879.572	959.934	1002.03	1014.73	1005.5	836.255	457.633	807.422	805.948	834.985	857.718	931.765	1027.64	1044.35	1018.25	1070.12	1138.01	1152.61
ΔCO_2	1870.84	2685.59	2814.62	3224.34	6364.98	7203.47	795.766	3159.24	-2480	-2046.8	1108.19	907.96	5777.07	1663.44	1242.27	9129.81	896.297	-3749.9	1684.42	9962.58	4518.91	3313.13

Fig. 1. Main figures for factors considered in LMDI analysis 1991–2013.
Source: Own elaboration.

Table 3
Decomposition effects by sectors and sub-periods (GT ΔCO_2).
Source: Own elaboration.

3a

ΔCI	1991–1996	1997–2006	2007–2013
1. Energy	−2583.055	−14,299.551	−11,786.221
2. Transport	333.893	−2288.281	2468.022
3. Industry	4.359	1573.424	−2004.833
4. USOP	−56.641	−63.793	−405.532
5. Agriculture	−2675.637	12,628.761	−9226.940
6. Waste	−406.098	823.346	−181.216
Total	−5383.180	−1626.094	−21,136.720

3b

ΔRES	1991–1996	1997–2006	2007–2013
1. Energy	72.170	47.317	86.054
2. Transport	22.939	−3.458	6.974
3. Industry	35.989	−405.411	244.558
4. USOP	26.966	32.595	83.280
5. Agriculture	38.123	−534.954	711.132
6. Waste	13.935	−93.836	66.086
Total	210.122	−957.747	1198.084

3c

ΔEI	1991–1996	1997–2006	2007–2013
1. Energy	2789.701	8475.080	−3518.954
2. Transport	−973.755	−3018.860	−2313.688
3. Industry	−130.048	−569.663	−483.257
4. USOP	2.221	3.958	347.761
5. Agriculture	−331.319	−19,684.966	7035.517
6. Waste	188.744	−557.640	−547.906
Total	1545.544	−15,352.090	519.474

3d

ΔES	1991–1996	1997–2006	2007–2013
1. Energy	−575.103	−3767.583	15,184.900
2. Transport	1514.784	1885.640	−1121.288
3. Industry	−137.604	−30.779	−136.375
4. USOP	−5.034	0.180	−26.338
5. Agriculture	−1035.478	3037.406	−1842.592
6. Waste	−418.237	−416.322	220.662
Total	−656.674	708.542	12,278.970

3e

ΔYp	1991–1996	1997–2006	2007–2013
1. Energy	7142.261	9267.417	9377.220
2. Transport	3551.695	4395.972	3800.987
3. Industry	1131.657	1650.035	1134.603
4. USOP	26.036	27.885	29.455
5. Agriculture	3875.938	3418.246	2283.499
6. Waste	819.169	972.786	688.840
Total	16,546.757	19,732.340	17,314.603

3f

ΔP	1991–1996	1997–2006	2007–2013
1. Energy	2022.518	3596.371	3436.325
2. Transport	1010.401	1701.450	1432.207
3. Industry	324.525	611.849	433.664
4. USOP	7.303	10.381	11.458
5. Agriculture	1100.506	1340.511	877.957
6. Waste	232.542	361.652	259.367
Total	4697.796	7622.213	6450.978

of massive natural gas imports from Argentina. Another relevant fact of this sub-period was the rationing of the electrical supply due to extensive droughts in 1998 and 1999. Together with this, as mentioned, the National Advisory Committee on Global Change began to operate at the beginning of 1998. The period finalizes with a sudden interruption in the supply of natural gas. In addition to the CI factor, RES and EI factors act as emissions' compensators. The Tapio's index for this sub-period is equal to 0.33; this translates into a weak decoupling between economic growth and CO_2 emissions.

For this second sub-period, CI continued to act as a compensating factor of CO_2 emissions, which increased the greater values in absolute terms. From Table 3a, it must be pointed out that the CI factor shows that the energy sector continued working as a compensating factor for CO_2 emissions together with Transport and USOP sector overweighting the role as a driver sector played by Agriculture, Industry and Waste.

To better explain the role of the energy sector for this sub-period, it must be highlighted that the CI factor captures the substitution of fuels for cleaner types. Upon contemplating this aspect, one must consider two key factors that may be observed in Annex 2 and in the energy balances. The first is the decreased use of coal halfway between the onset and the end of the period; this contributes to explaining the behavior of this factor in the industrial processing sector for the latter years analyzed. Thus, there is a substitution effect between fossil fuels that correctly capture the CI effect as was expected. Coal is the most pollutant of all primary sources. The second factor is the major penetration of natural gas, as shown by the energy balances. This fuel, although fossil in origin, has a much lower CO_2 emission level than coal or crude oil derivatives.

If in 1996 the import of natural gas in Chile was inexistent, by 2006 it reached 224,428 TJ. The generation of electricity powered by natural gas when from 307 GWh in 1996 to 11,438 GWh in 2006; electricity powered by coal decreased from 9499 GWh in 1996 to 7212 GWh in 2005 (IEA, 2017). In 1999, the installed wind power was seven times that of 1997.

As seen on Table 3 a, the sectoral analysis for the CI factor shows that one of the sectors that behaves, in this sub-period, as a compensating factor for CO_2 emissions is the transport sector. To explain this behavior, one must consider that despite the increase in electrical consumption in the transport sector (Annex 3), the energy balances show the progressive elimination of leaded gasoline, which is one of the most pollutant crude oil derivatives. Its use was finally abandoned in 2003. Ceasing to use leaded gasoline helped move Chile's economy forward, away from a high carbon system. Technological advances in engines to reduce fuel consumption contributes to explaining the behavior of this factor in the transport sector. Annex 3 shows that due to its importance, efforts to reduce CO_2 emissions are imposed on the highway and maritime transport sector.

The next factor analyzed is the RES factor that acted as a compensating factor of Chile's CO_2 emissions for this second sub-period (Table 3b). The RES factor captures the impact of renewable energy sources on energy related CO_2 emissions for countries without nuclear plants. It must be highlighted that the new Ralco hydropower plant began operations in 2004; it accounted for 10% of all power generation in the Central-SIC interconnected System (which shares 77.7% of total power capacity in Chile). The electricity generated by hydropower went form 21,979 GWh in 2004 to 29,129 in 2006 (IEA, 2017). The sub-period under analysis included the best hydrologic years between droughts (2002–2005). Another aspect of the explanation for this result could be found in the Project titled 'Removal of obstacles for the electrification of rural areas using renewable energies' (Ferón et al., 2016) implemented in the first part of 2000. This is coherent with the behavior show by the Agriculture and Waste sectors, as indicated in Table 3b. Besides hydropower, other relevant renewable energy sources in power generation include biomass (Pontt et al., 2008). The project mentioned above proposed a successful policy for rural electrification. The importance of such projects focusing on the rural sector must be underscored because it allows energy from biofuel and waste to be reduced. The main usage of such energy is for cooking and heating. In 1990, consumption was 3133 TPES of which 1809 was for the residential sector. Consumption in 2013 was 10,340 of which 3734 was for the residential sector. Despite the role of biomass as a renewable energy source, the negative impact of its emissions on the health of populations could be a key question on the political agenda (Pablo-Romero et al., 2015).

The energy intensity factor was analyzed next; this acted as a compensating factor of Chile's CO_2 emissions (Table 3 c). However, it is an effect with an unclear trend to help this economy's decoupling (positive in the first and last sub-periods but negative between 1997 and 2006).

