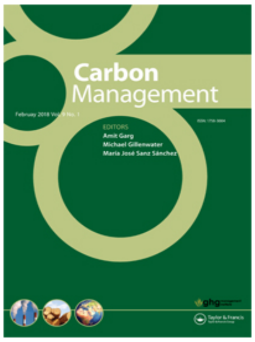

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Does forest matter regarding Chilean CO_2 international abatement commitments? A multilevel decomposition approach

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ABSTRACT
This paper assesses the role of the forestry sector in the CO_2-eq emissions change in Chile from 1990 to 2013. Due to its relevance, this sector is considered as a proxy LULUCF activities. A second objective of this paper is to explore whether the forestry sector has always contributed to a decoupling process between CO_2-eq emissions and economic growth. To address the first objective, the LMDI method has been used. For the second objective, the decoupling status between CO_2-eq emissions comes from the Tapio index, which was used for the first step. For the second step, a second level of decomposition was carried out. Major findings from the LMDI and second-level decomposition analysis reveal that Chile's forestry sector clearly acted as a sink but failed to outweigh the role played by all other sectors taken into consideration. The results show that Chile has also failed to reach decoupling between economic growth and CO_2-eq emissions. Efforts made in the forestry sector to reduce CO_2 emissions were interesting but not strong enough to meet decoupling objectives. It is recommended that native forest management be reinforced and strengthened, mainly by reforestation with oak, raulí and coigüe varieties.

KEYWORDS
sink; CO_2 emissions; LMDI; decoupling analysis; Chile

Introduction

From the Intergovernmental Panel on Climate Change (IPCC) report, human-induced contributions to climate change are strongly linked to energy-related CO_2-eq emissions due to the elevated weight of fossil fuels in the energy matrix [101]. This has increased the importance of human behavior in public policy and environmental legislation, where international cooperation is a critical juncture. It is recommended that countries design a road map that facilitates the transition toward a low-carbon economy [1]. The ultimate objective of this road map is to decouple CO_2-eq emissions from gross domestic product (GDP) growth. Decoupling (or de-linking) refers to a situation where the aggregate economic activity increases while environmental stress decreases during the same time period [2].

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) 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 [102]. In addition to its vulnerability to climate change, Chile's forests offer a relevant and useful tool in the battle against global warming. Following the UNFCCC, the rate of CO_2-eq build-up in the atmosphere could be reduced by taking advantage of the fact that atmospheric CO_2-eq may accumulate as carbon in vegetation and soils in terrestrial ecosystems. The UNFCCC states that any process, activity or mechanism that removes greenhouse gas – GHG – from the atmosphere is referred to as a 'sink' [103]. GHG may appear as an aerosol or a precursor of GHG from the atmosphere.

Human activities impact on 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 [103]. As a result, the role of LULUCF activities in the mitigation of climate change has long been recognized; this is clearly revealed in the last National Inventory of Chilean GHG emissions (Table A1 in the appendix), which covers the 1990 to 2013 period. For that whole period, contributions of the LULUCF sector to GHG emissions were negative, highlighting its role as a sink.

Due to their importance within LULUCF activities, Chile's forestry sector may be considered a proxy for these activities (Table A2). In Chile, 22.9% of the territory is covered by forests (17.3 million hectares). Of the total hectares dedicated to woodlands, 14.18 million are native forests and 2.96 million are forest plantations. Ackerknecht [3] proved that CO_2 sequestration

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by Chile's forests could compensate for emissions from the pollutant sector in a variety of scenarios analyzed up to 2020.

Based on this, and as part of the Intended Nationally Determined Contributions (INDC) submitted by Chilean Authorities at the 2015 Conference of the Parties in Paris (COP 21), they communicated a two-level commitment to be included in the final document known as the Paris Agreement. While the first did not consider the LULUCF sector, 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 into consideration as a part of Chile's Paris Agreement commitments, this country is committed to the sustainable development and recovery of 100,000 hectares of mainly native forests, 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 committed to reforesting 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 [4].

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 between 1990 and 2013. The second is to explore whether 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 [5]. This technique consists of using one type of index decomposition analysis (IDA). LMDI-I has proven 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 the authors' knowledge, this is the first time that the forestry sector has been included in such a tool to test the expected inhibitor effect of the sector on CO_2 emissions. Accordingly, this 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 forestry 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 [6]. For the second step, by considering the effects from the LMDI-I analysis, a second level of decomposition is conducted to analyze whether the forestry sector deployment outweighs pollutant sectors, thus allowing movement 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, the Tapio index and a second-level decomposition of LMDI results; together, they all focus on a sector that is traditionally excluded from this analysis.

The article is structured as follows. The next section describes the methodologies used. The third section details the database. The results are shown and discussed in the fourth section, while the fifth section presents the conclusions and offers policy recommendations from the results obtained.

Methodology

LMDI analysis

The literature offers various and 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 [7]. Among these various IDA methods, the LMDI method seems to offer the most advantages [8–16,104]. This paper follows Ang's [8] criteria to assess the various decomposition methods.

The IPAT (Impact = Population × Affluence × Technology) equation is the starting point for the LMDI-I conducted. Specifically, the IPAT model [17–19] and the 'Kaya identity' [20,21] 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 [22–34]. Two recent papers are noteworthy, one by Mundaca [35] and another by Duran *et al.* [36], focusing on the Chilean economy. The annual International Energy Agency (IEA) report regarding the Kaya identity could be also taken into account. Notwithstanding, Duran *et al.* [36] carried out a decomposition of the energy consumption by Chilean industry, but not of the CO_2 emissions as done herein.

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.* [37], 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 could facilitate the assessment of the role played by the forestry sector.

Decomposition factors include the carbon intensity effect (CI), renewable energy sources penetration effect (RES), energy intensity effect (EI), economic structure effect (ES), income effect (Y_p) and population effect (P).

By applying the decomposition proposed to these seven productive sectors, the total CO_2-eq emissions may be decomposed as follows:

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

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*., and *Y* denotes the total output for the entire economy, the same as in CO_2-eq, while *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 between period 0 and *t* is decomposed as follows:

$$\Delta\, CO_2 = CO_{2t} - CO_{20} = \Delta CI + \Delta RES + \Delta EI + \Delta ES + \Delta \mathrm{Yp} + \Delta P \quad (2)$$

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

By considering the additive decomposition identity, Equations (3)–(8) expose the LMDI formulas for each effect:

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

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

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

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

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

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

The term $w_i\,(t)$ is the estimated weight for the additive LMDI-I method and is defined by Ang [5]:

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

Equation (3) captures the CI. Variable ΔCI shows changes in CO_2-eq emissions from fossil fuel consumption in sector *i* (= CO_{2i} / FF_i), between periods *t* and 0, respectively. The available statistical information does not offer fossil fuel consumption broken down by type of fuel, so FF_i is total fossil fuels by sector without differentiating fuels. Despite this lack of information, the CI factor could be used to evaluate the substitution between fossil fuel types. This is possible if statistics show changes in the types of primary energy sources used (e.g. natural gas replacing coal or vice versa). It is assumed that the higher the quality of a fossil fuel, the less CO_2-eq it emits.

Equation (4) shows the RES penetration factor. The 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, the role of RES in Chile's energy matrix can be studied. Even so, one problem must be solved; it is linked to the fact that RES technologies are free or almost free of CO_2-eq emissions and this is observed to be a crucial variable. To bridge this lack of information, this work noted the evolution of the total fossil fuel consumption ratio on total primary energy consumption [38, footnote 3]. A decline in values for the ratio of total fossil use to total energy use could show a higher share of RES in Chile's energy matrix.

Equation (5) presents the EI factor. Variable ΔEI shows the total primary energy required in comparison to the output of 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 [39,40].

