A multilevel decomposition approach of Chilean CO2 emissions. The role of the forest sector

1.- Introduction

From the Intergovernmental Panel on Climate Change (IPCC) report, human-induced contributions to Climate Change are strongly linked with energy-related CO_2-eq emissions due to the high weight of fossil fuels in the energy matrix (IPCC, 2014). This has elevated the importance of human behavior in public policy and environmental legislation, where international cooperation is a critical juncture. The recommendation for countries is to design a road map that allows a transition towards a low carbon economy (Fankhauser et al., 2015). The ultimate objective of this road map is to decouple CO_2-eq emissions from GDP growth. Decoupling (or de-linking) refers to a situation where the aggregate economic activity increases but environmental stress decreases during the same time period (Vehmas et al., 2007).

Chile is a highly vulnerable country 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 zones, 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).

At the same time that Chile shows its vulnerability to Climate Change, its forests offer a relevant and useful tool in the battle against global warming. Following the UNFCCC, the rate of build-up of CO_2-eq in the atmosphere can be reduced by taking advantage of the fact that atmospheric CO_2-eq can accumulate as carbon in vegetation and soils in terrestrial ecosystems. Under the UNFCCC any process, activity or mechanism which removes a greenhouse gas –GHG- from the atmosphere is referred to as a "sink" (UNFCCC, n.d.). "Sink" means any process, activity or mechanism which removes a greenhouse gas, (GHG) an aerosol or a precursor of a GHG from the atmosphere.

Human activities impact terrestrial sinks through land use, land-use change and forestry (LULUCF) activities. Consequently, the exchange of CO_2 (carbon cycle) between the terrestrial biosphere system and the atmosphere is altered (UNFCCC, n.d.). As a result, the role of LULUCF activities in the mitigation of Climate Change has long been recognized and is clearly revealed in the last National Inventory of Chilean GHG emissions (Table A.1 in the annexes) which covers the period 1990 to 2013. For the whole period, contributions of the LULUCF sector to GHG emissions were negative, highlighting its role as a sink.

Due to their importance within the LULUCF activities, the activities of the Chilean forestry sector can be considered as a proxy of these activities (Table A.2). 22.9% of the Chilean territory is covered by forests (17.3 million hectares). Of the total hectares of forest 14.18 million are native forests and 2.96 million forest plantations. Ackerknecht (2013) proved that CO_2 sequestration by Chilean forests could compensate emissions from the pollutant sector in different scenarios analyzed up to 2020.

Based on this, as part of the Intended Nationally Determined Contributions (INDC) submitted by the Chilean Authorities to the Conferences of the Parties in Paris in 2015 (COP 21), they communicated a two-level commitment to be included in the final document known as the Paris Agreement. The first did not consider the LULUCF sector but the second did.

When the LULUCF sector is excluded (first level) and no international cooperation is considered, the exact commitment was to reduce Chile's CO_2 emissions per GDP unit by

30% below its 2007 levels by 2030. However, when the LULUCF sector is taken as a part of the Chilean commitments in the Paris Agreement, this country is committed to i) the sustainable development and recovery of 100,000 hectares of forest land, mainly native, which will account for GHG sequestrations and reductions of an annual equivalent of around 600,000 equivalent tons of CO_2 as of 2030 and ii) to reforest 100,000 hectares, mostly with native species, which will represent sequestrations of about 900,000 and 1,200,000 annual equivalent tons of CO_2 as of 2030 (Government of Chile, 2015).

This paper has two main objectives. The first is to assess the role of the forest sector (LULUCF activities) in the CO_2-eq emissions change from1990 to 2013. The second is to explore if the forestry sector has always contributed to a decoupling process between CO_2-eq emissions and economic growth for the period considered.

To address the first aim, the log-mean divisia index method –LMDI I– is conducted (Ang, 2005). This technique consists of using one type of index decomposition analysis (IDA). LMDI I has been revealed to be a useful tool to understand the evolution of energy-related CO_2 emissions, and to identify the driving forces that have impacted these changes. Such a method may be easily applied to any source of available data at any aggregation level in a given time period but, to the best of our knowledge, this is the first time that the forest sector has been included in such a tool to test the expected inhibitor effect of the sector on CO_2 emissions. In this sense, the paper contributes to the growing body of knowledge based on LMDI analysis.

To achieve the second goal of the paper, a decoupling index is used from the results of the LMDI to study the contribution of the forest sector to a possible decoupling process between CO_2 emissions and economic growth. In the first step, the decoupling status between CO_2-eq emissions and GDP growth is analyzed from the decoupling elasticity approach following Tapio (2005). In a second step, by considering the effects from the LMDI-I analysis, a second level of decomposition was conducted to analyze if forest sector deployment outweighs pollutant sectors, allowing to head toward a decoupling process between CO_2-eq emissions and economic growth. Here the contribution to the state of knowledge derives from the use of LMDI, Tapio's index and a second level decomposition of LMDI results, all together focused on a sector usually excluded from this analysis.

The article is structured as follows. After this introduction, Section 2 describes the methodologies used. Section 3 details the database. The results are shown and discussed in Section 4, while section 5 presents the conclusions and offers policy recommendations from the results obtained.

2.- Methodology

2.1.- LMDI analysis

The literature offers various, different decomposition techniques, such as the Arithmetic Mean Divisia Index method-1, the Modified Fisher Ideal Index, the Marshall-Edgeworth method, and the Laspeyres, Paasche, Sato-Vartia and Torqvist indices (Liu and Ang, 2003). Among these various IDA methods, the LMDI method seems to be the one offering most advantages (Ang, 2004; Timilsina and Shrestha, 2009; Zhang et al., 2009; González et al., 2014; Guo et al., 2014, Chen and Yang, 2015; Moutinho et al., 2015b; Shahiduzzaman and Layton, 2015; Zhang et al., 2016 and Sumabat et al., 2016). This paper follows Ang's (2004) criteria that assessed the various decomposition methods.

The IPAT (Impact=Population×Affluence×Technology) equation is the starting point for the LMDI I conducted. Specifically, the IPAT model (Commoner et al., 1971; York et al., 2002 and Brizga et al., 2013) and the 'Kaya Identity' (Kaya, 1990; Yamaji et al., 1991) are extended using IDA to assess the key drivers behind Chile's CO_2 emissions. The 'Kaya Identity' has been used in a number of studies addressing energy, economy and climate-related intensities at the global level (Ang and Pandiyan, 1997; Sun, 1998; Ang and Zhang, 2000; Choi and Ang, 2001, 2002; Paul and Bhattacharya, 2004; Metz et al., 2007; Lu et al., 2007; Oh et al., 2010; Wang et al., 2010; Akbostanci et al., 2011; Sheinbaum-Pardo et al., 2012 and Lin and Moubarak, 2013). Two recent papers focused on the Chilean economy by Mundaca (2013) and Duran et al. (2015) might be cited. The annual report from the IEA regarding the Kaya Identity could be also taken into account. Notwithstanding, Duran et al. (2015) carried out a decomposition of the energy consumption by the Chilean industry, but not of the CO_2 emissions as we do.

The analysis conducted considers seven productive sectors for the Chilean economy: energy, transport, industry, use of solvents and other products –USOP- agriculture, forest (LULUCF activities) and residuals and waste. Following Cansino et al. (2015), six factors 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. The results might enable the assessing of the role played by the forest sector.

Decomposition factors include the Carbon Intensity effect (CI), the Renewable Energy Sources penetration effect (RES), the Energy Intensity effect (EI), the Economic Structure effect (ES), the Income effect (Y_p) and the Population effect (P). Applying the decomposition proposed to seven productive sectors, the total CO_2-eq emissions may be decomposed as follows:

$$CO_2 = \sum_{i=1}^{7} CI_i \cdot RES_i \cdot EI_i \cdot ES_i \cdot \mathrm{Yp} \cdot P = \sum_{i=1}^{7} \frac{CO_{2i}}{FF_i} \cdot \frac{FF_i}{E_i} \cdot \frac{E_i}{Y_i} \cdot \frac{Y_i}{Y} \cdot \frac{Y}{P} \cdot P \qquad (1)$$

CO_{2i} represents the energy-related CO_2-eq emissions of sector *i*; FF_i denotes the share of fossil fuels of sector *i*; E_i stands for 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-eq, and *P* represents the population.

Changes in CO_2-eq 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-eq emissions during the period 0 and t is decomposed as follows:

$$\Delta CO_2 = CO_{2_t} - CO_{2_0} = \Delta CI + \Delta RES + \Delta EI + \Delta ES + \Delta \mathrm{Yp} + \Delta P \qquad (2)$$

ΔCO_2 represents changes in aggregate CO_2-eq emissions in the economy from one period to another, the right-hand side variables being the representatives of the various contributing determinants as previously defined, but now being referred to as changes.