The sign of the EI effect is determined by the decrease of the electrical supply due to the serious droughts suffered in Chile in 1998 and 1999. For the most part, generating electricity in the country depends upon annual water flow, given that hydroelectric power plants in Chile have no inter-annual reservoir capacity. The only exception was the Laja Lake hydroelectric power plant. Hydroelectric power generation decreased by 15.8% in 1998 and 14.8% in 1999 (IEA, 2017). The crisis led to an electricity supply rationing program in November of 1998; however, the system continued to be vulnerable, in which case there were a series of disruptions in the electrical supply in January and February of 1999. In June of 1999, the government of Chile approved the electricity rationing decree that was in place until August 31 of that year.

Between 2006 and 2008 and also linked to energy efficiency measures, two relevant policies were put into force by Chilean Authorities. The first was the Country Energy Efficiency Program instituted at the onset of 2005 and that began to operate as of December 1, 2008 (CNE, 2008). In line with these results, it could be said that this initiative helped to enhance Chile's Energy Efficiency together with others factors such as high prices of oil products. Derived from the data shown on Table 3c, there were four key sectors that defined the EI path: the Transport sector, the waste sector, the Agriculture (greatly affected by droughts) and the industry sector. Even so this latter had a quantitative contribution that was less important. In fact, although Industry worked as a compensating sector in the data provided by the Energia2050; it advised on the energy intensity trend in the mining sector. This latter accounts for approximately 14% of the total energy consumption (CNE, 2008). Generally speaking, between 2000 and 2010, the energy intensity of the mining sector went from 0.63 Koe/K CLP$ in 2003 to 0.89 in 2010.

Different from first sub-period, the ES factor drove CO_2 emissions (Table 3d). The main change from a sectoral perspective is registered in the Agriculture sector which became a higher driver sector of CO_2 emissions. When considering the National Accounts, between 1997 and 2006, this sector increased 29.9%. The Transport sector responded in the same way, as it also increased either its weight on Chile's total GDP (10.68% between the beginning and the end of the sub-period) or its role driving CO_2 emissions. On the contrary, the Energy sector continued to work as a compensating sector as was the case in the previous sub-period. Indeed, its role increased but failed to balance the driver sectors.

During these years, Chile was one of the countries that registered the most Clean Development Mechanism (CDM) projects, because at the beginning of this period, a study on the strategic use of this market based instrument, the establishment of the Designated National Authority for the CDM in Chile and an intensive campaign promoting opportunities for implementing CDM projects were performed. Despite attempts by Chile's government to integrate these developments into national policies (mainly in the energy sector), integrating CDM projects into national policy was weak until the COP-15 in Copenhagen.

For the previous sub-period, the results for Income and Population effects show a clear coupling between economic growth and emissions. Once again, these effects reveal as clear drivers of CO_2 emissions. Result of Income effect is in line with Mundaca (2013).

4.4. From 2007 to 2013

This sub-period began with the interruption of the natural gas supply from Argentina and concludes when the series ends. In 2007, natural gas imports were reduced by 51.5% due to Argentina's decision to interrupt its exports of this power source (CNE, 2015). Argentina, was experiencing internal political and economic turmoil, restricted the export of natural gas. Chile had already suffered a cut in natural gas supplies from Argentina in 2002 due to labour strikes. Utility companies alerted the Chilean Government to the sudden energy security crisis (Mundaca, 2013). Power production –mainly electricity– then counted on the use of coal and diesel fuel. That same year when Argentina interrupted the natural gas supply, Chile's coal imports increased by 38.9% while diesel reached 112.3%. Those facts are coherent with a Tapio's index value of 1.53; thus implying an expansive negative decoupling. Only the CI factor works as a compensator for CO_2 emissions.

In 2009, the COP-15 in Copenhagen was conducted to negotiate a new climate treaty. National awareness of the climate change problem, establishing climate change policy and procedures for implementing this policy were, in these years, the most important actions. Another relevant fact for this sub-period was Chile's intention to become a member of the Organization for Economic Co-operation and Development (OECD) and the guidelines set out for its members. In 2010, the Ministry of the Environment and the Office for Climate Change (later renamed Departamento de Cambio Climático, meaning Climate Change Department) were created. During this sub-period, the National Climate Change Action Plan (PNACC from the name in Spanish: Plan Nacional de Acción Contra el Cambio Climático 2008–2012 (CONAMA, 2008). It was the first document to articulate climate change policies in Chile.

CI continues to prove to be a compensating factor. The sectorial analysis shows that the energy sector continues to be the greatest influence on the total effect of CI, but it reduces its absolute value with respect to the previous sub-period. Reductions in natural gas imports forced the power system to use more diesel and coal. The country needed to replace the (no longer available) natural gas supply from Argentina as fast as possible to reduce possible black outs while at the same time avoid increasing power prices as much as possible. Between 2006 and 2007 natural gas imports were reduces by 51.5% and between 2007 and 2008, 72%. For these last two years, diesel imports increased 112% while coal imports reached 38.9% (IEA, 2017). Between 2006 and 2007 electricity powered by natural gas decreased 59.5%; this was compensated by a 444% increase in electrical power produced from crude oil derivatives 21.5% from coal. As of 2009 and 2010, Chile once again imported natural gas, mainly from Algeria, Equatorial Guinea, Egypt and Indonesia. To avoid another 'Argentinean crisis', Chile embarked on the construction of large-scale liquefied natural gas (LNG) terminals (Mundaca, 2013).

Although Chile managed to progressively substitute natural gas from Argentina in favor of other supplier countries, natural gas imports in 2014 were still well below 1999 statistics. Coal imports saw an upturn in 2011 and since then, these have remained stable. Diesel imports, on the other hand, have maintained a similar level as registered in 2007 when this resource was used to substitute, in part, natural gas from Argentina.

Together with the Energy, USOP, Agriculture and Waste sectors, the industry sector also favored the mitigation of CO_2 emissions regarding its value for CI effect on Table 3a. For the two previously considered sub-periods, the industrial sector operated as a driver of CO_2 emissions once disaggregated from the CI factor. Offshoring processes could help explain this for the case of industry. When analyzing ES results, one must go back to this issue. This is an interesting result because one needs to bear in mind that the industrial sector is the country's largest energy consumer; it accounts for approximately 36% of the total energy consumption. Together with the mining sector, Chile's industry demands 64% of all electricity generated in the country (CNE, 2012; Duran et al., 2015).

As was pointed out between 2007 and 2013, the CI factor took on a negative sign for the agricultural sector proving to favor the mitigation of CO_2 emissions (see Table 3a). This behavior is due to the policies implemented such as codes for the rational use of fertilizers or the incorporation of new technologies for cleaner production; these have improved agricultural practices. The healthy use of fertilizers and the adoption of diversified crop systems have also contributed to this result.

However, the possible substitution effect that the negative value of the CI factor points out flows in the opposite direction than the behavior of the RES penetration factor. The RES factor works as a driver from 2007 to 2013 as a whole. This is coherent with the fact that Chile has intensified the use of fossil fuels as an electricity generation source, thus reducing the relative weight of hydropower. Also, this is partially associated with drought. Between 2006 and 2007, the electricity generated by hydropower decreased 20.6% and 14.1% between 2009 and 2010 (Ministry of Energy, 2016; IEA, 2017).