Equation (6) yields the economic mix or the economic structure factor (ES). Variable ΔES shows the sectoral structure of Chile's economy between periods *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) determines the income factor (Y_p). Variable ΔY_p is the output per capita between periods *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 periods *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 [41], Ang *et al.* [42] and Ang and Liu [43] 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 [43].

Decoupling analysis

Bearing in mind that the desired objective of Chile's government in the battle against climate change is to decouple CO_2-eq emissions from GDP growth, the decoupling approach herein analyzes change in 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 [6], measures the possible dissociation between economic growth and environmental problems in a specific period of time. Decoupling elasticity (ε) may be expressed by the percentage CO_2-eq emissions change in terms of the percentage GDP change during period *t* and 0, as in Equation (10):

$$\varepsilon = \frac{\frac{\Delta CO_2}{CO_2}}{\frac{\Delta GDP}{GDP}} \tag{10}$$

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

$$\Delta\left(\frac{CO_2}{GDP}\right) < 0 \tag{11}$$

Weak de-linking implies that the environmental stress of the GDP decreases over time. CO_2-eq emissions may still increase, but at a lower rate than economic growth. For the de-linking to be considered strong, $\Delta\ CO_2 < 0$ [2] is required.

Although De Bruyn [44] initially distinguished only between weak decoupling ($\varepsilon < 0$) and strong decoupling ($\Delta CO_2 < 0$), Tapio [6] and Vehmas *et al.* [2] provided a broader list of eight possible statuses. When positive economic growth takes place simultaneously with a CO_2-eq emissions increase, these authors identified this as '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 there is negative economic growth simultaneously with an increase in $\Delta CO_2/CO_2$, the aforementioned authors named this status 'strong negative decoupling'. However, if $\Delta CO_2/CO_2$ decreases coincidently with negative economic growth, then three other new statuses appear, these being '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' ($\varepsilon < 0$).

Nonetheless, the percentage change of CO_2-eq emissions of GDP given by Equation (10) only gives a rough measure of Chile's performance. To provide a more detailed analysis, a second-level decomposition is conducted. To better probe the role as a sink for the forestry sector outweighing pollutant sectors, the decoupling index was applied to LMDI decomposition to demonstrate the decoupling status influenced by the various effects included in the LMDI analysis [45]. In other words, this allows the effort made in factors and sectors to achieve decoupling to be examined.

Following Diakoulaki and Mandaraka [46], an effort is conceived as a general term referring to any kind of action that could directly or indirectly induce a decrease in Chile's CO_2-eq emissions, including those actions oriented toward promoting CO_2-eq sequestration. The efforts undertaken during the period analyzed are termed the inhibiting effect (ΔC_t) and may 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 may be reduced through government measures oriented toward mitigation (i.e. improving energy efficiency, measures for reforestation of native forests, firefighting, setting restrictions in the use of highly pollutant fuels and so forth). To show the total inhibiting effect, and from Equation (2), the following equation is used:

$$\Delta C_t = \Delta CO_2^t - \Delta Yp^t = \Delta CI_i^t + \Delta RES_i^t + \Delta EI_i^t + \Delta ES_i^t + \Delta P^t \tag{12}$$

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

To obtain further understanding of the efforts deployed, a new decoupling measurement between CO_2-eq emissions and economic growth is applied. This decoupling index presents an intuitive relationship between environmental impacts and is defined in Equations (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, RES, energy intensity, structure and effects of population on decoupling between CO_2-eq emissions and economic growth, respectively.

Equations (13) and (14) properly capture the inhibiting effect. It must be considered that a negative value of the inhibiting effect could occur because of a positive change in CO_2-eq emissions ($\Delta CO_2{}^T$) being offset by 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 [45]. 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 Equation (14). Sectoral analysis would give information about the role played by the forest sector and others.

In absolute terms, δ_t may take the following values. If the index value $\delta_t \geq 1$, this denotes strong decoupling efforts; that is, the inhibiting effect ΔC_t is more significant than the output effect. If the decoupling index is $0 < \delta_t < 1$, this denotes weak decoupling efforts; in other words, the inhibiting effect ΔC_t is weaker than the output effect. Finally, if the decoupling index $\delta_t \leq 0$, this indicates that there have been no decoupling efforts [45,46].

Database

The emission data for CO_2-eq stem from the official emission inventories that the government of Chile has sent to the UNFCCC [105]. The most recent year for which information is available is 2013 and thus establishes the period being analyzed. These data were supplied by Chile's Ministry of the Environment for this research. Energy consumption data – both for fossil fuels and for energy consumption – have been taken from the energy balances published by Chile's Ministry of Energy [106]. All energy consumption data are measured in tera-calories. Energy balances available at Energia2050 were also considered.

GDP time series were used due to the lack of available data for gross value added. GDP data came from national accounting drafted by the Central Bank of Chile. All data used correspond to real GDP data at constant prices for 2008 [107]. These GDP series, in real terms, were 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's national accounting [108]. The total Chilean economy was grouped into the following seven sectors: energy, transport, industry, USOP, agriculture, forestry and waste. Because of the relevance of Chile's forests, as explained in the introduction, its emissions correspond to those that are assigned to LULUCF in the national inventory. The criteria for grouping productive activities into these seven sectors were twofold. First, it was a matter of matching official emission inventories information, energy balances and GDP data. Second, it was necessary to manage those sectors included in the Chilean INDC submitted to Paris in 2015. Population data were taken from the Central Bank of Chile [109]. Finally, information about forest fires came from Historical Fire Statistics in Chilean Forest Ecosystems (1990–2013), available in the digital repositories of Forestry National Corporation (CONAF in Spanish acronyms).

Results and discussion

LMDI results

Results from Table 1 and Figure 1 reveal that the only two factors acting as clear drivers of CO_2-eq emissions for the whole period analyzed were the effects of income and population. These results are in line with those obtained by Mundaca [35] and IEA [110]. The affluence effect in Mundaca [35] could be considered the income factor in this analysis. The role played by the effects of income and population driving CO_2-eq

Table 1. **Decomposition factor values, 1991–2013. CO_2-eq emissions (Gg).**

	CI	RES	EI	ES	YP	P	ΔCO_2
1991–1992	7549.6	355.7	− 12,840.8	3147.4	779.7	160.0	− 848.4
1992–1993	− 27,475.7	− 20.8	29,493.0	517.2	426.6	176.9	3117.3
1993–1994	24,177.1	240.2	− 21,787.5	− 386.8	398.0	208.2	2849.2
1994–1995	3627.2	169.6	− 1010.2	664.9	1056.8	252.7	4761.0
1995–1996	3685.7	2463.6	1692.6	− 3341.0	2875.7	276.2	7652.9
1996–1997	5672.1	− 676.4	− 3813.6	1497.6	1496.7	344.5	4520.8
1997–1998	− 22,667.7	4289.9	21,078.9	− 850.0	829.9	383.7	3064.8
1998–1999	12,100.3	3412.7	− 7609.3	− 2618.9	− 66.2	431.6	5650.1
1999–2000	− 11,811.5	− 3316.0	1449.0	25.5	963.9	382.3	− 12,306.7
2000–2001	861.0	− 671.6	− 1510.8	− 1597.9	474.0	246.9	− 2198.3
2001–2002	15,280.1	− 613.6	2395.9	− 517.1	337.1	186.3	17,068.7
2002–2003	− 12,551.6	1913.3	− 4285.3	686.0	877.8	343.6	− 13,016.2
2003–2004	− 7913.1	1229.6	19,558.1	− 2520.9	1399.4	318.3	12,071.4
2004–2005	2214.7	− 3588.6	792.1	− 1280.4	1475.6	368.1	− 18.5
2005–2006	7486.6	− 1118.5	− 8030.7	− 347.5	1555.9	366.6	− 87.6
2006–2007	8502.9	8101.4	13,142.4	− 13,752.2	1040.9	464.3	17,499.7
2007–2008	− 3980.6	− 723.3	4823.0	− 518.1	1212.2	579.2	1392.4
2008–2009	− 7556.0	− 775.2	− 6610.1	6562.2	− 979.1	553.5	− 8804.7
2009–2010	− 28,655.1	2677.6	15,117.9	2891.7	1692.6	465.7	− 5809.7
2010–2011	5521.3	2003.6	3981.9	1085.9	2175.1	483.9	15,251.7
2011–2012	− 7506.8	− 752.8	11,338.2	3283.5	2143.8	521.1	9027.0
2012–2013	− 5460.6	3039.2	− 9045.1	3379.7	1470.7	485.4	− 6130.7

Gg: gigagram.