By considering the additive decomposition identity, Eq [3] to [8] expose the LMDI formulas for each effect:

$$\Delta CI = \sum_{i=1}^{7} w_i(t) \cdot \ln\left(\frac{CI_{i,t}}{CI_{i,0}}\right) \tag{3}$$

$$\Delta RES = \sum_{i=1}^{7} w_i(t) \cdot \ln\left(\frac{RES_{i,t}}{RES_{i,0}}\right) \tag{4}$$

$$\Delta EI = \sum_{i=1}^{7} w_i(t) \cdot \ln\left(\frac{EI_{i,t}}{EI_{i,0}}\right) \tag{5}$$

$$\Delta ES = \sum_{i=1}^{7} w_i(t) \cdot \ln\left(\frac{ES_{i,t}}{ES_{i,0}}\right) \tag{6}$$

$$\Delta \mathrm{Yp} = \sum_{i=1}^{7} w_i(t) \cdot \ln\left(\frac{\mathrm{Yp}_t}{\mathrm{Yp}_0}\right) \tag{7}$$

$$\Delta P = \sum_{i=1}^{7} w_i(t) \cdot \ln\left(\frac{P_t}{P_0}\right) \tag{8}$$

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

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

Equation [3] captures the Carbon Intensity factor (CI). Variable ΔCI shows the changes in CO_2-eq emissions from fossil fuels consumption in sector i ($= CO_{2i}/FF_i$), between the periods t and 0, respectively. The 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 distinguishing different fuels. Despite this lack of information, the CI factor could be used to evaluate the substitution between fossil fuels. This is possible if statistics show changes in types of primary energy sources used (i.e., natural gas replacing coal or vice versa). We assume that the better a fossil fuel is, the less CO_2-eq it emits.

Equation [4] shows the Renewable Energy Source penetration factor (RES). Variable ΔRES indicates 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.

A specific comment regarding RES needs to be made to better understand their link with CO_2-eq emission data. By carrying out a decomposition analysis, we could research the role of RES in Chile's energy matrix. Yet, one problem must be solved, which is linked to the fact that RES technologies are free or almost free of CO_2-eq emissions and we observe this as a crucial variable. To bridge this lack of information, we noted the evolution of the ratio between the total fossil fuel consumption for the total primary energy consumption (O'Mahony 2013, footnote 3). A decline in values for the ratio of total fossil use of total energy use might show a higher share of RES in Chile's energy matrix.

Equation [5] presents the Energy Intensity factor (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. The EI factor is often used as a measure or aggregate proxy of the energy efficiency or technology level of a country's economy (Goldemberg and Johansson, 2004; Voigt et al. 2014).

Equation [6] is the Economic mix or the Economic Structure factor (ES). Variable ΔES shows the sectoral structure of Chile's economy between period t and 0, respectively. It incorporates the relative impact of structural changes on Chile's economy in terms of CO_2-eq emissions for a given year included in the analysis.

Equation [7] is the Income factor (Y_p). Variable ΔY_p is the output per capita between period *t* and 0, respectively. The Y_p factor captures the income factor in CO_2-eq emission changes from energy consumption.

Equation [8] shows the Population factor (P). Variable ΔP indicates the total population between period *t* and 0, respectively. The P factor enables the effects of population growth as a determinant for CO_2-eq emissions to be analyzed.

To accommodate cases of zero value, Ang and Choi (1997), Ang et al. (1998) and Ang and Liu (2007a) 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, 2007).

2.2.- Decoupling analysis

Bearing in mind that the desired objective of the government of Chile in the battle against Climate Change is to decouple CO_2-eq emissions from GDP growth, the decoupling approach here analyzes the reaction of CO_2-eq emissions in response to a change in the GDP as an elasticity index. The decoupling elasticity index, developed and used by Tapio (2005), measures the possible dissociation between economic growth and environmental problems in a period of time. Decoupling elasticity (ε) can be expressed by the percentage CO_2-eq emissions change in terms of the percentage GDP change during the period t and 0 as in equation [10]:

$$\varepsilon = \frac{\frac{\Delta CO_2}{CO_2}}{\frac{\Delta GDP}{GDP}}$$

(10)

Using the difference (Δ) between the values of environmental intensities at two time moments, a sufficient condition for weak de-linking is:

$$\Delta\left(\frac{CO_2}{GDP}\right) < 0$$

(11)

Weak de-linking implies that the environmental stress of the GDP decreases over time. Nevertheless, CO_2-eq emissions can still increase, but at a lower rate than the economic growth. For the de-linking to be called strong, $\Delta\ CO_2 < 0$ (Vehmas et al., 2007) is required.

Although De Bruyn (2000) initially only distinguished between weak decoupling ($\varepsilon < 0$) and strong decoupling ($\Delta CO_2<0$), Tapio (2005) and Vehmas et al. (2007) provided a broader list of possible statuses, including eight statuses. When positive economic growth happens at the same time as CO_2-eq emissions increase, these authors call it 'Expansive negative decoupling' ($\varepsilon>1.2$), 'Expansive coupling ($0.8< \varepsilon<1.2$) and 'Weak decoupling' ($0< \varepsilon<0.8$). The term 'Expansive' is due to positive economic growth. When negative economic growth happens while ($\Delta CO_2/CO_2$) increases, then the authors name this status as 'Strong negative decoupling'. However, if ($\Delta CO_2/CO_2$) decreases when negative economic growth appears, then another three new statuses are called 'Weak negative decoupling' ($0<\varepsilon<0.8$), 'Recessive coupling' ($0.8< \varepsilon<1.2$) and 'Recessive decoupling ($\varepsilon>1.2$). Finally, when ($\Delta GDP/GDP$) >0 and ($\Delta CO_2/CO_2$) <0, they refer to this status as 'Strong decoupling' ($\varepsilon <0$).

Yet, the percentage change of CO_2-eq emissions of GDP given by equation [10] only gives a rough measure of Chile's performance. In order to provide a more stylized analysis a second level decomposition is conducted. With a view to better probing the role as a sink of the forest sector outweighing pollutant sectors, we applied the decoupling index to LMDI decomposition, demonstrating the decoupling status influenced by different effects included in the LMDI analysis (Jiang et al. 2016). In other words, this allows examining the effort made in factors and sectors to achieve decoupling.

Following Diakoulaki and Mandaraka (2007), an effort is conceived as a general term referring to any kind of actions that directly or indirectly might induce a decrease in Chilean CO_2-eq emissions, including those oriented to promoting CO_2-eq sequestration. The efforts undertaken during the period analyzed are termed the inhibiting effect (ΔC_t) and can be represented as the sum of the explanatory factors included in equation [12].

As a starting point, it is assumed that economic growth causes CO_2-eq emissions. At the same time, CO_2-eq emissions can be reduced because of government measures oriented to mitigation (i.e., improving energy efficiency, measures for reforestation of native forests, firefighting, setting restrictions of using higher pollutant fuels, and so forth). In order to show the total inhibiting effect and from Eq [2] we use the following equation

$$\Delta C_t = \Delta CO_2^t - \Delta Yp^t = \Delta CI_i^t + \Delta RES_i^t + \Delta EI_i^t + \Delta ES_i^t + \Delta P^t \qquad (12)$$

where ΔCt is the total inhibiting effect on CO_2-eq emissions.

To obtain a further understanding of the efforts deployed, we apply a new decoupling measurement between CO_2-eq emissions and economic growth. This decoupling index presents an intuitive relationship between environmental impacts and is defined in Eq [13] and [14]

$$\frac{\Delta C_t}{-\Delta Yp^t} = \frac{\Delta CO_2^t - \Delta Yp^t}{-\Delta Yp^t} = \frac{\Delta CI_i^t + \Delta RES_i^t + \Delta EI_i^t + \Delta ES_i^t + \Delta P^t}{-\Delta Yp^t} \tag{13}$$

$$\delta_t = \delta_{CI}^t + \delta_{RES}^t + \delta_{EI}^t + \delta_{ES}^t + \delta_P^t \tag{14}$$

where δ_t refers to the total decoupling index and $\delta_{CI}{}^t$, $\delta_{RES}{}^t$, $\delta_{EI}{}^t$, $\delta_{ES}{}^t$ and $\delta_P{}^t$ indicate the carbon intensity, the RES, the energy intensity, the structure and the population effects on the decoupling between CO_2-eq emissions and economic growth.