After the electrical supply was rationed in 1999 and natural gas imports from Argentina were interrupted in 2007, the main objective behind Chile's power policy was to attain a reliable power supply. Proof of this was that between 2010 and 2013, eight new coal-powered power plants began producing, with a 2147.9 MW capacity (these new plants were Nuevas Ventanas, Santa María, Campiche, Bocamina II, Andina, Angamos 1 and 2 and Hornitos). For that same period, the new capacity of the hydroelectric power plants was less (430.2 MW). Recently Agurto et al. (2013) has stressed the relationship between power generation and the business cycle in Chile. In fact, the power industry has often been considered to be a leading indicator because of the positive correlation between economic development and the trend in electricity consumption (Karanfil and Yuanjing, 2015).

In 2010, a policy measure promoting non-conventional renewable energies (NCRES), Law No. 20.257 (MEFR, 2008) to encourage the use of RES was put into practice. This law states that energy generating companies in Chile, with a capacity of 200 MW or more, must ensure that 10% of their energy generation each year originates from NCRE sources. This required quota started at 5% between 2010 and 2014, with an increase of 0.5% in 2015 and the final quota of 10% set for 2024. Electrical energy distributors supplying regular consumers are required to reach the 10% quota by 2010. The positive sign showed by the RES factor does not support the relevant impact for these measures.

The presence of other renewable technologies is still minimal for these years in Chile, and therefore, the greater or lesser contribution of hydroelectric power is what determines the sign for this factor in the sector analyzed. Wind power production began in 2001 (7 MWh). In 2013, the wind energy generation capacity was still a minority (554 MWh compared to 19,737 MWh from hydropower). Solar power (PV) began in 2013 with 8 MWh. Despite its scarcity, RES deployment in Chile is also interesting because it would help deal with a difficult situation due to the unreliable energy supply, exacerbated by periods of pronounced droughts and problems accessing natural gas from neighboring countries, mainly Argentina. This became clear with the 2006 gas crisis in Argentina (Ponzo et al., 2011; Duran et al., 2015).

The EI factor acted as a driver for this sub-period (Table 3 c). This is specifically true for USOP and Agriculture sectors. Nevertheless, during these years, interesting initiatives were launched, which focused on energy efficiency. Between 2012 and 2014 36 energy-savings projects had been launched and financed by the Asociación Chilena de Eficiencia Energética (Chilean Association for Energy Efficiency). However, these programs allow for a 34.18 GW/year savings in comparison with the 66,639.88 GWh generated in Chile in 2013, based on the information supplied by the aforementioned association (AChEE) and the Ministry of Energy (2016).

Although insufficient to attain a negative EI sign, it must be mentioned that other initiatives were also launched in those same years. For example, the Programa País de Eficiencia Energética (Country's Energy Efficiency Program) was launched at the end of 2006; it was mining initiative for clean energy (IMEL in Spanish acronyms) that counted on the collaboration of the Corporación de Fomento de la Producción (COFRO in Spanish acronyms, meaning Development Cooperation for Production) (CNE, 2008). The development of IMEL was based on volunteer agreements by which mining companies were committed to focusing a greater percentage of their demand though NCRES projects and energy efficiency.

Measures focusing on the residential sector must also be mentioned. In 2006, the Ministry of Housing launched a regulatory program for the thermal conditioning of dwelling. Since 2007, there are mandatory norms to be complied with when insulating buildings. The residential sector (including business premises and offices, in addition to housing) represent 73% of all wood burned. As of 2007, it was mandatory that refrigerators and light bulbs indicate their level of energy efficiency. Despite the initiatives mentioned and coherently with the EI factor sign, the Energy 2050 document has recognized that the measures to promote energy efficiency in Chile have failed to attain the expected results.

The ES factor, when considering Chile's economy in general, does not allow a clear reading to be extracted regarding its role as a driver or how to compensate CO_2 emissions (see Table 3 d). One must look at the breakdown of its values sector by sector to be able to identify how the change in the relative weight of each sector on the general economy impacts on CO_2 emissions. With this in mind, it is useful to show the output for the sectors of Chile's economy considered for the period analyzed (Annex 1).

When the ES factor is broken down by sectors, although the Energy and Waste sectors failed favoring the mitigation of CO_2 emissions, the rest of the sectors succeed. The energy sector increased its share on total GDP up to 36% from 2007 to 2013. Particular interest might be paid to industry because its role as a compensating factor increased over the previous period. Total energy consumption in Chile has more than doubled since 1991 (Ministry of Energy, 2013).

Chilean national GHG inventories offer more detailed information of certain disaggregated industries. This information allows the results to be discussed in a more stylized way. Unfortunately, this level of disaggregation is not offered by others key data sources such as energy balances. That is why productive sectors were grouped into six in order to conduct the LMDI analysis. However, information from it is useful when looking at the figures of Table 3d. The iron industry (which is the most important) registered continued decreases in the absolute volume of emission as of 2007. Others-Methanol registered improved behavior. Between 2006 and 2010, the volume of total emissions decreased by 70%. The production of lime registered a poor behavior, which is nevertheless, not correlated with the volume of emissions by the cement industry.

It must be also noted that in the case of Industry this result could be due to offshoring processes of Chile's more polluting industry towards other countries where environmental legislation is less demanding. The analysis in this paper does not allow us to perform such an analysis. It would be necessary to develop a Multi-Regional Input Output analysis to be able to respond to this question, which is similar to those by Andrew and Peters (2013) and Mundaca et al. (2015). Nevertheless, this analysis exceeds the objective of this article. On the other hand, the agriculture sector, although it shows an erratic behavior, needs special attention as it works as a driver during most of the latter years considered.

For the case of the Yp and P factors, coupling is also seen for the 2007–2013 sub-period. A positive value is obtained for all of the economic sectors analyzed (Table 3e and f). The sectors where greater absolute values take on this factor are energy, transport and agriculture.

In spite of their importance, the main result of PNACC 2008–2012 was improving the GEI inventory information at the national and regional level (University of Chile et al., 2015). This information may be useful to correctly design measures in the future; mitigating CO_2 measures were limited. The Assessment Plan report deepened very little into the elaboration of impact indicators and the development of mitigating policies.

4.5. Innovative Accounting Approach

To avoid errors due to the variability of the data, before estimating the VAR model we studied the statistical properties (mean, variance, autocorrelation, etc.) of the times series of the VAR model. Statistical properties all remain constant over time (Brooks, 2014).

4.5.1. Generalized variance decomposition

Table 4 shows the results of the generalized variance decomposition over a ten-year period for decomposition factor of CO_2 emissions. The variance decomposition shows how much of the predicted error

Table 4
Variance decomposition.
Source: Own elaboration.