Figure 1. **LMDI results.**

emissions were also identified for other countries, by Hatzigeorgiou, Polatidis and Haralambopoulos [47] for the case of Greece; Donglan, Dequn, and Peng [48] for China's residential sector; and Moutinho, Moreira and Silva [12] for Europe. Increasing income and population add environmental stress, measured in terms of CO_2-eq emissions, mainly due to higher levels of energy 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, even presenting positive values for some periods (driving CO_2-eq emissions) and negative values in others (thus acting as compensating factors). The only mentionable exception 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 the findings of Wang, Jiang and Li [49], who conducted an analysis also based on LMDI and decomposition analysis, but limited their work to the industrial sector in China.

When a sectoral analysis of these two clear drivers – P and Yp – of the CO_2-eq emissions is conducted (see Tables A3 and A.4 in the appendix), it is observed that the forestry sector is the only one that behaves like an inhibiting sector against the increase of emissions. Nonetheless, its behavior as a sink for 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 less clearly than in the aforementioned factors (see Tables A5–A8). In the specific case of EI, this performance is different from that identified by Löfgren and Muller [50] for Sweden. In that study (a rare case in the literature because it includes 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 forestry sector produces higher peaks as a compensator for the CO_2-eq emissions when compared to other productive sectors. Additionally, the forestry sector proves to be the determining factor in the total mitigation value of the period, with its mitigating action coinciding with periods when CI shows negative values.

Decoupling analysis results

Table 2 shows the results for the Tapio index, which reports the degree of decoupling between CO_2-eq emissions and economic growth in Chile's economy for the period under analysis. The results show that for most of the years, the Chilean economy has been unable to offset CO_2-eq emissions from economic growth, and when it has done so, it has been due to the growth rate of emissions being higher than the rate of economic growth. The most common result from Table 2, identified as 'expansive negative decoupling' status, is in line with the results obtained by Mundaca [35].

For the period of Chile's economy analyzed, only nine years showed good results from the standpoint of the decoupling process (1990–1991, 1999–2001, 2002–2003, 2004–2006, 2008–2010 and 2012–2013). It should be noted that on February 27, 2010 there was an 8.8 M_W earthquake, followed by a tsunami. This natural disaster delayed the economic growth until 2011. In any case, for most of the years showing good results from a decoupling perspective, in which Chile's economy achieved positive economic growth and a reduction in CO_2-eq emissions, the LMDI sector

Table 2. Tapio's decoupling analysis.

Years	CO_2-eq emissions (Gg)	GDP (constant prices for 2008)	CO_2-eq emissions change year by year	GDP change year by year	Tapio's index
1991	8485.1	41,723,186.00			
1992	11,602.4	44,638,077.94	− 0.09	0.12	− 0.74
1993	14,533.0	47,186,072.59	0.37	0.07	5.26
1994	19,514.4	52,200,808.89	0.25	0.06	4.43
1995	27,459.0	56,070,719.11	0.34	0.11	3.23
1996	32,247.8	60,069,673.96	0.41	0.07	5.49
1997	35,600.0	62,530,098.11	0.17	0.07	2.45
1998	41,315.7	62,188,441.61	0.10	0.04	2.54
1999	29,101.5	65,372,653.52	0.16	− 0.01	− 29.38
2000	26,575.8	67,508,950.77	− 0.30	0.05	− 5.77
2001	43,826.3	69,325,028.12	− 0.09	0.03	− 2.66
2002	30,732.2	71,940,238.90	0.65	0.03	24.13
2003	43,022.4	76,987,661.20	− 0.30	0.04	− 7.92
2004	43,696.6	81,742,968.60	0.40	0.07	5.70
2005	43,447.0	86,397,687.67	0.02	0.06	0.25
2006	61,626.0	90,856,521.59	− 0.01	0.06	− 0.10
2007	63,465.7	93,847,932.01	0.42	0.05	8.11
2008	54,661.6	92,875,262.22	0.03	0.03	0.91
2009	48,719.9	98,219,034.45	− 0.14	− 0.01	13.38
2010	64,995.1	103,954,673.05	− 0.11	0.06	− 1.89
2011	74,899.9	109,627,615.34	0.33	0.06	5.72
2012	70,054.4	114,260,687.34	0.15	0.05	2.79
2013	8485.1	116,424,840.77	− 0.06	0.04	− 1.53

GDP: Gross domestic product.

analysis shows that the forestry sector acted as a compensating sector regarding EI, CI and ES factors.

The frequently occurring status of 'expansive negative decoupling', as revealed in Table 2, may be explained by considering that the Chilean energy matrix is based mainly on the use of fossil fuels. This situation has been accentuated since 2007, when imports of natural gas from Argentina ceased and Chilean authorities decided to substitute the use of natural gas with coal, which is a much more contaminating fuel [106]. On the other hand, although renewable energy sources, apart from hydropower, entered the Chilean energy mix in 2007, their presence continues to be limited for the period under evaluation.

Despite its significant role as a CO_2-eq sink, the Chilean forestry sector was unable to compensate for the increasing carbonization of Chile's energy matrix, although it did contribute significantly to achieving a 'strong decoupling' status when this was reached. Thanks to this result, the forestry sector offers a chance to help Chile's energy matrix move to a low carbon one. This happens when biomass plants to generate electricity from forest waste begin operating, thus replacing coal-powered thermal plants. This option was explored by Colinet *et al*. [51] 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 woodlands and thermal plants, following Spain's experience on the island of El Hierro (in the Canary Islands) [52–54]. While waste materials are available, biomass plants make the use of (more pollutant) coal unnecessary, with thermal plants remaining halted. Such technology could be managed in a planned manner if raw materials are available. This differs from other non-conventional RES technologies, such as wind and solar, which are 'variable' and dependent upon natural phenomena such as rain, wind or solar radiation [55]. Reducing the installed thermal plants' generation levels means reducing Chile's dependency on foreign suppliers for coal, as was proved for the Spanish case in Colinet *et al.* [51]. It also worthy of mention that the use of waste from forests as a fuel for biomass plants would reduce the risk of forest fires.

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

Major second-level decomposition findings indicate that the inhibiting effect (δ_t) for the period under

Table 3. Second-level decoupling analysis.