Eq [13] and [14] properly capture the inhibiting effect. It must be considered that the negative value of the inhibiting effect might occur because of a positive change in CO_2-eq emissions ($\Delta CO_2{}^T$) being offset by the emissions change due to the output effect. Therefore, a negative value of the ΔC_t does not necessarily lead to a negative value of the total CO_2-eq emissions change ΔCO_2 (Jiang et al., 2016). In order to assess the degree to which these efforts are effective in terms of decoupling economic growth from emissions changes, a new decoupling index δ_t, is calculated in Eq [14]. Sectoral analysis would give information about the role played by the forest sector and others.

In absolute terms, the δ_t can take the following values. If the index value is $\delta_t \geq 1$, this denotes strong decoupling efforts; that is, the inhibiting effect ΔC_t is more significant than the output effect. If the decoupling index is between $0 < \delta_t < 1$, this denotes weak decoupling efforts; that is, the inhibiting effect ΔC_t is weaker than the output effect. Finally, if the decoupling index is $\delta_t \leq 0$, this denotes that there have been no decoupling efforts (Diakoulaki and Mandaraka, 2007 and Jiang et al., 2016).

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 (Government of Chile, 2016). The most recent year for which information is available is 2013 and this establishes the period being analyzed. This data has been supplied by the Ministry of the Environment for this research. Energy consumption data –both for fossil fuels and 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).

Gross Domestic Product (GDP) time series were used because there are not data of Gross Value Added available. The GDP data come from National Accounting drafted by the Central Bank of Chile. All the data used correspond 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). The total Chilean economy was grouped into the following seven sectors: Energy, Transport, Industry, Use of solvents and other products (USOP), Agriculture, Forestry sector and Waste. Because of the relevance of Chilean forest, as is explained in the introduction section, its emissions correspond to those that appear assigned to Land-use change and forestry (LULUCF) in the national inventory. The criteria for grouping productive activities into these seven sectors were twofold. First, to match official emission inventories information, energy balances and GDP data. Secondly, to manage those sectors included in the Chilean Intended Nationally Determined Contribution submitted to Paris in 2015. Population data have been taken from the Central Bank of Chile (BCC, 2016c).

Finally, information of forest fires came from Historical Fire Statistics in Chilean Forest Ecosystems (1990-2013), available in the digital repositories of CONAF.

4.- Results and discussion

4.1.- LMDI results.

Results from Table 1 and Figure 1 reveal that the only two factors that act as clear drivers of CO_2-eq emissions for the whole period under analysis were the income and population effects. These results are in line with those obtained by Mundaca (2013) and IEA (2017 a). The affluence effect in Mundaca (2013) might be considered as the income factor in our analysis. The role of income and population effects driving CO_2-eq emissions were also identified for other countries: Hatzigeorgiou, Polatidis and Haralambopoulos (2008) for the case of Greece, Donglan, Dequn, and Peng (2010) for China's residential sector and Moutinho, Moreira and Silva (2015) for eastern, western, northern and southern Europe. Increasing income and population add environmental stress, measured in terms of CO_2-eq emissions, mainly due to higher levels of energy in consumption.

Table 1 and Figure 1 also reveal that the rest of the decomposition factors fail to show a clear pattern for the period under analysis, presenting positive values for some periods (driving CO_2-eq emissions) and negative values in other cases (acting as compensating factors). The only exception that could be mentioned is the behavior of the energy intensity factor, which has negative values for most of the years analyzed. The results for energy intensity factors are in line with those find by Wang, Jiang and Li (2016). These authors conducted an analysis also based on LMDI and decomposition analysis, but limited to the Industry sector in China. A literature revision offered by Löfgren and Muller (2010) showed that for developed countries, energy intensity decreases and contributes to lower emissions, while for developing countries, increasing energy intensity contributes to higher emissions. The energy intensity in Chile was nearer to that of developed countries, implying technological changes oriented to reducing energy consumption per unit of output.

(Table 1)

(Figure 1)

When a sectoral analysis of these two clear drivers -P and Yp- of the CO_2-eq emissions is conducted (see Tables A.3 and A.4 in the annexes), it is observed that the forestry sector is the only one that behaves as an inhibiting sector against the increase of emissions. Nonetheless, its behavior as a sink of CO_2-eq emissions is not enough to compensate for the effect of strongly emitting sectors such as energy, agriculture or industry.

Sectoral analyses for factors CI, RES, EI and ES also reveal a good performance of the forestry sector as compensating for CO_2-eq emissions, although in a less clear way than in the aforementioned factors (see Tables A.5 to A .8). In the specific case of EI, this performance is different for the one identified by Löfgren and Muller (2010) for Sweden. In this research (a rare case in the literature including the forestry sector in a decomposition analysis), the effect of energy intensity for forestry contributed to increased emissions for the 1996-2006 period.

Regarding the CI factor, the forest sector is the one that produces higher peaks as a compensator of the CO_2-eq emissions when it is compared to the other productive sectors. In addition, the forest sector shows itself to be the determining factor in the total mitigation value of the period, its mitigating action coinciding with periods when CI shows negative values.

4.2.- Decoupling analysis results

Table 2 shows the results for the Tapio index, which reports on the degree of decoupling between CO_2-eq emissions and economic growth in the Chilean economy for the period under analysis. The results show that for most of the years, the Chilean economy has not been able to offset CO_2-eq emissions from economic growth and when it has done so, it has been because the rate of growth of emissions has been higher than the rate of economic growth. The most common result from Table 2 is called 'Expansive negative decoupling' status and is in line with the results obtained by Mundaca (2013).

Only in nine years of the period analyzed did the Chilean economy show good results from the point of view of the decoupling process (1990-1991, 1999-2001, 2002-2003, 2004-2006, 2008-2010 and 2012-2013). It might be noted that on February 27, 2010 an earthquake occurred that reached a magnitude of 8.8 MW and was followed by a tsunami. This natural disaster delayed the activation of the country's economy until 2011. In any case, for most of the years showing good results from a decoupling perspective, in which the Chilean economy achieved positive economic growth and a reduction in CO_2-eq emissions, the LMDI sector analysis shows that the forestry sector acted as a compensating sector regarding EI, CI and ES factors.

(Table 2)

The frequent status of 'Expansive negative decoupling', revealed in Table 2, can be explained by considering that the Chilean energy matrix is based mainly on the use of fossil fuels. This situation was accentuated from 2007 when imports of natural gas from Argentina ceased and the Chilean authorities decided to substitute the use of natural gas with coal, which is a more polluting fuel (CNE, 2015). On the other hand, although renewable energies sources apart from hydropower entered the Chilean energy mix in 2007, their presence continues being small for the period under evaluation.

Despite its important role as a CO_2-eq sink, the Chilean forestry sector was not able to compensate for the increasing carbonization of the Chilean energy matrix, although it did contribute significantly to achieving a ‘Strong Decoupling’ status when this was reached. This result gives the forest sector a chance to help the Chilean energy matrix move to a low carbon one. This happens when building up biomass plants for electricity generation powered by waste coming from forests replacing coal-powered thermal plants. This way was explored in Colinet et al. (2014) with Combined Cycle Plants and it implies no risk for the security of the electricity supply. Biomass plants partially powered by waste coming from forests could be strategically located near to forest areas and near to thermal plants, following the experience of El Hierro (in the Canary Islands) in Spain (Bueno and Carta, 2005 and 2006; Neves et al., 2014). While waste materials are available, biomass plants make the use of coal (more pollutant) unnecessary and thermal plants would remain halted. This technology can be managed in a planned manner if raw materials are available. This differs from other Non-Conventional RES technologies, such as wind and solar, that are “variable” and dependent on natural phenomena such as rain, wind or solar radiation (Sovacool, 2009). Reducing the installed thermal plants generation levels means reducing Chile's dependency on foreign suppliers for coal. It might be added that the use of waste from forest as a fuel for biomass plants would reduce the risk of forest fires.

Even though Tapio's index only gives a rough measure of the Chilean decoupling process, its values coincide with those provided by δ_t in Eq [14] for most of the years. Table 3 offers the results of the second level decomposition conducted. Efforts made to achieve decoupling can be examined from these figures.