Period	CI	RES	EI	ES	Yp	P
Variance decomposition of CI						
1	100.0000	0.000000	0.000000	0.000000	0.000000	0.000000
2	78.68459	14.12759	6.036208	0.919729	0.127448	0.104432
3	62.40732	22.55178	8.845984	3.332951	0.098039	2.763927
4	57.76604	21.65709	8.579019	4.489065	0.498203	7.010589
5	57.01630	19.66260	7.789011	4.334628	1.825365	9.372095
10	57.36806	17.79772	7.230208	3.835006	4.163441	9.605572
Variance decomposition of RES						
1	24.89783	75.10217	0.000000	0.000000	0.000000	0.000000
2	35.78299	58.67517	0.601012	0.813575	0.925649	3.201607
3	35.17092	55.78895	3.919351	0.935910	0.882389	3.302483
4	31.20122	55.24450	6.638193	2.445270	1.001830	3.468993
5	30.21001	52.96596	7.062505	3.376165	0.956703	5.428663
10	31.95710	48.83296	6.714224	3.252251	2.540219	6.703241
Variance decomposition of EI						
1	37.98300	20.27005	41.74695	0.000000	0.000000	0.000000
2	38.06957	15.78465	43.70422	0.778734	0.292270	1.370554
3	31.15882	22.20378	40.87566	3.613985	0.738783	1.408967
4	29.22731	22.33477	38.02486	5.497191	0.630469	4.285403
5	30.20942	20.68818	35.39482	5.663372	1.231191	6.813022
10	33.65725	19.02483	31.46369	5.049301	3.380212	7.424720
Variance decomposition of ES						
1	0.334286	39.44275	57.48359	2.739378	0.000000	0.000000
2	3.034888	39.51262	54.23979	2.500600	0.000174	0.711930
3	5.054140	37.53578	53.93384	2.573431	0.014537	0.888271
4	5.986930	36.96307	53.21447	2.893571	0.034331	0.907630
5	6.613335	36.48545	52.32681	3.183683	0.040556	1.350168
10	8.783025	35.02054	50.18719	3.169882	0.674321	2.165047
Variance decomposition of Yp						
1	0.673929	5.285425	6.412169	4.448004	83.18047	0.000000
2	1.399817	5.055993	9.761632	4.149186	78.70506	0.928312
3	1.557434	7.560474	13.84851	4.423392	71.60208	1.008107
4	1.596117	9.230652	15.66796	5.237689	67.03681	1.230772
5	1.911601	9.151710	15.87435	5.625918	65.40882	2.027602
10	3.894205	9.211015	15.33564	5.475892	63.53469	2.548558
Variance decomposition of P						
1	3.371292	11.03700	4.339709	2.097658	0.082839	79.07150
2	7.175800	10.42025	6.891046	2.815543	0.262147	72.43521
3	6.940962	15.27302	10.09441	2.744607	0.761851	64.18515
4	6.337022	18.40638	11.91689	3.733337	1.182109	58.42426
5	6.340097	18.21802	12.14377	4.295290	1.146931	57.85589
10	7.975771	18.15517	11.77387	4.207951	1.889267	55.99798

variance of a variable is described by innovations generated from each independent variable in a system, over several time horizons.

The empirical evidence indicates that 57.37% of the CI effect is due to its own innovative shocks. The standard deviation shock in RES factor is the variable that better explains carbon intensity with a percentage of 17.80%. Other factors that explain the CI are the P and EI effects with 9.61% and 7.23%, respectively. The rest of the factors, i.e., ES and Yp, explain carbon intensity with a lower percentage 3.83% and 4.16%, respectively.

A strong and significant portion of 48.83% of RES effect is explained by its own innovative shock. Carbon intensity explains the RES factor with 31.96%. RES explains the carbon intensity factor with 31.96%. The EI factor is explained, almost in the same portion, by its own standard innovative shock and by the shock on carbon intensity effect, 33.65% and 31.46%, respectively.

The structural composition of Chile's economy is mainly affected by the RES penetration effect (35.02%) and Energy Intensity effect (50.19%). This factor is explained solely by its own innovative shock by a low portion of 3.17%. A significant portion of the Yp factor is explained by its own shocks (63.53%), while the contribution of the RES factor and EI factor to the economic activity effect is 9.21% and 15.33% respectively.

Finally, the population effect is explained by its own standard innovative shock with a portion of 55.99%. The standard deviation shock in the RES penetration effect and Energy Intensity effect are 18.15% and 11.77%, respectively.

Taking 5% as a threshold, we may infer that there is bidirectional causality between the carbon intensity and RES penetration effect. This means that one way to reduce the CO_2 emission intensity would be by decreasing fossil fuel consumption with respect to the total primary energy, i.e., increasing the use of renewable energies. By also considering the reference of 5%, we may infer that there is unidirectional causality from CI to EI, from RES to EI and to ES and from EI to ES and to Yp.

Common to this statistical evidence of the variance decomposed into CO_2 emission driver results allow us to highlight the following:

1. If the RES penetration effect decreases, then the carbon intensity decreases also. This is because the renewable energy source share in total primary energy is greater; therefore, the quality of fossil fuels is better.

2. The CI effect and RES penetration effect causes the Energy Intensity effect. Besides there is a unidirectional causality from RES penetration effect to Economy Structure effect. This means that if the share of the RES increases in the total primary energy matrix i.e., the carbon intensity and RES penetration effect decrease, the energy efficiency or the technology level of Chile's economy will be changed, which could highlight the importance of certain sectors in this economy.
3. The impact of structural change in Chile's economy in terms of CO_2 emissions and the income effects on CO_2 emission changes from energy consumption are changed by the energy efficiency of a Chile's economy due to the unidirectional causality of Energy Intensity factor to ES effect.

4.5.2. Impulse-response analysis

With the aim of simulating the behavior of the variables involved in the study over time, the correlations among decomposition factors of CO_2 emissions were examined by the assistance of Impulse-Response Functions (IRF). Fig. 2 represents the IRFs for the six-factor of decomposition of CO_2 emissions.

It can be seen that in the short term, carbon intensity reacts more significantly to shocks in itself and the RES penetration effect, compared to shocks in other variables. The reaction to RES has the same behavior and opposite to shocks in ES and Yp. Nevertheless, the latter ends up disappearing in the long term.

The RES penetration effect has a significant reaction to a shock in the carbon intensity factor and to a shock in itself until it reaches the 4th time horizon, but dissipates in the long run. The response to shocks in other factors decreasing in the long run.

The energy intensity reacts more sharply to shocks in RES and CI. From the 4th horizon, there is a bigger reaction to shock in CI than to shock in RES.

The economy structure reacts to all factors; it is the strongest reaction to shocks in CI, RES and EI. After the 5th period, the response to these shocks decreases to dissipate in the long run.

The income and population effects have a significant reaction to a shock in all variables in the sense explained in Section 4.1; consequently, acting on these factors through policy measures is recommended; consequently, acting on these factors through policy measures is recommended. The response to these shocks decreasing in the long run. The analysis of IRFs suggests the occurrence of the same causality relationships that were observed in variance decomposition analysis.

Most of the factors have a significant reaction to a shock in the RES penetration and the Energy Intensity effect. These results show the importance of the mix level resource efficiency that can mitigate CO_2 emissions and energy consumption without compromising economic growth and change of population. These are useful findings to evaluate