Years	δ_{CI}	δ_{RES}	δ_{EI}	δ_{ES}	δ_P	δ_t
1991–1992	− 9.7	− 0.5	16.5	− 4.0	− 0.2	2.1
1992–1993	64.4	0.0	− 69.1	− 1.2	− 0.4	− 6.3
1993–1994	− 60.7	− 0.6	54.7	1.0	− 0.5	− 6.2
1994–1995	− 3.4	− 0.2	1.0	− 0.6	− 0.2	− 3.5
1995–1996	− 1.3	− 0.9	− 0.6	1.2	− 0.1	− 1.7
1996–1997	− 3.8	0.5	2.5	− 1.0	− 0.2	− 2.0
1997–1998	27.3	− 5.2	− 25.4	1.0	− 0.5	− 2.7
1998–1999	182.7	51.5	− 114.9	− 39.5	6.5	86.3
1999–2000	12.3	3.4	− 1.5	0.0	− 0.4	13.8
2000–2001	− 1.8	1.4	3.2	3.4	− 0.5	5.6
2001–2002	− 45.3	1.8	− 7.1	1.5	− 0.6	− 49.6
2002–2003	14.3	− 2.2	4.9	− 0.8	− 0.4	15.8
2003–2004	5.7	− 0.9	− 14.0	1.8	− 0.2	− 7.6
2004–2005	− 1.5	2.4	− 0.5	0.9	− 0.2	1.0
2005–2006	− 4.8	0.7	5.2	0.2	− 0.2	1.1
2006–2007	− 8.2	− 7.8	− 12.6	13.2	− 0.4	− 15.8
2007–2008	3.3	0.6	− 4.0	0.4	− 0.5	− 0.1
2008–2009	− 7.7	− 0.8	− 6.8	6.7	0.6	− 8.0
2009–2010	16.9	− 1.6	− 8.9	− 1.7	− 0.3	4.4
2010–2011	− 2.5	− 0.9	− 1.8	− 0.5	− 0.2	− 6.0
2011–2012	3.5	0.4	− 5.3	− 1.5	− 0.2	− 3.2
2012–2013	3.7	− 2.1	6.2	− 2.3	− 0.3	5.2

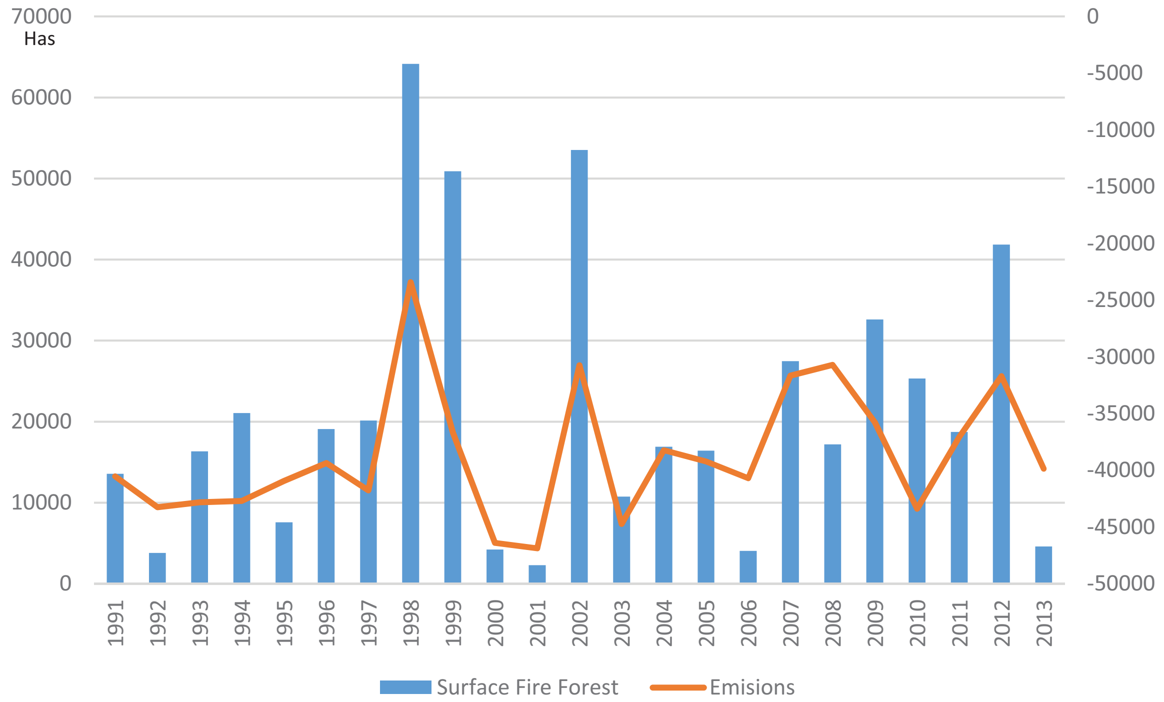

Figure 2. CO_2-eq emissions (Gg) and forest area burned (ha), 1991–2013.
Source: Authors' elaboration from [117].

evaluation failed to achieve 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 greater efforts coincided with natural gas imports from Argentina, until their 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 by 112% while coal imports reached 38.9% [111]. In the second case, the results correspond to the coming into force of initiatives such as the Country Energy Efficiency Program set up at the onset of 2005 and that began operating as of December 1, 2008 [112]. The decrease of energy intensity is also an inhibiting factor for carbon emissions in Zhang and Da [113] and in Zhang, Mu and Ning [104], but fails to curb them. Both studies 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 for CO_2-eq emissions. For most of the years included in the period under analysis, the value for the forestry sector is greater than 1. Table A9 in the appendix details the sectoral results. These results confirm the relevance of the forestry sector that has already been proven by the LMDI analysis.

Discussion of the above is reinforced when burned forest area and the CO_2-eq emissions of the Chilean economy are shown together, as in Figure 2. The interannual variation of Chile's GHG balance observed, with maximums in 1998 and 2002, is mainly due to the influence of forest fires [105]. Many of these fires have degraded the native forest, especially in the last decade [56]. Table A2 offers detailed information regarding forest fire CO_2-eq emissions.

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

Discussion

Although the importance of the forestry sector as a sink for CO_2 emissions depends on nature and past anthropogenic actions (for or against preservation), current and future anthropogenic actions are decisive in defining this sector's future role. The results of both the LMDI analysis and the second-level 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 when designing national measures oriented toward mitigation, but also regarding international agreements involved in the battle against climate change.

In light of the results from the LMDI analysis, decomposition analysis, Figure 2 and Table A2, further efforts should be recommended for the prevention of forest fires 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 [114]. Currently, most reforestation efforts are oriented toward productive uses and allow economic activity to be reconciled with the role of Chilean forestry as a sink for CO_2 emissions [57,58]. Another activity that could make reforestation compatible with economic activity is silviculture. Sustainable silviculture could reduce emissions without affecting economic growth [59,115].

Together with reforestation, there is room to improve the management of Chile's native forests. 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, contrary to the plantations which are managed in clear-felling rotations. Furthermore, the intervention processes in native forest, especially intermediate cuttings carried out to clean and improve woodland productive quality, promote an increase in their biomass by directly increasing their fixing capacity. All of the above, together with their greater surface area, places native forests as the major contributor in the fixation of CO_2.

Greater detail regarding the native species must be provided. Coigue, oak and raulí have all been identified as the native species that set more CO_2 per year among the species in the temperate forests of Chile. This is due to their rapid growth [60,61,116]. Among them, the greatest contribution is from the coigue, which, because it is perennial, maintains a higher biomass fixing year round, and there are higher volume trees in the forests.

Currently, there are approximately 4.3 million hectares of renewables where the main forest varieties include oak (*Nothofagus obliqua*), raulí (*Nothofagus alpina*) and coigue (*Nothofagus dombeyi*). These forests may be managed sustainably for multiple or individual uses (wood, firewood, non-timber forest products, ecotourism 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 that present possibilities of management for environmental services, landscape contemplation – tourism – and non-timber forest products.

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 emission variations was conducted, and the efforts made in this sector to improve its contribution to the decoupling process between these emissions and GDP growth were also studied. The analysis was carried out for the years 1991–2013.

Focusing on Chile's forestry sector, major findings from LMDI and second-level decomposition analysis reveal that it clearly manages to act as a 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. Despite its role as a compensator for these factors, it cannot prevent CO_2-eq emissions from increasing for most of the years analyzed. The forestry sector is revealed to be a relevant sector.

