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Analysis of the main drivers of CO_2 emissions changes in Colombia (1990–2012) and its political implications

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ABSTRACT

In this study, an Index Decomposition Analysis-Logarithmic Mean Divisia Index (IDA-LMDI) model was developed to find the drivers behind the changes in CO_2 emissions between 1990 and 2012 in Colombia. The results facilitate the assessment of the impact in Colombia of the main measures regarding the mitigation of CO_2 emissions. Likewise, it allows us to analyze whether the recent measures implemented by the Colombian authorities to mitigate emissions are moving in the right direction. To carry out the decomposition analysis, six effects were taken into consideration: carbonization, the substitution of fossil fuels, the penetration of renewable energy, energy intensity, wealth and population. The effects of income and population appear as drivers of emissions for the period analyzed. A stylized analysis allows richer conclusions to be extracted regarding a battery of recommendations for emission mitigation policies that are compatible with economic growth in Colombia.

1. Introduction

Colombia's Green House Gas (GHG) accounted for 0.37% of global and 3.4% of Latin American emissions, as indicated in the Kyoto Protocol [1]. Currently, its contribution to GHG emissions is below its contribution to the region's GDP [2]. In per capita terms, Colombian emissions reach 4.4 tCO_2 eq, that is below the average for Latin America and the Caribbean, which is −9.9 tCO_2 eq-. This is mainly due to the fact that hydropower has, until now, been the main source of electricity generation, which comprises 76% of Colombia's electricity matrix [3].

Due to its geographical location and socioeconomic characteristics, Colombia is vulnerable to natural disasters[62]. However, in the specific case of risks associated with Climate Change in Colombia, an elevated concern is not seen, as evidenced by this country's not sending any data to the Nationally Appropriate Mitigation Action (NAMA) to the United Nations Framework Convention on Climate Change (UNFCCC) until 2012 and the voluntary action assumed was very limited. It can be said that the development of climate change policies in Colombia is still in its initial stages.

Despite this poor legal framework, after approving the Kyoto Protocol at the national level by Act 629 dated 2000 (the [4], the national government approved the initial policy lines against climate change in 2002 [5].

In terms of GDP, Colombia is the fourth most important economy in Latin America [6]. From 1990 to 2012, Colombia's CO_2 emissions (the main GHG) increased 43.8%, well over the 9.4% increase represented by the OECD-America [7]. For the same period, Colombia's energy efficiency indicator showed a good trend by reducing its value up to 45.4% (34.8% OECD-America), the electricity consumption per capita rose to 29.9% (10.4% OECD-America) and the primary energy matrix moved forward from one of low carbon (the ratio of CO_2 emissions to total primary energy sources increased by 11.5% compared with a decrease of 5.4% for the OECD-

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America area) [8].

With the exception of [9,10] and [11–13]; scientific literature on Colombia's CO_2 emissions is scarce. Only some official national and international documents are available. Most of them are provided by Colombia's Department of the Environment and Sustainable Development, the Institute of Hydrology, Weather and Environmental Studies [14] and by the CONPES.

In addition to official national documents, a number of international institutions are interested in Colombian GHG emissions. On the one hand [15], shows the importance of CO_2 emissions in Colombia and estimated that out of total GHG emissions, the CO_2 emissions' share was 48.2% for 1990, 52.80% for 2000 and 49.79% for 2005. On the other hand, the OECD [16] offered a sectoral analysis of GHG emissions. This document identifies the energy sector as the main driver behind emissions followed by the agricultural, industry and residual sectors. This hierarchy is the same from 1990 to 2010. Focusing on emissions coming from the energy sector, the OECD's document revealed eight sectors as the main energy consumers (transport, manufacturing, construction, electricity and heating, the residential sector, retail and public services, and agriculture). Finally, the [17] also offers information for Colombia as shown in the results.

These key indicators suggest that there is space to implement policies oriented toward mitigating and improving energy efficiency. Yet, to improve the effectiveness of future policies it is useful to have robust information about the main drivers of changes in CO_2 emissions in Colombia.