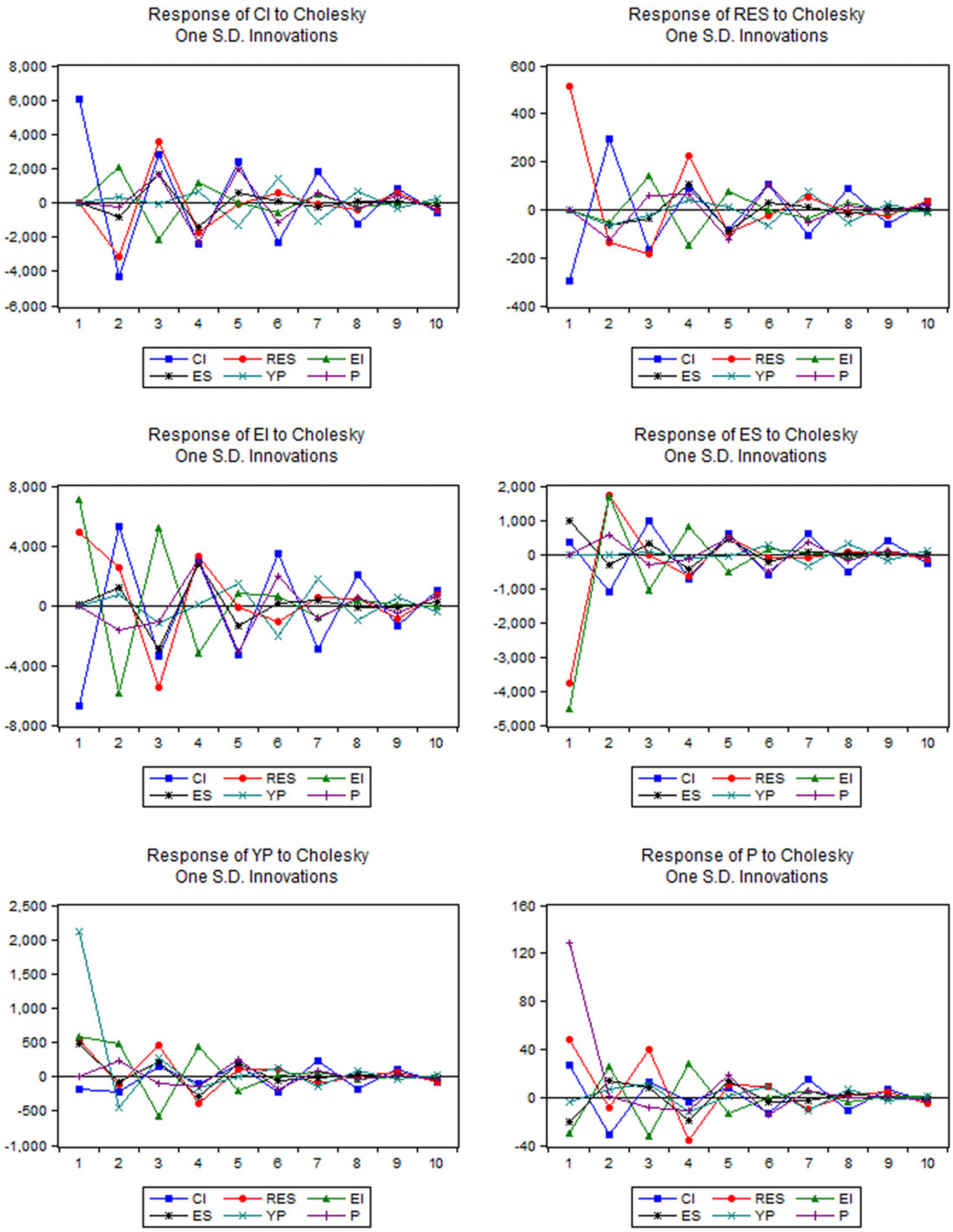


Fig. 2. Impulse-Response Functions.
Source: Own elaboration.

the measures in force to meet commitments derived from the Paris Agreement.

5. Policy implications regarding Paris Agreement

To attain the commitments of the Paris Agreement, Chile has two major instruments with long-term implications; one of these is Chile's future energy policy with the horizon on 2050 – hereafter Energia2050 – (Ministry of Energy, 2016). The other is the 2017–2022 National Action Plan against Climate Change – PNACC 2017–2020 – (Ministry of Environment, 2016). PNACC 2017–2020 also contains measures for Chile to adapt to climate change. This point falls outside the scope of this paper. Table 5 provides a detailed list of the most relevant measures included in both instruments. As can be observed, not all of the measures are accompanied by quantified objectives. Additionally, the objectives are referred to 2035, although the commitment acquired through the Paris Agreement is for 2030.

The long-term energy policy needs to underscore three lines that are directly related to the mitigation CO_2 emissions and Paris Agreement commitments; the change in the energy matrix towards one that is low in high carbon technologies, the assessment towards an electrical power distributed generation system accompanied with demand-active management measures and an improvement in energy efficiency. Each of these lines is debated below in terms of the results from LMDI and IAA.

Table 5
Main measures Paris Agreement.

Main measures	Targets up to 2035	Actions and relevant documents
Changes in energy matrix (Energy 2050)	60% power from RES	Law number 20257
	50% of fuels being low carbon emissions	Regulation of forest biomass as fuel affecting 40% of native forests Energy2050
Generation system distributed with smart management of the demand (Energy 2050)	Unavailability of the electrical supply no more than 4 h/yr.	Law number 20571 Development of an Andean inter-connected electrical system (without specifications in the exchange capacity) Energy2050
	Bi-directional electrical system with smart management system of the demand.	Energy2050
Energy efficiency (Energy 2050 and PNACC 2017–2020)	All new buildings meeting OECD energy efficiency standards and 25% of existing lower income buildings	Energy2050
	Major consumers with energy efficiency programs in force (industry, mining, transport and residential sectors)	Energy2050
	70% of the main appliance categories being energy efficient	Energy2050
	30% of buildings with control systems and smart energy management.	Energy2050
Green taxes	No specific targets (for example in terms of CO_2 abatements)	Energy2050 Development of regulations and follow-up systems (PNACC)
'FootprintChile' program	No specific targets	PNACC
Specific measures Transport sector oriented	100% of all heavy transport vehicles with an energy efficiency label.	Energy2050 Transantiago (PNACC)
	100% of all public transportation vehicles include Energy Efficiency criteria.	Energy2050
	100% of all heavy transport acquire by the public sector include Energy Efficiency criteria.	Energy2050
	At least 6% bicycle participation in major cities.	Energy2050
	At least 15% of the railways modal share of cargo transportation.	Energy2050
Specific measures Waste sector oriented	No specific targets	Framework legislation for the management of wastes, liability extensive to the Producer and the promotion of recycling PNACC
Educational measures	100% of all formal educational plans incorporate transversal contents regarding energy development.	Energy2050

In 2015, the generation of electricity in Chile continued to be predominated by thermal power (52%) from fossil fuels (coal, diesel and natural gas). The main renewable energy source was hydraulic (43%). The participation of nonconventional renewable energy sources (NCRES) represented 5% mainly wind energy). The participation of wind energy in the generation of electricity has increases, especially since 2010 (when it tripled the installed capacity), although a major leap forward was seen in 2014 when wind-generated electricity reached 1443 GWh; this almost tripled the statistics from the previous year. The study titled 'Energy Consumption and GHG Emissions in Chile 2007–2030 and Mitigation Options' (O'Ryan et al., 2010), which forecasts the country's GHG emissions up to 2030 and evaluated various policy instruments to reduce emissions, was commissioned by the company Endesa Latinoamérica. This study was part of the Environmental Economics Management Program at the University of Chile (PROGEA). The major GHG reduction measures were also identified and evaluated for the electric energy generation sectors.

The weight of RES in Chile changes if instead of analyzing only the electricity matrix, the primary energy source matrix is analyzed. In this case, behind crude oil, which represents 32.9% – 95% of which is imported – the use of firewood is outstanding, as is biomass to heat homes, hot water and cooking. Remember that the emissions generated by this energy source have an important impact on health (Pablo-Romero et al., 2015). This impact could be mitigated if by 2035 the 50% fuel matrix objective for Chile is met, which is based on the use of fuel that is low in greenhouse gas emissions. Part of the success will depend on the use of high quality firewood (pellets). A specific mention needs to be made regarding a hydroelectric power plant project in Aysén. It started as a project in 2005 but was under analysis for an extended period of time. In 2011, it was approved environmentally and in 2014, its environmental permission was revoked. Currently is under revaluation by the owners.