The results show that Chile has not yet reached decoupling for the whole period under evaluation between economic growth and CO_2-eq emissions and that it has become a heavily carbonized economy in which CO_2-eq emissions have increased at a higher rate than has its economic growth. However, within recent 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 appears to be 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 the efforts of Chilean authorities to incorporate mitigation actions specifically focused on the forestry sector, when comparing these actions with those focused on the other sectors included in the LMDI analysis, they are clearly revealed to be poor. The recent Biennial Update report submitted by the Chilean Government to the UNFCCC on April 21, 2017, distinctly shows such a difference. To contribute to solving this deficiency, additional recommendations are provided in the light of the results obtained.

First, it is recommended that Chilean authorities include the analysis and management of changes in the forestry sector through LULUCF activities in their international commitments. If these international commitments on climate change subscribed to by Chile fail to include obligations in the development and protection of the forestry sector, they will obviously be incomplete. Of course, this does not mean excluding them from the mitigating actions of 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.

Second, due to the role of the forestry sector as an inhibitor 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 to reduce the environmental stress they cause. This makes sense for any additional effort oriented toward the forestry sector regarding its potential effectiveness. That is why we recommend that the authorities in Chile encourage reforestation and restoration processes more intensively, especially taking into account the losses in recent years due to forest fires. Specifically, authorities are advised to strengthen the management of native forests, mainly reforestation where hardwood forests are made up of oak, raulí and coigue. Such woodlands may feasibly be managed in a sustainable manner for multiple or individual uses, such as for wood, firewood, non-timber forest products, eco-tourism or for the carbon market, among others. To ensure the constant contribution of woodland ecosystems to CO_2 fixation, it is recommended that integrated management of forest ecosystems be improved, understanding this as the multiple use of the forest, as a producer not only 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 that 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. To carry out all the activities proposed, it is essential to improve the current Native Forest Law of Chile, enhancing the management, restoration and reforestation of native forests.

The third recommendation derives from the frequently found status of 'expansive negative decoupling'; it is revealed by the results explained when considering that Chile's energy matrix is strongly based on the use of fossil fuels. This gives biomass plants a chance to generate electricity powered by waste coming from forests to replace coal-powered thermal plants. Our recommendation is to establish a mandatory target for the deployment of such plants in terms of megawatts installed in the Chilean energy policy. This technology could be managed in a planned manner to reduce Chile's dependency on foreign coal suppliers and to reduce the risk of forest fires. Regarding the results from the second-level decomposition analysis for most of the years analyzed, the value for the forestry sector was greater than 1, so this sector could help curb the coupling status of Chile's economy, making its energy matrix a low-carbon one.

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Appendix

Table A1. Total Chilean CO_2-eq emissions (Gg) per sector, 1990–2013.

Year	1. Energy	2. Transport	3. Industrial processes	4. Solvent and other products	5. Agriculture	6. LULUCF	7. Waste	TOTAL
1991	21,800.56	9653.50	3065.70	92.77	12,668.47	– 40,529.04	2581.58	9333,53
1992	21,892.79	10,471.38	3723.13	90.45	12,882.43	– 43,248.29	2673.23	8485,13
1993	22,986.71	11,615.16	3941.05	78.95	13,072.59	– 42,816.58	2724.54	11,602,42
1994	24,528.94	12,555.52	4065.30	86.21	13,189.12	– 42,700.60	2808.54	14,533,03
1995	26,064.04	13,891.56	4043.81	87.63	13,454.41	– 40,943.56	2916.51	19,514,40
1996	30,669.05	15,113.45	4294.58	93.62	13,640.61	– 39,363.95	3011.64	27,458,99
1997	36,414.62	16,033.42	4817.74	95.27	13,558.64	– 41,778.57	3106.72	32,247,84
1998	36,021.54	16,904.59	5046.02	95.79	13,565.91	– 39,222.14	3188.34	35,600,04
1999	38,534.42	17,091.52	5431.96	31.01	13,662.26	– 36,665.70	3230.26	41,315,71
2000	34,773.94	17,348.92	6334.78	114.81	13,580.69	– 46,399.92	3348.28	29,101,51
2001	33,608.23	16,402.86	6139.36	186.71	13,476.55	– 46,878.81	3640.94	26,575,84
2002	33,814.25	16,940.37	6434.58	125.99	13,550.98	– 30,736.51	3696.67	43,826,33
2003	34,717.92	16,714.01	6585.11	147.25	13,269.45	– 44,738.64	4037.06	30,732,15
2004	38,760.11	17,336.00	7061.11	99.18	13,818.56	– 38,225.46	4172.91	43,022,41
2005	38,483.88	19,095.01	7294.26	108.30	13,526.63	– 39,214.70	4403.23	43,696,61
2006	39,733.67	18,705.88	7647.19	106.48	13,763.65	– 40,706.55	4196.70	43,447,02
2007	47,750.38	20,272.46	7289.05	101.90	13,896.62	– 31,657.43	3972.97	61,625,95
2008	48,124.95	21,227.84	6801.12	247.95	13,933.04	– 30,714.00	3844.79	63,465,68
2009	45,943.17	21,229.08	6232.82	140.93	13,128.34	– 35,768.14	3755.40	54,661,59
2010	48,471.22	20,952.45	5767.05	241.03	12,879.79	– 43,394.22	3802.61	48,719,94
2011	56,665.39	21,861.57	6739.41	128.89	12,741.69	– 37,081.64	3939.78	64,995,10
2012	59,521.25	22,555.34	7026.84	188.03	13,285.03	– 31,695.78	4019.16	74,899,87
2013	60,529.70	24,545.67	6477.41	141.99	13,735.20	– 39,854.36	4478.81	70,054,41

Source: Authors' elaboration from Government of Chile [105].
Gg: gigagrams.

Table A2. LULUCF activities emissions by main subsectors. $CO_{2\text{-eq}}$ Gg, 1990–2013.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
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	– 36,665.7	– 46,399.9	– 46,878.8	– 30,736.5	– 44,738.6	– 38,225.5	– 39,214.7	– 40,706.6	– 31,657.4	– 30,714.0	– 35,768.1	– 43,394.2	– 37,081.6	– 31,695.8	– 39,854.4
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	– 38,694.6	– 48,437.9	– 48,893.8	– 32,759.4	– 46,774.4	– 40,289.4	– 41,235.5	– 42,771.9	– 34,228.0	– 33,289.1	– 38,298.0	– 45,999.2	– 39,684.0	– 34,356.1	– 42,491.2
Forest fire	1433.1	2937.5	510.4	2863.1	3058.0	1440.2	6449.0	4559.0	26,572.9	11,553.5	831.1	437.3	17,547.9	1525.0	2844.3	1495.6	726.2	6,490.4	4279.4	6948.5	4015.8	2647.7	10,240.9	951.1
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	– 50,248.1	– 49,269.0	– 49,331.0	– 50,307.2	– 48,299.4	– 43,133.7	– 42,731.0	– 43,498.1	– 40,718.4	– 37,568.5	– 45,246.4	– 50,015.0	– 42,331.8	– 44,597.0	– 43,442.3
Cropland	329.2	369.6	377.6	385.4	380.7	406.1	487.1	401.0	434.2	483.5	501.5	479.9	540.4	555.7	584.7	540.0	550.5	660.6	660.6	611.6	684.8	683.4	739.4	721.9
Grassland	1150.8	1153.6	1150.1	1152.4	1155.2	1146.2	1146.2	1147.2	1148.1	1153.4	1144.7	1143.3	1066.1	1064.1	1063.2	1065.1	1057.8	1069.1	1069.8	1073.4	1075.4	1074.0	1075.7	1069.7
Wetlands	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	9.3	9.3	9.3	9.3	12.4	12.1	12.5	12.5	12.5	12.5	12.5	12.5
Settlements	218.3	218.2	218.1	218.1	218.1	218.2	218.3	218.3	218.3	218.3	218.2	218.2	169.3	169.1	169.1	168.9	176.3	247.0	268.7	268.8	268.8	269.0	269.1	269.2
Other land	173.5	173.4	173.3	173.3	173.2	173.2	173.2	173.3	173.3	173.3	173.2	173.2	237.8	237.6	237.6	237.5	268.3	581.7	563.6	563.6	563.6	563.6	563.7	563.6

Source: Authors' elaboration from Government of Chile [105].
Gg: gigagrams.