(Table 3)

The major findings of second level decomposition tell us that the inhibiting effect (δ_t) for the period under evaluation failed to achieve the decoupling between economic growth and CO_2-eq emissions for the Chilean economy when decoupling is understood in terms of achieving positive economic growth with a reduction in CO_2-eq emissions, or at least an increase in CO_2-eq emissions in absolute values lower than the rate of economic growth. The results from Table 3 show that, although insufficient, the greatest efforts were made in the use of less polluting fuels (CI factor) and in improved energy efficiency (EI). In the first case, these greatest efforts coincided with the years of importing Argentina's natural gas until its interruption. Between 2006 and 2007 natural gas imports were reduced by 51.5% and between 2007 and 2008 by 72%. For these last two years, diesel imports increased 112% while coal imports reached 38.9% (IEA, 2017 b). In the second case, the results correspond with the coming into force of initiatives such as the Country Energy Efficiency Program set up at the onset of 2005 and that began to operate as of December 1, 2008 (CNE, 2008). The decrease of energy intensity is also an inhibiting factor for carbon emission in Zhang and Da (2015) and in Zhang, Mu and Ning (2009), but does not curb them. Both investigations use

LMDI and decomposition analysis jointly, but not for Chile and without considering the forestry sector.

When the sectoral analysis is conducted, the results provide interesting information for the forestry sector. This information highlights its contribution to the behavior of the decomposition factors CI and EI, mentioned as compensators of CO_2-eq emissions. For most of the years included in the period under analysis, the value for the forestry sector is greater than one. Table A.9 in the annexes details the sectoral results. These confirm the relevance of the forestry sector that has been already shown by the LMDI analysis.

Discussion of the above is reinforced when the forest area burnt and the CO_2-eq emissions of the Chilean economy are shown together. This is what Figure 2 does. The interannual variation of Chile's GHG balance observed, with maximums in 1998 and 2002, is mainly due to the influence of forest fires (Government of Chile, 2016). Many of these fires have degraded the native forest, especially in the last decade (Molina, Moreno, and Moreno, 2017). Table A.2 offers a detailed information of forest fires' CO_2-eq emissions.

(Figure 2)

In summary, the results of the second level of decomposition indicate that efforts to decouple CO_2-eq emissions from economic growth have been insufficient, although the forestry sector reveals itself to be a markedly inhibiting sector when sectoral analysis is conducted.

4.3.- Discussion

Although the importance of the forestry sector as a sink for CO_2 emissions depends on the nature and past anthropogenic actions (for or against preservation), current and future anthropogenic actions are decisive in defining this sector's future role. Both the results of the LMDI analysis and the second level of decomposition show the importance of the forestry sector when determining Chile's responsibility in the global warming process. This is a key result not only for designing national measures oriented to mitigation, but also regarding international agreements in the battle against Climate Change in which they would be involved.

In light of the results from the LMDI analysis, decomposition analysis, Figure 2 and Table A.2, further efforts should be recommended in forest fire prevention and short-term restoration of affected areas. These actions should be included in the Habitat Protection and Restoration of Degraded Habitats tasks set by the Climate Change Adaptation Plan (Ministry of Environment, 2014). Currently, most reforestation actions are oriented to productive uses and allow the economic activity to be reconciled with the role of Chilean forestry as a sink of CO_2 emissions (CORMA, 2014; ODEPA, 2010). Another activity in which it is possible to make reforestation compatible with economic activity is silviculture. Sustainable silviculture can reduce emissions without affecting economic growth (Sathaye and Ravindranat, 1998; Dixon et al., 1993).

Together with reforestation actions, there is room to improve the forest management of the native forests of Chile. The potential of native forest ecosystems, especially renewables, is higher than exotic plantations, as it is a resource that always maintains a standing stock of wood, fixing CO_2, contrariwise to the plantations which are managed in clear-felling rotations. In addition, the intervention processes in native forest, especially the intermediate cuttings that are carried out for the purpose of cleaning and improving the productive quality of the forests, promote an increase in their biomass by directly increasing their fixing capacity. All of the above, along with their greater surface area, places the native forests as the major contributor in the fixation of CO_2.

A greater detail of the native species must be provided. Coigue, oak and raulí have all been identified as the native species that set more CO_2 each year among the species in the temperate forests of Chile. This is due to their rapid growth (Gayoso and Guerra, 2005; Gayoso, 2001; Moreno-García, Herrera, and Caraciolo, 2011). Among them, the greatest contribution is from coigue, which, because it is perennial, maintains a higher biomass fixing all year round and there are trees of greater volume in the forests.

Currently, there are approximately 4.3 million hectares of renewables where the main forest type is oak-raulí-coigue. This type of forest can be managed sustainably for multiple or individual uses (wood, firewood, non-timber forest products, eco-tourism or the carbon market among others). In addition, Chile has almost 9 million hectares of adult forests and stunted forests that also contribute to CO_2 fixing and which present possibilities of management for environmental services, landscape contemplation –Tourism- and non-timber forest products.

5.- Conclusions and policy recommendations

To analyze the importance of the forestry sector in the CO_2-eq emissions change in Chile, a decomposition analysis of the emissions variation has been conducted and an analysis of the efforts made in this sector to improve its contribution to the decoupling process between these emissions and GDP growth has been done. The analysis has been carried out for the years 1991-2013.

Focusing on the Chilean forestry sector, major findings from LMDI and second level decomposition analysis reveal that it clearly manages to sink, but fails to outweigh the role played by the rest of the sectors considered. Particularly important is the behavior of this sector as an inhibitor of population and income factors that behave as a clear driver of CO_2-eq emissions for the period considered. In spite of its role as a compensator of these factors, it cannot prevent CO_2-eq emissions from increasing for the majority of years analyzed. The forestry sector reveals itself as a relevant sector.

The results show that Chile has also not reached the decoupling between economic growth and CO_2-eq emissions and that it has become a heavily carbonized economy in which CO_2-eq emissions have shown a level of increase higher than that of economic growth. However, in some years, the economy has reached a situation of decoupling. In those years the forestry sector has always contributed to decoupling. Also, in this second analysis, the forestry sector reveals itself as a relevant sector, although the efforts made to improve its role as a sink of CO_2 emissions have not been enough to achieve decoupling.

Despite Chilean authorities including mitigation actions specifically focused on the forest sector, when one compares these actions with those focused on the other sectors included in the LMDI analysis they are clearly revealed as being poor. The recent Biennial Update report submitted by the Chilean Government to the UNFCCC on April 21st 2017 distinctly shows such a difference. To contribute to solving this lack, some additional recommendations are provided in the light of the results obtained.

Firstly, it is recommended that the Chilean authorities include in their international commitments the analysis and management of changes in the forestry sector through the LULUCF activities. If the international commitments on Climate Change subscribed by

Chile do not include obligations in the development and protection of the forestry sector, they will be evidently incomplete. Of course, this does not mean excluding from the mitigating actions other sectors that have been revealed as clear contaminants. What it does show is that the forestry sector must be part of these international commitments.

Secondly, due to the role of the forestry sector as an inhibiting one when a sectoral analysis of the two clear drivers -P and Y_p- of the CO_2-eq emissions is conducted, every action enhancing this sector would go directly against these mean drivers reducing the environmental stress caused by them. This makes sense of any additional effort oriented to the forest sector regarding its potential effectiveness. That is why we recommend the Chilean authorities to encourage reforestation and restoration processes more intensively, especially taking into account the losses of forest fires in recent years. In particular, it is recommended to strengthen the forest management of native forests, mainly reforestation where the oak forest is oak-raulí-coigue. This has the feasibility of being managed in a sustainable way for multiple or individual uses, wood, firewood, non-timber forest products, eco-tourism or for the carbon market among others. To ensure the constant contribution of forest ecosystems to CO_2 fixation, it is recommended to improve the integrated management of forest ecosystems, understanding this as the multiple use of the forest, not only as a producer of wood, but also of non-timber forest products and ecosystem services such as the contemplation of the landscape associated with tourism, and to generate forest ecosystems which have a greater permanent volume of biomass that would reinforce their importance as CO_2 sinks. Additionally, this view justifies political measures aimed at preventing and combating forest fires. In order to carry out all the activities proposed, it is necessary to improve the current

Native Forest Law in Chile, enhancing the management, restoration and reforestation of native forest.

The third recommendation derived from the frequent status of 'Expansive negative decoupling', revealed by results that were explained by considering that the Chilean energy matrix is strongly based on the use of fossil fuels. This gives biomass plants a chance for electricity generation powered by waste coming from forests replacing coal-powered thermal plants. Our recommendation is to set a mandatory target for the deployment of such plants in terms of Megawatts installed in the Chilean energy policy. This technology can be managed in a planned manner reducing i) Chile's dependency on foreign suppliers for coal and ii) the risk of forest fires. Regarding results from second level decomposition analysis for most of the years under analysis, the value for the forest sector was greater than one, so this sector could help in curbing the coupling status of the Chilean economy, making its energy matrix a low carbon one.