The goal is that by 2035 at least 60% of all electricity is generated from a renewable source, thus impacting on CI and RES factors. From the general variance decomposition results there is bidirectional causality between RES and CI; so, when acting improves RES penetration in Chile's energy matrix, CI is also improved. Together with this, it might be considered that the RES effect is revealed as a driver of CO_2 emissions for two of the three sub-periods evaluated. This measure goes in the right way to meet the Paris Agreement commitments.

The evaluation of the energy matrix towards a greater presence of NCRES and not only hydraulic if one takes into consideration the variations in the hydroelectric generation potential for SIC would be a 11% reduction for the 2011–2040 period (CEPAL, 2012). The penetration of NCRES could be favored by the reduction of the costs for this technology (IEA and NEA, 2015) and the development of the distributed generation system.

The success of the penetration of the NCRES would be facilitated if advances are made in the Andean electrical inter-connection system, which includes Chile, Colombia, Ecuador and Peru with Bolivia as an observer. Greater penetration of NCRES would translate into a growing part of the power installed in the four interior systems for the electrical inter-connection of Chile being non-manageable type (the amount of electrical power generated would depend on atmospheric factors). Improved management of the installed capacity recommends improving the inter-connection systems. In 2015, the bidirectional inter-connection was authorized with the system in Argentina, (known as Sistema Argentino de Interconexión or SADI) but only with a 345 kV capacity.

Moving towards a distributed generation system that includes smart management of the demand is the second strategic line for Chile's 2050 energy policy, and it is regulated by Law 20,571 for distributed generation in force since 2014. The initiative must favor the development of solar power, both to thermal as well as photovoltaic use. The measure would favorable impact on the CI and RES factors. It might be remarked that results from IRF showed that CI reacts more significantly to shocks in RES effect. A noteworthy fact is that it would also have a favorable impact on the behavior of the residential sector in the Yp and P factors that have behaved as drivers of CO_2 emissions in the LMDI analysis and for the three sub-periods analyzed. The measure is moving in the right direction. Its development would be favored if power storage systems were improved. It is possible that developments in the distributed generation impact on the ES factor if the conventional power sector loses relative weight. It must be borne in mind that the ES factor behaved as a driver of CO_2 emissions in the last sub-periods assessed.

Regarding electricity storage systems, Chile has lithium; batteries using this resource represent an interesting option. Together with these, hydrogen batteries are about to become a mature technology at the market level (Vivas et al., 2016). Finally, the penetration of EVs could be interesting (Malvik et al., 2013; Mwasilu et al., 2014). One must be cautious when it comes to the expectations for distributed generation systems. At the beginning of 2016, the installed distributed generation was 5.3 MW compared to a total of 22,910 MW which represented the total installed capacity in Chile (Ministry of Energy, 2016).

Together with the change in the energy matrix and the development of distributed generation systems, the third strategic line of Chile's future energy policy is to improve power efficiency. The success of the measures developed will impact on the EI factor, which drove CO_2 emissions for 1991–2006 and 2007–2013. This is also a well-oriented measure due to unidirectional causality from EI to Yp. Together with this and in line with results from IRF, it is expected that EI will be impacted by RES deployment from the aforementioned actions.

The objective for 2035 is to attain efficient energy use by means of smart systems in industrial sectors –especially mining, as well as transportation and residential sectors. In the case of the residential sector, the Swedish experience could be taken into account (Bager and Mundaca, 2015).

When planning urban transportation, 100% of the vehicles used must comply with energy efficiency standards. Also, improvements in the Santiago transportation system must also be mentioned.

Actions focusing on energy efficiency in the mining sector continue along the already described lines (IMEL) and measures for the residential sector as promoted by Ministry in charge. Whatever affects housing affects Yp and P and these are good when considering the role played by both effects for the whole period 1991–2013. The income effect was the most important driving factor for the growth of CO_2; the population change played a positive role in promoting the growth of these emissions. Results from the IRF analysis also revealed that income and population effects have a significant reaction to a shock in all variables.

Together with the measures included in the future energy policy, Table 5 shows others complemented by PNACC 2017–2020. The Plan incorporates initiatives that have already been launched. This is the case of a program titled "HuellaChile", which started in 2015 to offer a tool to quantify GHG both for private and public bodies.

It also incorporated the 2014 tax reform law. This law includes a tax on contamination from vehicles and fixed sources and a tax on thermal sources of emissions (boilers or turbines) in place since 2017 (Coronado, 2016). It is foreseeable that these taxes will have an impact on CI and ES factors, both because they promote the substitution of high emission fuels for other, cleaner types; this could alter the relative weight of more contaminating sectors. Likewise, the tax reform will necessarily have an impact on the transportation sector, which could benefit the penetration of electric vehicles. This latter would facilitate the development of a distributed generation model if EVs are used as storage systems. Nevertheless, the risk of offshoring derived from the 2014 tax reform must also be considered.

At the sectorial level, the PNACC counts on the development of the Framework Law for waste management, the extended responsibility of the producer and the promotion of recycling. This measure is also going in the right direction, when considering that for the 1991–2013 period, the sector behaved as a driver of emissions after the disaggregation of the Yp and P factors by sectors.

Regarding these same factors, the educational actions included in the PNACC must act in the right direction, as the counted on a precedent in the previous plan. In the 2008–2012 Plan, a guide was designed "Guía de apoyo docente para el Cambio Climático" (Teacher Support Guide for Climate Change); it established an accreditation objective of 600 teachers for the Metropolitan Region in the field of climate change. By continuously guiding energy consumption psychology, the occasional energy-saving behavior may change into more consistent actions both in the general population and in industries.

The effectiveness of the action to fight against climate change could be reinforced by the development of carbon sequestration technologies. Although the forestry sector could be a major contributor for Chile in this regard (Bonilla et al., 2012), other technologies could also move in this same direction. This is the case of sequestration by oxy-combustion of emissions from thermal power plants. Nevertheless, the potential of Chile's forestry sector in the sequestration of carbon is much greater and its analysis justifies differentiated research.

6. Conclusions

The Bali Action Plan established that the design of a future international agreement must consider enhancing the participation of developing countries in greenhouse gas mitigation activities to achieve the ultimate objective of the UNFCCC at its 13th gathering (COP13), held in Bali, Indonesia in 2007. This aim was taken into account by the Copenhagen Accord in 2009 and by the Paris Agreement in 2015, where Chile accepted specific commitments in the global fight against Climate Change.

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.

NCRES deployment is also necessary for the Chilean case, not only from the perspective of CO_2 mitigation but also regarding energy security and foreign dependence. Due to climate change, the risk of hydropower plants in providing electricity justifies effort oriented towards NCRES if past episodes of disruption want to be avoided. This also goes hand in hand with reducing Chile's external dependence on fossil fuels, especially those derived from crude oil.

The development of NCRES will be favored by the expected decrease in the cost of these technologies, but it must also be accompanied by major investment efforts to increase the inter-connectivity of the Andean Inter-connection Electricity System.

In terms of the development of distributed generation systems, the difficulties behind its implementation have proven that it must be taken into consideration. The case of Spain should be analyzed by the authorities in Chile. 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.

Likewise, the actions foreseen for the transportation sector are moving in the right direction given the importance of its energy consumption.

Special attention must be given to the Green Taxes established by the 2014, although said taxes could help mitigate CO_2 emissions, there is a risk of offshoring by the most contaminating industries, which would become a major threat for Chile's economic development.