Table A3. Sectoral values for Yp decomposition factor. CO_2-eq emissions (Gg).

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	Total
1991–1992	1912.4	880.4	296.2	8.0	1118.3	− 3665.5	230.0	779.7
1992–1993	954.4	469.4	163.0	3.6	552.1	− 1830.6	114.8	426.6
1993–1994	787.2	365.7	132.7	2.7	435.2	− 1417.3	91.7	398.0
1994–1995	1801.9	786.2	288.9	6.2	949.2	− 2979.5	203.9	1056.8
1995–1996	4078.2	1589.7	600.5	13.1	1952.0	− 5784.8	427.0	2875.7
1996–1997	1984.2	654.3	269.9	5.6	806.5	− 2405.3	181.4	1496.7
1997–1998	1054.7	321.3	143.6	2.8	394.9	− 1179.0	91.7	829.9
1998–1999	− 76.0	− 22.5	− 10.7	− 0.1	− 27.8	77.3	− 6.5	− 66.2
1999–2000	1210.6	364.7	194.1	2.1	450.3	− 1366.7	108.7	963.9
2000–2001	737.0	237.8	134.4	3.2	291.6	− 1005.4	75.3	474.0
2001–2002	377.2	123.5	70.3	1.7	151.2	− 427.9	41.1	337.1
2002–2003	942.4	303.5	179.0	3.7	368.8	− 1025.9	106.3	877.8
2003–2004	1660.7	499.2	308.6	5.5	612.8	− 1873.1	185.7	1399.4
2004–2005	1575.3	450.0	292.7	4.2	557.7	− 1579.3	174.9	1475.6
2005–2006	1704.1	480.8	325.5	4.7	594.6	− 1741.2	187.3	1555.9
2006–2007	1028.5	260.2	176.1	2.5	326.1	− 848.7	96.3	1040.9
2007–2008	1100.2	253.2	161.6	3.8	319.4	− 715.7	89.7	1212.2
2008–2009	− 941.4	− 220.9	− 130.4	− 3.8	− 270.8	664.1	− 76.1	− 979.1
2009–2010	1913.9	447.4	243.2	7.6	527.3	− 1600.2	153.2	1692.6
2010–2011	2378.1	547.4	349.4	8.1	690.3	− 1992.1	193.9	2175.1
2011–2012	2110.4	495.1	292.3	8.5	607.0	− 1540.1	170.5	2143.8
2012–2013	1523.0	356.0	193.5	6.0	419.6	− 1149.4	121.9	1470.7

Gg: gigagrams.

Table A4. Sectoral values for P decomposition factor. CO_2-eq emissions (Gg).

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	Total
1991–1992	392.4	180.6	60.8	1.6	229.4	− 752.0	47.2	160.0
1992–1993	395.8	194.7	67.6	1.5	229.0	− 759.2	47.6	176.9
1993–1994	411.7	191.3	69.4	1.4	227.6	− 741.3	48.0	208.2
1994–1995	431.0	188.0	69.1	1.5	227.0	− 712.6	48.8	252.7
1995–1996	391.6	152.7	57.7	1.3	187.5	− 555.5	41.0	276.2
1996–1997	456.7	150.6	62.1	1.3	185.6	− 553.6	41.7	344.5
1997–1998	487.7	148.6	66.4	1.3	182.6	− 545.1	42.4	383.7
1998–1999	495.1	146.6	69.6	0.8	180.9	− 503.9	42.6	431.6
1999–2000	480.2	144.7	77.0	0.8	178.6	− 542.1	43.1	382.3
2000–2001	383.9	123.9	70.0	1.7	151.9	− 523.8	39.2	246.9
2001–2002	208.5	68.2	38.9	1.0	83.6	− 236.5	22.7	186.3
2002–2003	368.8	118.8	70.1	1.5	144.3	− 401.5	41.6	343.6
2003–2004	377.7	113.5	70.2	1.3	139.4	− 426.0	42.2	318.3
2004–2005	393.0	112.3	73.0	1.1	139.1	− 394.0	43.6	368.1
2005–2006	401.6	113.3	76.7	1.1	140.1	− 410.3	44.1	366.6
2006–2007	458.8	116.1	78.5	1.1	145.5	− 378.6	43.0	464.3
2007–2008	525.7	121.0	77.2	1.8	152.6	− 341.9	42.9	579.2
2008–2009	532.2	124.9	73.7	2.1	153.1	− 375.5	43.0	553.5
2009–2010	526.6	123.1	66.9	2.1	145.1	− 440.3	42.2	465.7
2010–2011	529.0	121.8	77.7	1.8	153.6	− 443.2	43.1	483.9
2011–2012	513.0	120.4	71.0	2.1	147.6	− 374.4	41.5	521.1
2012–2013	502.6	117.5	63.9	2.0	138.5	− 379.3	40.2	485.4

Gg: gigagrams.

Table A5. Sectoral values for EI decomposition factor. CO_2-eq emissions (Gg).

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	Total
1991–1992	− 8001.1	− 1503.1	234.8	10.0	1594.6	− 5226.6	50.7	− 12,840.8
1992–1993	1407.4	511.8	− 36.7	− 8.6	− 11,870.7	39,362.8	127.0	29,493.0
1993–1994	1135.7	− 2118.1	36.2	1.8	9297.6	− 30,276.4	135.7	− 21,787.5
1994–1995	− 399.6	− 2433.8	171.0	0.2	− 718.6	2255.6	115.0	− 1010.2
1995–1996	7574.0	− 1069.0	136.5	− 7.5	2598.7	− 7701.4	161.4	1692.6
1996–1997	1241.9	− 803.3	40.8	27.0	2204.3	− 6574.0	49.7	− 3813.6
1997–1998	8139.3	− 851.0	48.9	− 20.5	− 6827.6	20,382.2	207.6	21,078.9
1998–1999	− 574.2	− 653.6	564.0	9.2	3956.9	− 11,024.1	112.5	− 7609.3
1999–2000	824.4	608.0	98.4	− 6.1	52.1	− 158.2	30.4	1449.0
2000–2001	− 7558.4	28.6	204.8	− 0.1	− 2252.0	7763.8	302.7	− 1510.8
2001–2002	11,426.7	− 1608.8	159.6	− 12.5	4175.9	− 11,817.1	72.2	2395.9
2002–2003	− 8263.0	− 862.1	388.3	35.1	− 2461.5	6847.0	30.8	− 4285.3
2003–2004	9092.7	326.3	− 2.0	− 15.3	− 4893.6	14,959.2	90.8	19,558.1
2004–2005	− 4369.9	409.4	− 227.1	− 6.2	− 2684.9	7603.4	67.3	792.1
2005–2006	− 2936.5	2240.0	50.1	− 15.3	3790.6	− 11,099.9	− 59.8	− 8030.7
2006–2007	17,311.7	2109.7	− 118.2	− 25.6	3796.7	− 9880.8	− 51.0	13,142.4
2007–2008	− 937.8	469.4	− 128.2	8.1	− 4578.5	10,260.5	− 270.4	4823.0
2008–2009	− 9393.2	1012.8	122.2	− 27.9	− 1186.0	2909.0	− 46.9	− 6610.1
2009–2010	− 3832.9	− 474.6	− 227.3	1.2	− 9658.2	29,307.0	2.8	15,117.9
2010–2011	4938.8	278.7	86.9	− 84.3	4387.8	− 12,662.3	7036.4	3981.9
2011–2012	14,979.5	− 1231.1	158.1	− 54.6	1728.9	− 4386.4	143.9	11,338.2
2012–2013	− 6958.3	378.3	1.5	− 44.7	1373.9	− 3763.2	− 32.4	− 9045.1

Gg: gigagrams.