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ANNEXES

(Table A.1)

(Table A.2)

(Table A.3)

(Table A.4)

(Table A.5)

(Table A.6)

(Table A.7)

(Table A.8)

(Table A.9)

Table 1. Decomposition factors values 1991-2013. CO_2-eq emissions (Gg)

	CI	RES	EI	ES	YP	P	Δ CO_2
92-91	7,549.6	355.7	-12,840.8	3,147.4	779.7	160.0	-848.4
93-92	-27,475.7	-20.8	29,493.0	517.2	426.6	176.9	3,117.3
94-93	24,177.1	240.2	-21,787.5	-386.8	398.0	208.2	2,849.2
95-94	3,627.2	169.6	-1,010.2	664.9	1,056.8	252.7	4,761.0
96-95	3,685.7	2,463.6	1,692.6	-3,341.0	2,875.7	276.2	7,652.9
97-96	5,672.1	-676.4	-3,813.6	1,497.6	1,496.7	344.5	4,520.8
98-97	-22,667.7	4,289.9	21,078.9	-850.0	829.9	383.7	3,064.8
99-98	12,100.3	3,412.7	-7,609.3	-2,618.9	-66.2	431.6	5,650.1
00-99	-11,811.5	-3,316.0	1,449.0	25.5	963.9	382.3	-12,306.7
01-00	861.0	-671.6	-1,510.8	-1,597.9	474.0	246.9	-2,198.3
02-01	15,280.1	-613.6	2,395.9	-517.1	337.1	186.3	17,068.7
03-02	-12,551.6	1,913.3	-4,285.3	686.0	877.8	343.6	-13,016.2
04-03	-7,913.1	1,229.6	19,558.1	-2,520.9	1,399.4	318.3	12,071.4
05-04	2,214.7	-3,588.6	792.1	-1,280.4	1,475.6	368.1	-18.5
06-05	7,486.6	-1,118.5	-8,030.7	-347.5	1,555.9	366.6	-87.6
07-06	8,502.9	8,101.4	13,142.4	-13,752.2	1,040.9	464.3	17,499.7
08-07	-3,980.6	-723.3	4,823.0	-518.1	1,212.2	579.2	1,392.4
09-08	-7,556.0	-775.2	-6,610.1	6,562.2	-979.1	553.5	-8,804.7
10-09	-28,655.1	2,677.6	15,117.9	2,891.7	1,692.6	465.7	-5,809.7
11-10	5,521.3	2,003.6	3,981.9	1,085.9	2,175.1	483.9	15,251.7
12-11	-7,506.8	-752.8	11,338.2	3,283.5	2,143.8	521.1	9,027.0
13-12	-5,460.6	3,039.2	-9,045.1	3,379.7	1,470.7	485.4	-6,130.7

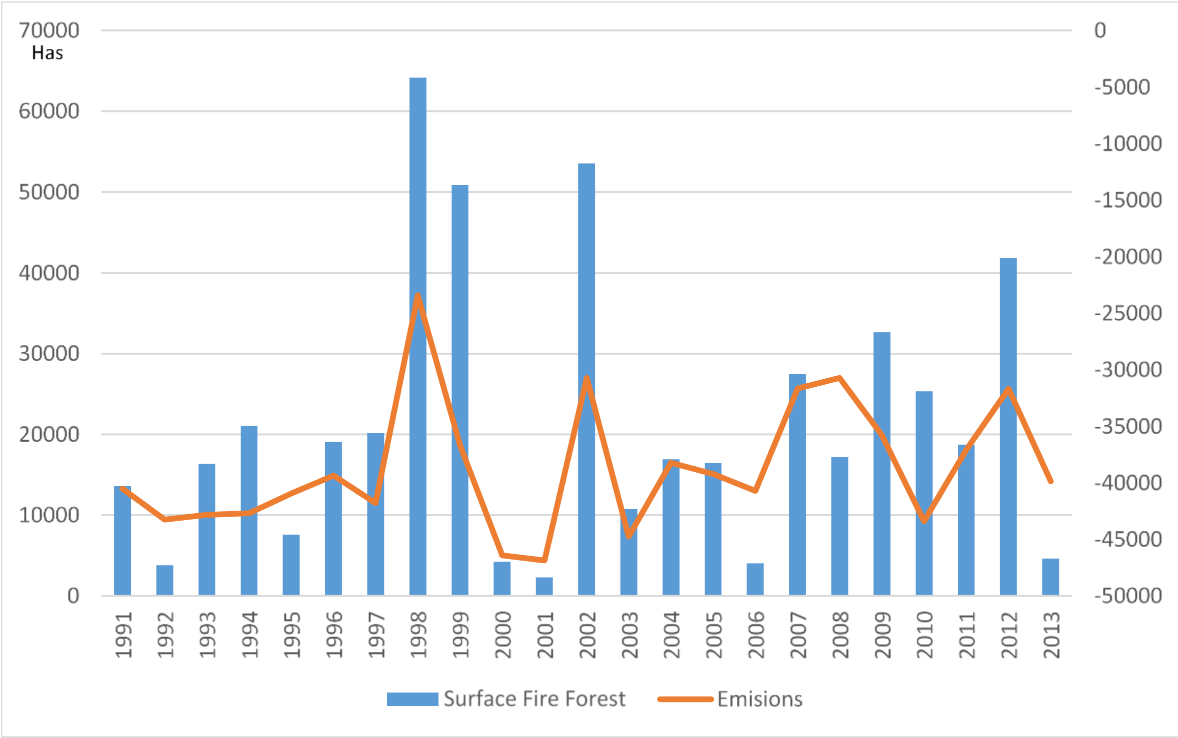
Table 3. Second level decoupling analysis

Years	δ_{CI}	δ_{RES}	δ_{EI}	δ_{ES}	δ_{P}	δ_{t}
92-91	-9.7	-0.5	16.5	-4.0	-0.2	2.1
93-92	64.4	0.0	-69.1	-1.2	-0.4	-6.3
94-93	-60.7	-0.6	54.7	1.0	-0.5	-6.2
95-94	-3.4	-0.2	1.0	-0.6	-0.2	-3.5
96-95	-1.3	-0.9	-0.6	1.2	-0.1	-1.7
97-96	-3.8	0.5	2.5	-1.0	-0.2	-2.0
98-97	27.3	-5.2	-25.4	1.0	-0.5	-2.7
99-98	182.7	51.5	-114.9	-39.5	6.5	86.3
00-99	12.3	3.4	-1.5	0.0	-0.4	13.8
01-00	-1.8	1.4	3.2	3.4	-0.5	5.6
02-01	-45.3	1.8	-7.1	1.5	-0.6	-49.6
03-02	14.3	-2.2	4.9	-0.8	-0.4	15.8
04-03	5.7	-0.9	-14.0	1.8	-0.2	-7.6
05-04	-1.5	2.4	-0.5	0.9	-0.2	1.0
06-05	-4.8	0.7	5.2	0.2	-0.2	1.1
07-06	-8.2	-7.8	-12.6	13.2	-0.4	-15.8
08-07	3.3	0.6	-4.0	0.4	-0.5	-0.1
09-08	-7.7	-0.8	-6.8	6.7	0.6	-8.0
10-09	16.9	-1.6	-8.9	-1.7	-0.3	4.4
11-10	-2.5	-0.9	-1.8	-0.5	-0.2	-6.0
12-11	3.5	0.4	-5.3	-1.5	-0.2	-3.2
13-12	3.7	-2.1	6.2	-2.3	-0.3	5.2

Table 2. Tapio's decoupling analysis

Years	CO_2–eq emissions change	GDP change	Tapio's index
92-91	-0.09	0.12	-0.74
93-92	0.37	0.07	5.26
94-93	0.25	0.06	4.43
95-94	0.34	0.11	3.23
96-95	0.41	0.07	5.49
97-96	0.17	0.07	2.45
98-97	0.10	0.04	2.54
99-98	0.16	-0.01	-29.38
00-99	-0.30	0.05	-5.77
01-00	-0.09	0.03	-2.66
02-01	0.65	0.03	24.13
03-02	-0.30	0.04	-7.92
04-03	0.40	0.07	5.70
05-04	0.02	0.06	0.25
06-05	-0.01	0.06	-0.10
07-06	0.42	0.05	8.11
08-07	0.03	0.03	0.91
09-08	-0.14	-0.01	13.38
10-09	-0.11	0.06	-1.89
11-10	0.33	0.06	5.72
12-11	0.15	0.05	2.79
13-12	-0.06	0.04	-1.53

Figure 2: CO_2eq emissions (Gg) and forest area burned (Has) 1991-2013.