Concerning actions focusing on the sequestration of CO_2, Chile's priority continues to be its forestry sector. Although it is extremely important as a carbon sink, this aspect is worthy of specific and separate analysis. Other CO_2 sequestrations technologies mentioned in this paper should be viewed with interest.

Finally, the educational actions in place are also adequate and correctly oriented towards impacting on income and population factors.

In summary, the policies currently applied in Chile are considered adequate with regards to its compliance with the Paris Agreement commitment. To facilitate success in the development of certain aspects, time is precious. The proposals included in this paper could contribute to that success.

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Appendix A

Annex 1
GDP by sectors at 2008 constant prices (millions of pesos).
Source: BCC (2016a).

	1. Energy	2. Transport	3. Industry	4. USOP	5. Agriculture	6. Waste
1990	1,258,518	1,327,898	25,441,342	865,738	1121,534	4,902,865
1991	1,597,855	1,439,636	27,285,939	911,944	1,146,455	5,107,068
1992	2,038,552	1,689,121	29,284,530	1,016,032	1282,559	5,456,188
1993	2,137,366	1,787,107	31,155,176	1,089,747	1,321,679	5,654,703
1994	2270,016	1,883,323	32,615,323	1134,229	1,417,832	5,872,955
1995	2,443,204	2,159,785	35,408,042	1,219,678	1,511,681	6,062,232
1996	2,351,488	2,379,518	38,286,119	1,258,879	1,550,327	6,415,260
1997	2,517,326	2,693,127	41,171,265	1,362,083	1,597,029	6,747,713
1998	2,572,137	2,876,912	43,101,643	1391,901	1,684,555	6,885,790
1999	2,409,807	2,830,806	44,204,058	1405,880	1,670,730	6,930,401
2000	2560,757	3,050,216	46,112,924	1,503,507	1,796,440	7,104,462
2001	2,575,485	3,203,295	47,738,968	1,507,816	1,903,395	7,279,439
2002	2,585,154	3,426,791	48,239,992	1,558,068	1,981,587	7,400,797
2003	2,671,099	3,805,958	49,902,749	1,568,572	2,036,805	7,524,380
2004	2,797,825	3,914,743	52,928,208	1,670,732	2,301,336	7,855,489
2005	2,974,660	4,080,559	55,580,223	1795,976	2,572,726	8,177,476
2006	3,212,589	4287,304	58,402,633	1,970,078	2,834,844	8553,841
2007	2,395,871	4,461,896	62,113,555	2,014,911	2,909,057	9,022,525
2008	2,498,997	4,462,918	64,203,317	2,103,302	3,116,985	9,502,672
2009	2,843,577	4,033,107	63,592,194	2,001,489	2,941,507	9,788,294
2010	3,081,725	4,352,219	66,779,682	2,113,808	2,949,963	10,283,205
2011	3,443,073	4,641,847	70,445,596	2,113,253	3,297,224	10,998,735
2012	3,732,843	5,152,642	74,249,838	2,163,491	3,226,009	11,579,693
2013	4,097,725	5,365,686	77,307,986	2,204,868	3,217,215	12,144,289

Annex 2
Energy consumption per industry (teracalories).
Source: CNE (2015).

		Sector industry & mining	Copper	Saltpeter	Iron	Paper & pulp	Steelwork	Petro-chemical	Cement	Sugar	Fishing	Various industries	Various mining
1991	Oil derivatives	16,342	5817	672	247	1380	136	17	68	12	1029	0	6888
	Electricity	9797	3952	168	267	1330	285	260	252	61	86	0	3136
	Coal	5333	466	30	478	91	0	0	1240	757	852	0	1419
	Others non-der.	12,343	33	0	1	6995	3125	0	0	164	28	0	2000
1992	Oil derivatives	18,170	5689	681	221	1642	207	141	75	23	1125	0	8366
	Electricity	11,415	4374	180	252	1795	347	323	292	79	109	0	3664
	Coal	6037	350	12	517	76	0	0	1731	1059	753	0	1539
	Others non-der.	14,890	49	0	0	7940	3801	0	0	261	0	0	2839
1993	Oil derivatives	20,239	5446	718	199	1440	133	120	94	21	1131	0	10,937
	Electricity	11,867	4488	179	234	1834	360	313	324	77	45	0	4013
	Coal	5466	586	3	431	13	0	0	1560	953	626	0	1294
	Others non-der.	11,680	51	0	0	4379	4003	0	117	141	0	0	2989

Annex 2 (*continued*)