Table A6. Sectoral values for CI decomposition factor. CO_2-eq emissions (Gg).

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	Total
1991–1992	9532.0	713.7	1230.5	6.2	1139.2	– 5752.0	680.2	7549.6
1992–1993	– 1841.2	9.7	– 62.2	– 10.6	11,401.6	– 36,744.9	– 228.2	– 27,475.7
1993–1994	– 6885.8	2398.5	– 1083.4	– 18.2	– 13,344.4	43,949.7	– 839.3	24,177.1
1994–1995	– 1054.3	2038.3	– 706.7	– 9.0	– 465.0	4049.6	– 225.7	3627.2
1995–1996	– 9698.7	930.2	– 1361.9	– 14.4	– 6493.9	21,376.6	– 1052.2	3685.7
1996–1997	3816.9	89.2	368.4	– 28.3	– 2042.2	3431.5	36.5	5672.1
1997–1998	– 18,207.7	706.4	– 1257.6	– 4.6	2780.3	– 5721.7	– 962.7	– 22,667.7
1998–1999	– 412.0	953.3	– 1143.4	– 83.7	– 5914.2	19,302.2	– 601.9	12,100.3
1999–2000	– 110.2	– 1266.8	1630.4	97.3	1370.1	– 14,140.0	607.7	–11,811.5
2000–2001	8292.7	– 1187.6	– 234.0	80.6	2194.9	– 8404.9	119.2	861.0
2001–2002	– 10,263.6	1220.5	272.0	– 48.3	– 4211.2	28,270.0	40.8	15,280.1
2002–2003	4906.9	– 444.3	– 1054.8	– 27.3	582.9	– 16,406.7	– 108.5	– 12,551.6
2003–2004	– 9020.1	– 234.2	– 345.0	– 48.0	2952.1	– 832.6	– 385.4	– 7913.1
2004–2005	7238.9	199.1	1133.7	22.6	2820.2	– 9802.5	602.6	2214.7
2005–2006	2950.4	– 3012.6	271.5	8.4	– 4258.7	11,672.9	– 145.3	7486.6
2006–2007	– 7172.4	– 1662.8	– 2526.8	– 6.8	– 7404.9	28,666.4	– 1389.7	8502.9
2007–2008	121.9	36.2	– 470.8	133.8	3895.1	– 7704.0	7.3	– 3980.6
2008–2009	2099.4	105.2	– 494.9	– 65.8	1442.0	– 10,564.5	– 77.3	– 7556.0
2009–2010	– 1550.6	– 510.3	– 1054.7	72.4	8238.3	– 33,378.7	– 471.5	– 28,655.1
2010–2011	– 5693.5	– 520.9	204.0	– 28.5	– 6936.0	25,895.7	– 7399.4	5521.3
2011–2012	– 15,503.6	424.0	– 95.2	125.6	– 591.5	8319.7	– 185.8	– 7506.8
2012–2013	– 802.8	107.7	– 1259.4	– 27.6	– 2049.1	– 1358.6	– 70.8	– 5460.6

Gg: gigagrams.

Table A7. Sectoral values for RES decomposition factor. CO_2-eq emissions (Gg).

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	Total
1991–1992	– 6760.0	0.0	– 1047.0	– 28.3	– 3953.0	12,956.9	– 812.9	355.7
1992–1993	465.7	0.1	79.5	1.8	269.4	– 893.3	56.0	– 20.8
1993–1994	5862.3	– 0.1	988.1	20.4	3241.2	– 10,554.5	682.8	240.2
1994–1995	1129.7	– 0.1	181.1	3.9	595.1	– 1868.0	127.9	169.6
1995–1996	7812.7	0.0	1150.5	25.0	3739.4	– 11,082.1	818.1	2463.6
1996–1997	– 1593.5	0.0	– 216.7	– 4.5	– 647.7	1931.6	– 145.7	– 676.4
1997–1998	8895.2	0.0	1211.1	23.5	3330.9	– 9943.7	773.0	4289.9
1998–1999	5928.3	0.0	833.1	9.1	2165.9	– 6034.2	510.6	3412.7
1999–2000	– 6699.7	0.1	– 1074.2	– 11.7	– 2491.9	7563.2	– 601.7	– 3316.0
2000–2001	– 2096.0	0.0	– 382.4	– 9.1	– 829.4	2859.4	– 214.1	– 671.6
2001–2002	– 1083.3	0.0	– 202.0	– 5.0	– 434.3	1228.9	– 117.9	– 613.6
2002–2003	3139.1	0.0	596.4	12.5	1228.5	– 3417.3	354.0	1913.3
2003–2004	2268.4	0.0	421.5	7.5	837.0	– 2558.6	253.7	1229.6
2004–2005	– 5512.3	0.0	– 1024.3	– 14.8	– 1951.3	5526.0	– 611.9	– 3588.6
2005–2006	– 1773.2	0.1	– 338.7	– 4.9	– 618.7	1811.7	– 194.9	– 1118.5
2006–2007	10,672.3	0.1	1826.9	25.5	3383.8	– 8806.3	999.2	8101.4
2007–2008	– 829.8	0.0	– 121.9	– 2.8	– 240.9	539.8	– 67.7	– 723.3
2008–2009	– 962.4	0.0	– 133.3	– 3.9	– 276.8	679.0	– 77.8	– 775.2
2009–2010	4115.8	0.0	523.0	16.3	1134.0	– 3441.1	329.6	2677.6
2010–2011	2927.1	0.0	430.0	10.0	849.7	– 2452.0	238.7	2003.6
2011–2012	– 963.6	0.0	– 133.5	– 3.9	– 277.2	703.2	– 77.9	– 752.8
2012–2013	4152.5	0.0	527.6	16.4	1144.1	– 3133.9	332.5	3039.2

Gg: gigagrams.

Table A8. Sectoral values for ES decomposition factor. CO_2-eq emissions (Gg).