An Index Decomposition Analysis (IDA) could contribute to this improvement by offering this useful information. In this paper, a type of IDA analysis called Log-Mean Divisia Index Method (LMDI) is used. The arguments for this choice are detailed in Section 2. IDA-LMDI methodology has been largely used to analyze ever-growing pollution. Results from IDA-LMDI speak to policy makers to better design mitigation policies specifically oriented to emissions drivers (also providing sectoral measures). These results also allow the enhancing of measures oriented to inhibitor factors of CO_2 emissions (i.e., energy efficiency plans). More recent articles regarding European countries include O'Mahony [18] for Ireland and Cansino et al. [19] for Spain. In the case of emerging Asian countries, there are articles by Ref. [20] for Korea, and for China [21–26] have written articles for the USA. For the case of Latin America, there are authors such as [27] for Brazil [28], for five Latin American countries and [29] for all of Latin America. However, to the best of our knowledge, this is the first paper to conduct this type of analysis for Colombia. Therefore, it seeks to contribute to this growing body of knowledge regarding the drivers behind changes in CO_2 emissions.

The aims of this paper are the following:

1. The decomposition of changes in CO_2 emissions during the 1990–2012 period take into account the following effects: carbonization, the substitution of fossil fuels, the penetration of renewable energy, energy intensity, income and population.
2. The analysis of most relevant energy policies implemented during the whole period.
3. A number of results-based policy recommendations have been included.

This paper has been structured as follows: After the introduction, Section 2 reviews the most relevant literature, while Section 3 explains the methodology. Section 4 describes the dataset used. The results are presented in Section 5 and discussed in Section 6. In light of our results, we reach several conclusions, which are provided in Section 7.

2. Methodology

There are two main decomposition techniques to identify the drivers of changes in CO_2 emissions: structural decomposition analysis (SDA) and IDA [30]. The latest comparisons between IDA and SDA are shown in Ref. [31]. Comparatively, IDA has certain advantages over SDA. IDA enables decompositions for any aggregate (value, ratio or elasticity). Also, IDA requires less data than decomposition methods based on input-output analysis and it is useful when decomposing CO_2 emission changes into their various components [19].

In this paper, a Log-Mean Divisia Index Method (LMDI I) was conducted as proposed initially by Ref. [32]; and revised by Refs. [33] and [34]. This paper follows [35] criteria that assessed the various decomposition methods. He concluded that LMDI I is a more recommendable method due to both its theoretical base and its set of properties, which are satisfactory in the case of index decomposition. LMDI I is a “refined,” non-parametric approach based on the IDA method, with a weighted logarithmic mean. An additional argument in favor of LMDI I is that it allows perfect decomposition (that is, without residuals) and provides a simple and direct association between the additive and the multiplicative decomposition form: [36].

The starting point for the LMDI I conducted is the IPAT equation. The Impact = Population × Affluence × Technology (IPAT) equation is used to assess the contribution of CO_2 emission drivers. Specifically, the IPAT model [37,38] and the ‘Kaya identity’ [39–41] and [42] are extended using IDA [43,44] to assess the key drivers behind Colombia's CO_2 emissions.

Firstly, Colombia's CO_2 emissions (C) are decomposed in six factors as follows in equation (1):

$$C = \sum_{i=1}^{n} \frac{C_i}{FF_i} \cdot \frac{FF_i}{FF} \cdot \frac{FF}{E} \cdot \frac{E}{Y} \cdot \frac{Y}{P} \cdot P = CF \cdot F \cdot ER \cdot I \cdot Q \cdot P \tag{1}$$

Being $C_i$the CO_2 emissions from fossil fuel i, $FF_i$is the fossil fuel i, $FF$is the total fossil fuel consumption in Colombia, $E$is the total primary energy consumption, $Y$is the output and $P$is the total population.

Changes in CO_2 emissions can be assessed by implementing additive or multiplicative decomposition. In this paper, a multiplicative LMDI I analysis is carried out but also, an additive analysis of the CO2 emissions changes for the whole period has been implemented in order to supplement the latter information.

The multiplicative LMDI-I analysis shows that the overall ratio of change in CO_2 emissions during the period t and 0 (D_{tot}) is decomposed as follows:

$$D_{tot} = \frac{C_t}{C_0} = D_{emc} \cdot D_{ffse} \cdot D_{repe} \cdot D_{\mathrm{int}} \cdot D_{ypc} \cdot D_{pop} \tag{2}$$

Related to the multiplicative decomposition in equation (2), D_{emc}shows the carbonization effect, D_{ffse}shows the substitution effect, D_{repe} the RES penetration effect, D_{int} is the intensity effect, D_{ypc} is the income effect and D_{pop} is the population effect.