Source: Own elaboration from CONAF 2015

Figure 1. LMDI results

Table A.8. Sectoral values for ES decomposition factor. CO_2-eq emissions (Gg)

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	TOTAL
92-91	3,016.6	546.3	-117.8	0.2	85.4	-280.0	-103.4	3,147.4
93-92	-288.3	-41.8	6.7	0.8	-391.1	1,296.9	-66.0	517.2
94-93	231.1	21.6	-18.7	-0.9	259.2	-844.2	-34.9	-386.8
95-94	-373.6	537.1	-24.9	-1.4	-322.4	1,012.0	-161.9	664.9
96-95	-5,552.8	-673.4	-332.5	-11.4	-1,797.4	5,326.8	-300.3	-3,341.0
97-96	-160.7	561.1	-1.4	0.6	-588.5	1,755.1	-68.6	1,497.6
98-97	-762.2	258.5	16.0	-2.0	146.1	-436.1	-70.3	-850.0
99-98	-2,848.3	-302.3	73.4	-0.1	-265.3	739.1	-15.4	-2,618.9
00-99	534.2	314.2	-22.9	1.3	359.3	-1,090.5	-70.3	25.5
01-00	-924.8	178.5	11.6	-4.4	338.8	-1,168.1	-29.5	-1,597.9
02-01	-459.4	552.4	-43.6	2.4	309.3	-875.2	-3.1	-517.1
03-02	-190.6	735.7	-28.5	-4.3	-144.6	402.2	-83.9	686.0
04-03	-337.2	-301.8	22.7	0.9	901.5	-2,755.7	-51.2	-2,520.9
05-04	398.7	-104.6	-14.9	2.2	827.3	-2,342.9	-46.3	-1,280.4
06-05	903.4	-48.8	-32.2	4.2	589.1	-1,725.1	-38.0	-347.5
07-06	-14,282.2	64.2	205.4	-1.2	-114.2	297.1	78.6	-13,752.2
08-07	394.3	-371.7	-5.8	1.5	488.7	-1,095.2	70.1	-518.1
09-08	6,483.6	-1,021.3	-5.6	-7.8	-666.1	1,633.7	145.6	6,562.2
10-09	1,355.2	269.6	-16.8	0.5	-635.1	1,927.2	-9.0	2,891.7
11-10	2,407.9	41.7	-50.7	-10.0	704.7	-2,033.6	25.9	1,085.9
12-11	1,176.6	536.3	-20.8	-6.1	-1,050.0	2,663.8	-16.4	3,283.5
13-12	2,376.0	-26.5	-15.3	-4.5	-593.6	1,626.0	17.7	3,379.7

Table A.9. Second level decoupling analysis at sectoral level.

	92-91	93-92	94-93	95-94	96-95	97-96	98-97	99-98	00-99	01-00	02-01	03-02	04-03	05-04	06-05	07-06	08-07	09
δCI Energy	-12.22	2.36	8.83	1.35	12.44	-4.90	23.35	0.53	0.14	-10.64	13.16	-6.29	11.57	-9.28	-3.78	9.20	-0.16	-2.
δCI Transport	-0.92	-0.01	-3.08	-2.61	-1.19	-0.11	-0.91	-1.22	1.62	1.52	-1.57	0.57	0.30	-0.26	3.86	2.13	-0.05	-0.
δCI Industry	-1.58	0.08	1.39	0.91	1.75	-0.47	1.61	1.47	-2.09	0.30	-0.35	1.35	0.44	-1.45	-0.35	3.24	0.60	0.6
δCI Solvent	-0.01	0.01	0.02	0.01	0.02	0.04	0.01	0.11	-0.12	-0.10	0.06	0.03	0.06	-0.03	-0.01	0.01	-0.17	0.0
δCI Agriculture	-1.46	-14.62	17.11	0.60	8.33	2.62	-3.57	7.59	-1.76	-2.82	5.40	-0.75	-3.79	-3.62	5.46	9.50	-5.00	-1.
δCI Forestry	7.38	47.13	-56.37	-5.19	-27.42	-4.40	7.34	-24.76	18.13	10.78	-36.26	21.04	1.07	12.57	-14.97	-36.77	9.88	13
δCI Waste	-0.87	0.29	1.08	0.29	1.35	-0.05	1.23	0.77	-0.78	-0.15	-0.05	0.14	0.49	-0.77	0.19	1.78	-0.01	0.1
δCI TOTAL	-9.68	64.41	-60.75	-3.43	-1.28	-3.79	27.31	182.68	12.25	-1.82	-45.33	14.30	5.65	-1.50	-4.81	-8.17	3.28	-7.
δRES Energy	8.67	-0.60	-7.52	-1.45	-10.02	2.04	-11.41	-7.60	8.59	2.69	1.39	-4.03	-2.91	7.07	2.27	-13.69	1.06	1.2
δRES Transport	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
δRES Industry	1.34	-0.10	-1.27	-0.23	-1.48	0.28	-1.55	-1.07	1.38	0.49	0.26	-0.76	-0.54	1.31	0.43	-2.34	0.16	0.1
δRES Solvent	0.04	0.00	-0.03	0.00	-0.03	0.01	-0.03	-0.01	0.02	0.01	0.01	-0.02	-0.01	0.02	0.01	-0.03	0.00	0.0
δRES Agriculture	5.07	-0.35	-4.16	-0.76	-4.80	0.83	-4.27	-2.78	3.20	1.06	0.56	-1.58	-1.07	2.50	0.79	-4.34	0.31	0.3
δRES Forestry	-16.62	1.15	13.54	2.40	14.21	-2.48	12.75	7.74	-9.70	-3.67	-1.58	4.38	3.28	-7.09	-2.32	11.29	-0.69	-0.
δRES Waste	1.04	-0.07	-0.88	-0.16	-1.05	0.19	-0.99	-0.65	0.77	0.27	0.15	-0.45	-0.33	0.78	0.25	-1.28	0.09	0.1
δRES TOTAL	-0.46	0.05	-0.60	-0.16	-0.86	0.45	-5.17	51.52	3.44	1.42	1.82	-2.18	-0.88	2.43	0.72	-7.78	0.60	-0.
δEI Energy	10.26	-1.81	-1.46	0.51	-9.71	-1.59	-10.44	0.74	-1.06	9.69	-14.65	10.60	-11.66	5.60	3.77	-22.20	1.20	12
δEI Transport	1.93	-0.66	2.72	3.12	1.37	1.03	1.09	0.84	-0.78	-0.04	2.06	1.11	-0.42	-0.53	-2.87	-2.71	-0.60	-1.
δEI Industry	-0.30	0.05	-0.05	-0.22	-0.18	-0.05	-0.06	-0.72	-0.13	-0.26	-0.20	-0.50	0.00	0.29	-0.06	0.15	0.16	-0.
δEI Solvent	-0.01	0.01	0.00	0.00	0.01	-0.03	0.03	-0.01	0.01	0.00	0.02	-0.05	0.02	0.01	0.02	0.03	-0.01	0.0
δEI Agriculture	-2.05	15.22	-11.92	0.92	-3.33	-2.83	8.76	-5.07	-0.07	2.89	-5.36	3.16	6.28	3.44	-4.86	-4.87	5.87	1.5
δEI Forestry	6.70	-50.48	38.83	-2.89	9.88	8.43	-26.14	14.14	0.20	-9.96	15.16	-8.78	-19.19	-9.75	14.24	12.67	-13.16	-3.
δEI Waste	-0.06	-0.16	-0.17	-0.15	-0.21	-0.06	-0.27	-0.14	-0.04	-0.39	-0.09	-0.04	-0.12	-0.09	0.08	0.07	0.35	0.0
δEI TOTAL	16.47	-69.13	54.75	0.96	-0.59	2.55	-25.40	-114.88	-1.50	3.19	-7.11	4.88	-13.98	-0.54	5.16	-12.63	-3.98	-6.