Years	Energy	Transport	Industry	USOP	Agriculture	Forest sector	Waste	Total
1991–1992	3016.6	546.3	– 117.8	0.2	85.4	– 280.0	– 103.4	3147.4
1992–1993	– 288.3	– 41.8	6.7	0.8	– 391.1	1296.9	– 66.0	517.2
1993–1994	231.1	21.6	– 18.7	– 0.9	259.2	– 844.2	– 34.9	– 386.8
1994–1995	– 373.6	537.1	– 24.9	– 1.4	– 322.4	1012.0	– 161.9	664.9
1995–1996	– 5552.8	– 673.4	– 332.5	– 11.4	– 1797.4	5326.8	– 300.3	– 3341.0
1996–1997	– 160.7	561.1	– 1.4	0.6	– 588.5	1755.1	– 68.6	1497.6
1997–1998	– 762.2	258.5	16.0	– 2.0	146.1	– 436.1	– 70.3	– 850.0
1998–1999	– 2848.3	– 302.3	73.4	– 0.1	– 265.3	739.1	– 15.4	– 2618.9
1999–2000	534.2	314.2	– 22.9	1.3	359.3	– 1090.5	– 70.3	25.5
2000–2001	– 924.8	178.5	11.6	– 4.4	338.8	– 1168.1	– 29.5	– 1597.9
2001–2002	– 459.4	552.4	– 43.6	2.4	309.3	– 875.2	– 3.1	– 517.1
2002–2003	– 190.6	735.7	– 28.5	– 4.3	– 144.6	402.2	– 83.9	686.0
2003–2004	– 337.2	– 301.8	22.7	0.9	901.5	– 2755.7	– 51.2	– 2520.9
2004–2005	398.7	– 104.6	– 14.9	2.2	827.3	– 2342.9	– 46.3	– 1280.4
2005–2006	903.4	– 48.8	– 32.2	4.2	589.1	– 1725.1	– 38.0	– 347.5
2006–2007	– 14,282.2	64.2	205.4	– 1.2	– 114.2	297.1	78.6	– 13,752.2
2007–2008	394.3	– 371.7	– 5.8	1.5	488.7	– 1095.2	70.1	– 518.1
2008–2009	6483.6	– 1021.3	– 5.6	– 7.8	– 666.1	1633.7	145.6	6562.2
2009–2010	1355.2	269.6	– 16.8	0.5	–635.1	1927.2	– 9.0	2891.7
2010–2011	2407.9	41.7	– 50.7	– 10.0	704.7	– 2033.6	25.9	1085.9
2011–2012	1176.6	536.3	– 20.8	– 6.1	– 1050.0	2663.8	– 16.4	3283.5
2012–2013	2376.0	– 26.5	– 15.3	–4.5	– 593.6	1626.0	17.7	3379.7

Gg: gigagrams.

Table A9. Second-level decoupling analysis at the sectoral level.

	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 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	– 2.69	1.99	7.30	19.88	1.03
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	– 0.13	0.65	0.67	– 0.54	– 0.14
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	0.63	1.35	– 0.26	0.12	1.62
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	0.08	– 0.09	0.04	– 0.16	0.04
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	– 1.85	– 10.57	8.90	0.76	2.63
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	13.55	42.81	– 33.21	– 10.67	1.74
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	0.10	0.60	9.49	0.24	0.09
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	– 7.72	16.93	– 2.54	3.50	3.71
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	1.23	– 5.28	– 3.75	1.24	– 5.33
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	0.00	0.00	0.00	0.00	0.00
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	0.17	– 0.67	– 0.55	0.17	– 0.68
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	0.00	– 0.02	– 0.01	0.00	– 0.02
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	0.36	– 1.45	– 1.09	0.36	– 1.47
δRES orestry	– 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	– 0.87	4.41	3.14	– 0.90	4.02
δRES saste	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	0.10	– 0.42	– 0.31	0.10	– 0.43
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	– 0.79	– 1.58	– 0.92	0.35	– 2.07
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	12.05	4.92	– 6.33	– 19.21	8.92
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	– 1.30	0.61	– 0.36	1.58	– 0.49
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	– 0.16	0.29	– 0.11	– 0.20	0.00
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	0.04	0.00	0.11	0.07	0.06
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	1.52	12.39	– 5.63	– 2.22	– 1.76
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	– 3.73	– 37.59	16.24	5.63	4.83
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	0.06	0.00	– 9.02	– 0.18	0.04
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	– 6.75	– 8.93	– 1.83	– 5.29	6.15
δES energy	– 3.87	0.37	– 0.30	0.48	7.12	0.21	0.98	3.65	– 0.69	1.19	0.59	0.24	0.43	– 0.51	– 1.16	18.32	– 0.51	– 8.32	– 1.74	– 3.09	– 1.51	– 3.05
δES transport	– 0.70	0.05	– 0.03	– 0.69	0.86	– 0.72	– 0.33	0.39	– 0.40	– 0.23	– 0.71	– 0.94	0.39	0.13	0.06	– 0.08	0.48	1.31	– 0.35	– 0.05	– 0.69	0.03
δES industry	0.15	– 0.01	0.02	0.03	0.43	0.00	– 0.02	– 0.09	0.03	– 0.01	0.06	0.04	– 0.03	0.02	0.04	– 0.26	0.01	0.01	0.02	0.07	0.03	0.02
δES solvent	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	– 0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01
δES agriculture	– 0.11	0.50	– 0.33	0.41	2.31	0.75	– 0.19	0.34	– 0.46	– 0.43	– 0.40	0.19	– 1.16	– 1.06	– 0.76	0.15	– 0.63	0.85	0.81	– 0.90	1.35	0.76
δES forestry	0.36	– 1.66	1.08	– 1.30	– 6.83	– 2.25	0.56	– 0.95	1.40	1.50	1.12	– 0.52	3.53	3.00	2.21	– 0.38	1.40	– 2.10	– 2.47	2.61	– 3.42	– 2.09
δES waste	0.13	0.08	0.04	0.21	0.39	0.09	0.09	0.02	0.09	0.04	0.00	0.11	0.07	0.06	0.05	– 0.10	– 0.09	– 0.19	0.01	– 0.03	0.02	– 0.02
δES total	– 4.04	–1.21	0.97	– 0.63	1.16	– 1.00	1.02	– 39.54	– 0.03	3.37	1.53	– 0.78	1.80	0.87	0.22	13.21	0.43	6.70	– 1.71	– 0.50	– 1.53	– 2.30
δP energy	– 0.50	– 0.51	– 0.53	– 0.55	– 0.50	– 0.59	– 0.63	– 0.63	– 0.62	– 0.49	– 0.27	– 0.47	– 0.48	– 0.50	– 0.52	– 0.59	– 0.67	– 0.68	– 0.68	– 0.68	– 0.66	– 0.64
δP transport	– 0.23	– 0.25	– 0.25	– 0.24	– 0.20	– 0.19	– 0.19	– 0.19	– 0.19	– 0.16	– 0.09	– 0.15	– 0.15	– 0.14	– 0.15	– 0.15	– 0.16	– 0.16	– 0.16	– 0.16	– 0.15	– 0.15
δP industry	– 0.08	– 0.09	– 0.09	– 0.09	– 0.07	– 0.08	– 0.09	– 0.09	– 0.10	– 0.09	– 0.05	– 0.09	– 0.09	– 0.09	– 0.10	– 0.10	– 0.10	– 0.09	– 0.09	– 0.10	– 0.09	– 0.08
δP solvent	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	0.00	0.00	0.00	0.00	0.00
δP agriculture	– 0.29	– 0.29	– 0.29	– 0.29	– 0.24	– 0.24	– 0.23	– 0.23	– 0.23	– 0.19	– 0.11	– 0.19	– 0.18	– 0.18	– 0.18	– 0.19	– 0.20	– 0.20	– 0.19	– 0.20	– 0.19	– 0.18
δP forestry	0.96	0.97	0.95	0.91	0.71	0.71	0.70	0.65	0.70	0.67	0.30	0.51	0.55	0.51	0.53	0.49	0.44	0.48	0.56	0.57	0.48	0.49
δP waste	– 0.06	– 0.06	– 0.06	– 0.06	– 0.05	– 0.05	– 0.05	– 0.05	– 0.06	– 0.05	– 0.03	– 0.05	– 0.05	– 0.06	– 0.06	– 0.06	– 0.05	– 0.06	– 0.05	– 0.06	– 0.05	– 0.05
δP total	– 0.21	–0.41	– 0.52	–0.24	– 0.10	– 0.23	– 0.46	6.52	– 0.40	– 0.52	– 0.55	– 0.39	– 0.23	– 0.25	– 0.24	– 0.45	– 0.48	0.57	– 0.28	– 0.22	– 0.24	– 0.33
δt	2.09	– 6.31	– 6.16	– 3.51	– 1.66	–2.02	– 2.69	86.30	13.77	5.64	– 49.63	15.83	– 7.63	1.01	1.06	– 15.81	– 0.15	– 7.99	4.43	– 6.01	– 3.21	5.17