		Sector industry & mining	Copper	Saltpeter	Iron	Paper & pulp	Steelwork	Petro-chemical	Cement	Sugar	Fishing	Various industries	Various mining
1994	Oil derivatives	20,470	5581	683	280	1642	201	124	88	39	1267	0	10,565
	Electricity	12,515	4747	179	236	1821	356	333	341	78	98	0	4326
	Coal	4306	358	3	401	11	0	0	1189	960	550	0	834
	Others non-der.	11,913	28	0	0	4287	3530	0	648	106	0	0	3314
1995	Oil derivatives	23,338	5451	683	251	1569	339	74	75	92	1044	0	13,760
	Electricity	14,277	5282	174	265	2037	353	359	354	93	99	0	5261
	Coal	4013	34	0	511	19	0	0	1247	992	326	0	884
	Others non-der.	4909	27	0	0	4444	3490	0	1043	94	0	0	3591
1996	Oil derivatives	25,759	5740	819	323	1576	395	44	198	121	1650	0	14,795
	Electricity	15,903	6391	182	283	2152	457	341	374	86	123	0	5514
	Coal	5274	184	0	568	12	0	0	1310	1088	812	0	1304
	Others non-der.	12,879	17	0	0	4369	3607	0	642	61	0	0	3973
1997	Oil derivatives	29,045	6585	841	355	1610	456	4	148	124	2270	12,279	4374
	Electricity	17,437	7388	203	272	1969	530	491	407	86	149	4781	1161
	Coal	10,248	295	0	540	9	0	0	1618	959	581	6029	217
	Others non-der.	13,889	3	0	0	2967	3785	0	437	54	0	6632	10
1998	Oil derivatives	26,402	6873	981	317	1520	414	47	228	104	1480	10,848	3590
	Electricity	18,107	8217	233	265	2188	462	405	402	99	95	4578	1163
	Coal	6116	50	0	603	5	0	0	1188	1136	282	2852	0
	Others non-der.	16,048	116	0	0	4951	3890	300	375	62	1	6312	41
1999	Oil derivatives	23,599	7336	1032	227	978	387	11	357	172	1397	8565	3137
	Electricity	20,989	9176	268	278	2366	528	480	345	80	126	5420	1922
	Coal	6139	40	0	523	270	0	0	1486	1066	194	2560	0
	Others non-der.	18,111	452	0	0	6043	4012	402	89	66	0	7018	29
2000	Oil derivatives	23,752	7265	996	326	1661	387	8	348	110	1824	6505	4322
	Electricity	22,090	10,543	192	303	2739	610	467	343	66	136	6038	653
	Coal	5169	25	0	577	270	0	0	1668	1036	100	1493	0
	Others non-der.	23,199	575	0	0	8242	4025	124	22	43	0	10,142	26
2001	Oil derivatives	23,355	6998	831	277	1477	26	24	197	15	1405	7845	4260
	Electricity	23,396	11,059	284	305	3134	586	468	364	77	122	6253	744
	Coal	6841	38	0	556	3	0	0	1442	1038	99	3647	18
	Others non-der.	21,697	841	174	0	5955	4244	168	420	51	158	9686	0
2002	Oil derivatives	22,301	8264	418	238	1612	74	20	122	82	1612	6170	3695
	Electricity	24,181	1,1687	281	291	3580	583	446	397	78	173	6138	527
	Coal	5297	55	0	488	2	0	0	1289	1074	109	2142	138
	Others non-der.	23,887	898	725	0	7238	4252	193	379	52	296	9854	0
2003	Oil derivatives	22,164	6867	298	202	1363	1	110	62	99	977	9047	3138
	Electricity	26,613	13,747	310	320	3322	605	581	439	60	148	6669	412
	Coal	4588	32	0	598	2	0	0	1618	663	75	1536	64
	Others non-der.	22,219	1165	853	0	4901	4320	178	793	35	513	9375	86
2004	Oil derivatives	22,024	5766	414	71	1098	209	9	293	113	1574	8066	4410
	Electricity	27,667	13,500	322	312	3477	500	546	414	82	117	7055	1343
	Coal	5190	26	0	600	0	0	0	1722	823	261	1667	92
	Others non-der.	23,656	1526	820	15	7174	3045	177	760	35	488	9545	73
2005	Oil derivatives	22,363	7345	415	89	1441	218	49	314	101	1054	7549	3787
	Electricity	27,885	13,639	356	310	3742	493	553	423	88	107	6918	1256
	Coal	4411	0	0	595	0	0	0	1393	879	130	1389	24
	Others non-der.	23,975	1724	829	0	8194	3482	99	715	38	513	8324	57
2006	Oil derivatives	26,705	8635	415	85	1682	215	29	364	98	751	10,523	3908
	Electricity	29,512	13,917	359	344	4282	494	526	510	80	156	7562	1282
	Coal	4439	9	0	577	0	0	0	1656	750	102	865	481
	Others non-der.	24,972	1075	596	0	10,652	3576	94	367	40	243	8298	30
2007	Oil derivatives	34,526	10,417	603	106	2550	348	23	425	75	874	15,036	4070
	Electricity	31,099	14,796	396	358	4586	582	420	504	76	210	7899	1271
	Coal	4329	1	0	557	4	0	0	1838	682	69	1169	9
	Others non-der.	22,340	497	238	0	12,280	3555	8	319	35	125	5253	29
2008	Oil derivatives	35,828	11,343	806	76	2554	535	17	280	192	1367	15,466	3193
	Electricity	31,505	15,349	348	407	4597	521	461	522	63	162	7739	1336
	Coal	3949	1	0	585	0	0	0	2143	409	73	738	0
	Others non-der.	21,299	352	39	0	12,409	3206	0	469	22	9	4761	32
2009	Oil derivatives	33,238	12,486	316	90	2674	538	11	232	4	1572	11,230	4084
	Electricity	31,469	15,948	330	377	4465	441	379	437	31	140	7663	1259
	Coal	2158	0	0	355	48	0	0	518	419	59	758	0
	Others non-der.	22,671	492	136	0	12,706	2888	1	1916	18	59	4311	142
2010	Oil derivatives	34,640	11,222	730	299	1073	153	2982	120	12	2878	8332	6838
	Electricity	30,928	16,251	423	477	3767	397	402	470	28	67	7016	1630
	Coal	2501	49	0	525	0	0	0	536	653	51	687	0
	Others non-der.	29,287	5742	173	0	11,374	1411	1171	1674	0	23	5029	2687
2011	Oil derivatives	38,665	13,456	1039	335	1391	541	20	244	13	3965	12,808	4850
	Electricity	33,110	16,710	367	461	4643	505	241	446	15	102	7988	1632
	Coal	2226	0	0	541	51	0	0	10	989	25	610	0
	Others non-der.	26,326	1120	71	0	13,690	3473	1425	1913	40	1	4551	43
2012	Oil derivatives	39,821	14,095	841	863	2320	509	1944	2276	148	2490	13,011	1322
	Electricity	36,366	18,356	499	417	5974	472	185	480	17	114	8250	1604

(*continued on next page*)

Annex 2 (*continued*)

		Sector industry & mining	Copper	Saltpeter	Iron	Paper & pulp	Steelwork	Petro-chemical	Cement	Sugar	Fishing	Various industries	Various mining
	Coal	1879	0	0	539	65	0	0	31	674	25	545	0
	Others non-der.	24,619	1098	255	0	14,925	700	1440	88	48	1	6013	49
2013	Oil derivatives	41,630	14,670	1165	399	2198	39	1759	2459	13	2248	15,137	1545
	Electricity	36,792	18,704	460	453	6210	399	148	493	17	126	8553	1228
	Coal	1388	0	0	0	63	0	0	1	690	24	609	0
	Others non-der.	28,616	1378	437	0	14,474	0	1527	54	53	1	10,647	46

Annex 3
Energy consumption in transport (Teracalories).
Source: CNE (2015).

		Total transport	Land	Rail	Maritime	Air
1991	Total derivatives	37,172	27,862	190	6014	3106
	No derivatives	268	147	121	0	0
1992	Total derivatives	40,153	30,331	205	5997	3620
	No derivatives	239	120	119	0	0
1993	Total derivatives	44,433	33,529	174	6622	4108
	No derivatives	274	138	136	0	0
1994	Total derivatives	48,877	37,832	148	6962	3935
	No derivatives	256	148	108	0	0
1995	Total derivatives	53,731	41,379	126	7675	4551
	No derivatives	241	150	91	0	0
1996	Total derivatives	56,947	44,727	156	7170	4894
	No derivatives	240	145	95	0	0
1997	Total derivatives	61,005	46,842	140	7845	6178
	No derivatives	239	157	82	0	0
1998	Total derivatives	65,586	49,273	159	8946	7208
	No derivatives	240	170	70	0	0
1999	Total derivatives	66,759	51,574	198	8281	6706
	No derivatives	229	162	67	0	0
2000	Total derivatives	69,559	53,092	194	10,207	6066
	No derivatives	276	200	76	0	0
2001	Total derivatives	67,010	49,814	186	10,165	6845
	No derivatives	310	228	82	0	0
2002	Total derivatives	68,559	51,671	201	9831	6856
	No derivatives	437	366	71	0	0
2003	Total derivatives	69,919	51,588	202	12,275	5854
	No derivatives	446	373	73	0	0
2004	Total derivatives	72,965	51,482	190	14,859	6433
	No derivatives	494	423	71	0	0
2005	Total derivatives	79,647	55,343	182	16,929	7193
	No derivatives	559	496	63	0	0
2006	Total derivatives	80,889	54,923	197	18,416	7353
	No derivatives	637	576	61	0	0
2007	Total derivatives	86,319	58,642	208	19,266	8204
	No derivatives	605	557	47	0	0
2008	Total derivatives	89,437	60,743	485	18,655	9553
	No derivatives	510	464	46	0	0
2009	Total derivatives	85,580	63,209	467	14,091	7813
	No derivatives	587	542	45	0	0
2010	Total derivatives	83,386	66,553	464	8915	7454
	No derivatives	573	228	340	4	0
2011	Total derivatives	86,590	68,828	481	9416	7866
	No derivatives	599	549	49	0	0
2012	Total derivatives	86,974	70,515	486	6047	9926
	No derivatives	733	682	51	0	0
2013	Total derivatives	93,158	76,324	489	6892	9453
	No derivatives	752	707	45	0	0

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2017.12.001.

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