Table A.1: Total Chilean CO_2-eq emissions (Gg) per sector 1990-2013

1. Energy	2. Transport	3. Industrial processes	4. Solvent and other products	5. Agriculture	6. LULUCF	7. Waste
21,800.56	9,653.50	3,065.70	92.77	12,668.47	-40,529.04	2,581.58
21,892.79	10,471.38	3,723.13	90.45	12,882.43	-43,248.29	2,673.23
22,986.71	11,615.16	3,941.05	78.95	13,072.59	-42,816.58	2,724.54
24,528.94	12,555.52	4,065.30	86.21	13,189.12	-42,700.60	2,808.54
26,064.04	13,891.56	4,043.81	87.63	13,454.41	-40,943.56	2,916.51
30,669.05	15,113.45	4,294.58	93.62	13,640.61	-39,363.95	3,011.64
36,414.62	16,033.42	4,817.74	95.27	13,558.64	-41,778.57	3,106.72
36,021.54	16,904.59	5,046.02	95.79	13,565.91	-39,222.14	3,188.34
38,534.42	17,091.52	5,431.96	31.01	13,662.26	-36,665.70	3,230.26
34,773.94	17,348.92	6,334.78	114.81	13,580.69	-46,399.92	3,348.28
33,608.23	16,402.86	6,139.36	186.71	13,476.55	-46,878.81	3,640.94
33,814.25	16,940.37	6,434.58	125.99	13,550.98	-30,736.51	3,696.67
34,717.92	16,714.01	6,585.11	147.25	13,269.45	-44,738.64	4,037.06
38,760.11	17,336.00	7,061.11	99.18	13,818.56	-38,225.46	4,172.91
38,483.88	19,095.01	7,294.26	108.30	13,526.63	-39,214.70	4,403.23
39,733.67	18,705.88	7,647.19	106.48	13,763.65	-40,706.55	4,196.70
47,750.38	20,272.46	7,289.05	101.90	13,896.62	-31,657.43	3,972.97
48,124.95	21,227.84	6,801.12	247.95	13,933.04	-30,714.00	3,844.79
45,943.17	21,229.08	6,232.82	140.93	13,128.34	-35,768.14	3,755.40
48,471.22	20,952.45	5,767.05	241.03	12,879.79	-43,394.22	3,802.61
56,665.39	21,861.57	6,739.41	128.89	12,741.69	-37,081.64	3,939.78
59,521.25	22,555.34	7,026.84	188.03	13,285.03	-31,695.78	4,019.16
60,529.70	24,545.67	6,477.41	141.99	13,735.20	-39,854.36	4,478.81

Source: Own elaboration from Government of Chile (2016).

Table A.2. LULUCF activities emissions by main subsectors. CO_{2-eq} Gg 1990-2013.

	1990	1991	1992	1993	1994	1995	1996	1997	1998
LULUCF activities (Total)	-43,499.8	-40,529.0	-43,248.3	-42,816.6	-42,700.6	-40,943.6	-39,364.0	-41,778.6	-23,415.0
Forest land	-45,371.9	-42,444.2	-45,167.8	-44,746.1	-44,628.2	-42,887.6	-41,389.1	-43,718.6	-25,389.2
Forest fire	1,433.1	2,937.5	510.4	2,863.1	3,058.0	1,440.2	6,449.0	4,559.0	26,572.9
Rest of forest land	-46,805.0	-45,381.7	-45,678.2	-47,609.2	-47,686.3	-44,327.7	-47,838.0	-48,277.6	-51,962.1
Cropland	329.2	369.6	377.6	385.4	380.7	406.1	487.1	401.0	434.2
Grassland	1,150.8	1,153.6	1,150.1	1,152.4	1,155.2	1,146.2	1,146.2	1,147.2	1,148.1
Wetlands	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Settlements	218.3	218.2	218.1	218.1	218.1	218.2	218.3	218.3	218.3
Other land	173.5	173.4	173.3	173.3	173.2	173.2	173.2	173.3	173.3

	1999	2000	2001	2002	2003	2004	2005	2006
LULUCF activities (Total)	-36,665.7	-46,399.9	-46,878.8	-30,736.5	-44,738.6	-38,225.5	-39,214.7	-40,706.6
Forest land	-38,694.6	-48,437.9	-48,893.8	-32,759.4	-46,774.4	-40,289.4	-41,235.5	-42,771.9
Forest fire	11,553.5	831.1	437.3	17,547.9	1,525.0	2,844.3	1,495.6	726.2
Rest of forest land	-50,248.1	-49,269.0	-49,331.0	-50,307.2	-48,299.4	-43,133.7	-42,731.0	-43,498.1
Cropland	483.5	501.5	479.9	540.4	555.7	584.7	540.0	550.5
Grassland	1,153.4	1,144.7	1,143.3	1,066.1	1,064.1	1,063.2	1,065.1	1,057.8
Wetlands	0.4	0.4	0.4	9.3	9.3	9.3	9.3	12.4
Settlements	218.3	218.2	218.2	169.3	169.1	169.1	168.9	176.3
Other land	173.3	173.2	173.2	237.8	237.6	237.6	237.5	268.3

Source: Own elaboration from Government of Chile (2016).

Table A.3. Sectoral values for Yp decomposition factor. CO_2-eq emissions (Gg)

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	TOTAL
92-91	1,912.4	880.4	296.2	8.0	1,118.3	-3,665.5	230.0	779.7
93-92	954.4	469.4	163.0	3.6	552.1	-1,830.6	114.8	426.6
94-93	787.2	365.7	132.7	2.7	435.2	-1,417.3	91.7	398.0
95-94	1,801.9	786.2	288.9	6.2	949.2	-2,979.5	203.9	1,056.8
96-95	4,078.2	1,589.7	600.5	13.1	1,952.0	-5,784.8	427.0	2,875.7
97-96	1,984.2	654.3	269.9	5.6	806.5	-2,405.3	181.4	1,496.7
98-97	1,054.7	321.3	143.6	2.8	394.9	-1,179.0	91.7	829.9
99-98	-76.0	-22.5	-10.7	-0.1	-27.8	77.3	-6.5	-66.2
00-99	1,210.6	364.7	194.1	2.1	450.3	-1,366.7	108.7	963.9
01-00	737.0	237.8	134.4	3.2	291.6	-1,005.4	75.3	474.0
02-01	377.2	123.5	70.3	1.7	151.2	-427.9	41.1	337.1
03-02	942.4	303.5	179.0	3.7	368.8	-1,025.9	106.3	877.8
04-03	1,660.7	499.2	308.6	5.5	612.8	-1,873.1	185.7	1,399.4
05-04	1,575.3	450.0	292.7	4.2	557.7	-1,579.3	174.9	1,475.6
06-05	1,704.1	480.8	325.5	4.7	594.6	-1,741.2	187.3	1,555.9
07-06	1,028.5	260.2	176.1	2.5	326.1	-848.7	96.3	1,040.9
08-07	1,100.2	253.2	161.6	3.8	319.4	-715.7	89.7	1,212.2
09-08	-941.4	-220.9	-130.4	-3.8	-270.8	664.1	-76.1	-979.1
10-09	1,913.9	447.4	243.2	7.6	527.3	-1,600.2	153.2	1,692.6
11-10	2,378.1	547.4	349.4	8.1	690.3	-1,992.1	193.9	2,175.1
12-11	2,110.4	495.1	292.3	8.5	607.0	-1,540.1	170.5	2,143.8
13-12	1,523.0	356.0	193.5	6.0	419.6	-1,149.4	121.9	1,470.7

Table A.4. Sectoral values for P decomposition factor. CO_2-eq emissions (Gg)

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	TOTAL
92-91	392.4	180.6	60.8	1.6	229.4	-752.0	47.2	160.0
93-92	395.8	194.7	67.6	1.5	229.0	-759.2	47.6	176.9
94-93	411.7	191.3	69.4	1.4	227.6	-741.3	48.0	208.2
95-94	431.0	188.0	69.1	1.5	227.0	-712.6	48.8	252.7
96-95	391.6	152.7	57.7	1.3	187.5	-555.5	41.0	276.2
97-96	456.7	150.6	62.1	1.3	185.6	-553.6	41.7	344.5
98-97	487.7	148.6	66.4	1.3	182.6	-545.1	42.4	383.7
99-98	495.1	146.6	69.6	0.8	180.9	-503.9	42.6	431.6
00-99	480.2	144.7	77.0	0.8	178.6	-542.1	43.1	382.3
01-00	383.9	123.9	70.0	1.7	151.9	-523.8	39.2	246.9
02-01	208.5	68.2	38.9	1.0	83.6	-236.5	22.7	186.3
03-02	368.8	118.8	70.1	1.5	144.3	-401.5	41.6	343.6
04-03	377.7	113.5	70.2	1.3	139.4	-426.0	42.2	318.3
05-04	393.0	112.3	73.0	1.1	139.1	-394.0	43.6	368.1
06-05	401.6	113.3	76.7	1.1	140.1	-410.3	44.1	366.6
07-06	458.8	116.1	78.5	1.1	145.5	-378.6	43.0	464.3
08-07	525.7	121.0	77.2	1.8	152.6	-341.9	42.9	579.2
09-08	532.2	124.9	73.7	2.1	153.1	-375.5	43.0	553.5
10-09	526.6	123.1	66.9	2.1	145.1	-440.3	42.2	465.7
11-10	529.0	121.8	77.7	1.8	153.6	-443.2	43.1	483.9
12-11	513.0	120.4	71.0	2.1	147.6	-374.4	41.5	521.1
13-12	502.6	117.5	63.9	2.0	138.5	-379.3	40.2	485.4

Table A.5. Sectoral values for EI decomposition factor. CO_2-eq emissions (Gg)

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	TOTAL
92-91	-8,001.1	-1,503.1	234.8	10.0	1,594.6	-5,226.6	50.7	-12,840.8
93-92	1,407.4	511.8	-36.7	-8.6	-11,870.7	39,362.8	127.0	29,493.0
94-93	1,135.7	-2,118.1	36.2	1.8	9,297.6	-30,276.4	135.7	-21,787.5
95-94	-399.6	-2,433.8	171.0	0.2	-718.6	2,255.6	115.0	-1,010.2
96-95	7,574.0	-1,069.0	136.5	-7.5	2,598.7	-7,701.4	161.4	1,692.6
97-96	1,241.9	-803.3	40.8	27.0	2,204.3	-6,574.0	49.7	-3,813.6
98-97	8,139.3	-851.0	48.9	-20.5	-6,827.6	20,382.2	207.6	21,078.9
99-98	-574.2	-653.6	564.0	9.2	3,956.9	-11,024.1	112.5	-7,609.3
00-99	824.4	608.0	98.4	-6.1	52.1	-158.2	30.4	1,449.0
01-00	-7,558.4	28.6	204.8	-0.1	-2,252.0	7,763.8	302.7	-1,510.8
02-01	11,426.7	-1,608.8	159.6	-12.5	4,175.9	-11,817.1	72.2	2,395.9
03-02	-8,263.0	-862.1	388.3	35.1	-2,461.5	6,847.0	30.8	-4,285.3
04-03	9,092.7	326.3	-2.0	-15.3	-4,893.6	14,959.2	90.8	19,558.1
05-04	-4,369.9	409.4	-227.1	-6.2	-2,684.9	7,603.4	67.3	792.1
06-05	-2,936.5	2,240.0	50.1	-15.3	3,790.6	-11,099.9	-59.8	-8,030.7
07-06	17,311.7	2,109.7	-118.2	-25.6	3,796.7	-9,880.8	-51.0	13,142.4
08-07	-937.8	469.4	-128.2	8.1	-4,578.5	10,260.5	-270.4	4,823.0
09-08	-9,393.2	1,012.8	122.2	-27.9	-1,186.0	2,909.0	-46.9	-6,610.1
10-09	-3,832.9	-474.6	-227.3	1.2	-9,658.2	29,307.0	2.8	15,117.9
11-10	4,938.8	278.7	86.9	-84.3	4,387.8	-12,662.3	7,036.4	3,981.9
12-11	14,979.5	-1,231.1	158.1	-54.6	1,728.9	-4,386.4	143.9	11,338.2
13-12	-6,958.3	378.3	1.5	-44.7	1,373.9	-3,763.2	-32.4	-9,045.1

Table A.6. Sectoral values for CI decomposition factor. CO_2-eq emissions (Gg)

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	TOTAL
92-91	9,532.0	713.7	1,230.5	6.2	1,139.2	-5,752.0	680.2	7,549.6
93-92	-1,841.2	9.7	-62.2	-10.6	11,401.6	-36,744.9	-228.2	-27,475.7
94-93	-6,885.8	2,398.5	-1,083.4	-18.2	-13,344.4	43,949.7	-839.3	24,177.1
95-94	-1,054.3	2,038.3	-706.7	-9.0	-465.0	4,049.6	-225.7	3,627.2
96-95	-9,698.7	930.2	-1,361.9	-14.4	-6,493.9	21,376.6	-1,052.2	3,685.7
97-96	3,816.9	89.2	368.4	-28.3	-2,042.2	3,431.5	36.5	5,672.1
98-97	-18,207.7	706.4	-1,257.6	-4.6	2,780.3	-5,721.7	-962.7	-22,667.7
99-98	-412.0	953.3	-1,143.4	-83.7	-5,914.2	19,302.2	-601.9	12,100.3
00-99	-110.2	-1,266.8	1,630.4	97.3	1,370.1	-14,140.0	607.7	-11,811.5
01-00	8,292.7	-1,187.6	-234.0	80.6	2,194.9	-8,404.9	119.2	861.0
02-01	-10,263.6	1,220.5	272.0	-48.3	-4,211.2	28,270.0	40.8	15,280.1
03-02	4,906.9	-444.3	-1,054.8	-27.3	582.9	-16,406.7	-108.5	-12,551.6
04-03	-9,020.1	-234.2	-345.0	-48.0	2,952.1	-832.6	-385.4	-7,913.1
05-04	7,238.9	199.1	1,133.7	22.6	2,820.2	-9,802.5	602.6	2,214.7
06-05	2,950.4	-3,012.6	271.5	8.4	-4,258.7	11,672.9	-145.3	7,486.6
07-06	-7,172.4	-1,662.8	-2,526.8	-6.8	-7,404.9	28,666.4	-1,389.7	8,502.9
08-07	121.9	36.2	-470.8	133.8	3,895.1	-7,704.0	7.3	-3,980.6
09-08	2,099.4	105.2	-494.9	-65.8	1,442.0	-10,564.5	-77.3	-7,556.0
10-09	-1,550.6	-510.3	-1,054.7	72.4	8,238.3	-33,378.7	-471.5	-28,655.1
11-10	-5,693.5	-520.9	204.0	-28.5	-6,936.0	25,895.7	-7,399.4	5,521.3
12-11	-15,503.6	424.0	-95.2	125.6	-591.5	8,319.7	-185.8	-7,506.8
13-12	-802.8	107.7	-1,259.4	-27.6	-2,049.1	-1,358.6	-70.8	-5,460.6

Table A.7. Sectoral values for RES decomposition factor. CO_2-eq emissions (Gg)

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	TOTAL
92-91	-6,760.0	0.0	-1,047.0	-28.3	-3,953.0	12,956.9	-812.9	355.7
93-92	465.7	0.1	79.5	1.8	269.4	-893.3	56.0	-20.8
94-93	5,862.3	-0.1	988.1	20.4	3,241.2	-10,554.5	682.8	240.2
95-94	1,129.7	-0.1	181.1	3.9	595.1	-1,868.0	127.9	169.6
96-95	7,812.7	0.0	1,150.5	25.0	3,739.4	-11,082.1	818.1	2,463.6
97-96	-1,593.5	0.0	-216.7	-4.5	-647.7	1,931.6	-145.7	-676.4
98-97	8,895.2	0.0	1,211.1	23.5	3,330.9	-9,943.7	773.0	4,289.9
99-98	5,928.3	0.0	833.1	9.1	2,165.9	-6,034.2	510.6	3,412.7
00-99	-6,699.7	0.1	-1,074.2	-11.7	-2,491.9	7,563.2	-601.7	-3,316.0
01-00	-2,096.0	0.0	-382.4	-9.1	-829.4	2,859.4	-214.1	-671.6
02-01	-1,083.3	0.0	-202.0	-5.0	-434.3	1,228.9	-117.9	-613.6
03-02	3,139.1	0.0	596.4	12.5	1,228.5	-3,417.3	354.0	1,913.3
04-03	2,268.4	0.0	421.5	7.5	837.0	-2,558.6	253.7	1,229.6
05-04	-5,512.3	0.0	-1,024.3	-14.8	-1,951.3	5,526.0	-611.9	-3,588.6
06-05	-1,773.2	0.1	-338.7	-4.9	-618.7	1,811.7	-194.9	-1,118.5
07-06	10,672.3	0.1	1,826.9	25.5	3,383.8	-8,806.3	999.2	8,101.4
08-07	-829.8	0.0	-121.9	-2.8	-240.9	539.8	-67.7	-723.3
09-08	-962.4	0.0	-133.3	-3.9	-276.8	679.0	-77.8	-775.2
10-09	4,115.8	0.0	523.0	16.3	1,134.0	-3,441.1	329.6	2,677.6
11-10	2,927.1	0.0	430.0	10.0	849.7	-2,452.0	238.7	2,003.6
12-11	-963.6	0.0	-133.5	-3.9	-277.2	703.2	-77.9	-752.8
13-12	4,152.5	0.0	527.6	16.4	1,144.1	-3,133.9	332.5	3,039.2