The additive LMDI-I analysis shows the

$$\Delta C = C_t - C_0 = \Delta C_{emc} + \Delta C_{ffse} + \Delta C_{repe} + \Delta C_{\mathrm{int}} + \Delta C_{ypc} + \Delta C_{pop} \tag{3}$$

With relation to the additive decomposition of equation (3), the total change of CO_2 emissions between period *0* and *t*, can be decomposed into the following effects: ΔC_{emc} shows the carbonization effect, ΔC_{ffse}shows the substitution effect, ΔC_{repe} the RES penetration effect, $\Delta C_{\mathrm{int}}$is the intensity effect, ΔC_{ypc} is the income effect and $\Delta C_{pop}$is the population effect.

The calculation of the effects according to the additive and multiplicative LMDI-I method is shown in Annex A.

To accommodate cases of zero value [32,33], and [36] analyzed and proposed that the best way to handle this is by substituting zeros for a δ value between 10^{-10} and 10^{-20}. This is known as the small value (SV) strategy [45]. also showed that the SV strategy is robust when an appropriate value is used, and that it would provide satisfactory results even for highly extreme cases.

3. Dataset

The data used comes from the International Energy Agency. All data are free access and are available online for the period 1990–2012. The CO_2 emissions data are taken from the fossil fuels combustion. The emissions of CO_2 from fossil fuels and the total primary energy requirements have a direct relationship and their behavior shows the coupling of these variables with fluctuations of GDP growth during the period analyzed.

Population is expressed in millions of inhabitants, while CO_2 emissions are listed in millions of tonnes of CO_2. Total primary energy requirements (TPER) are measured in millions of tons of crude oil equivalent. Lastly, the GDP is measured in billions of US dollars in 2005.

To analyze the use of various types of fuels, energy balance information from the IEA was used. These balances offer the total primary energy required (TPER) by year according to the type of fossil fuel (FF_i) (coal, crude oil and gas) expressed in millions of tons of crude oil equivalent (toe).

Based on the IEA data, we calculated both the TPER for all fossil fuels (FF) as well as for CO_2 emissions coming from all other fossil fuels (C). The TPER was measured in millions of crude oil equivalents for (FF) and emissions were measured in millions of tons of CO_2 for (C).

A specific comment about RES needs to be made to better understand their link with CO_2 emissions data. By carrying out a decomposition analysis, we could research the role of RES in Colombia's energy matrix. However, one problem must be solved. This is linked with the fact that RES technologies are free or almost free of CO_2 emissions and we observe this as a crucial variable. To bridge this lack of information, we observed the evolution of the ratio of total fossil fuel consumption to total primary energy consumption [18]. Nuclear energy in Colombia not being part of the energy matrix, the role played by RES in CO_2 emissions trend can be derived from the C_{repe} effect [46]. A decline in values for the ratio of total fossil use on total energy use might show a higher share of RES in Colombia's energy matrix.

Nevertheless, we must be circumspect when interpreting these ratios. Their use as a factor, when capturing the penetration of RES, is reliable only for technologies that do not spark a consumption increase of primary energy. This is the case of solar or wind power. Other RES technologies, such as the use of biomass as fuel at combined cycle power plants, do increase primary power consumption. If this use of biomass were to be extended during the period under consideration, the C_{repe} effect would not be a good indicator. Nonetheless, in the case of Colombia, the only RES technology used until 2012 is wind energy. That is why the C_{repe} effect would correctly capture the penetration of RES in the Colombian power matrix.

4. Results

The results for the additive LMDI-I period-wise decomposition analysis of CO_2 emissions in Colombia for the whole period 1990–2012 are displayed in Fig. 1. Additionally, the multiplicative LMDI-I results show that the total CO_2 emissions increased around 46% in the period analyzed (last row Table 1.A). This increase was driven by the effects of income and population. Both of those effects usually increase emissions due to the rise of output and population. An analysis allows us to determine that the CO_2 emissions also increased due to carbonization (4%) and RES penetration (12%) effects. However, the fossil fuels substitution and the intensity effects contributed positively to diminishing CO_2 emissions during this period.

In addition to the prior information, the inter-annual multiplicative chain-linked LMDI decomposition analysis of CO_2 emissions in Colombia (1990–2012) is displayed in Table 1. These results do not allow us to distinguish a regular pattern for the various effects, with the exception of the population effect, which increases total emissions throughout all the sub-periods, and the income effect, which raises the CO_2 emissions all the sub-periods with the exception of 1997–1998 and 1998–1999.

To display further information and considering that the period analyzed was affected by an economic crisis and other important milestones related to climate change, a period-wise multiplicative LMDI decomposition has been carried for three sub-periods, 1990–1998, 1998–2000 and 2000–2012 (Table 2).

The first sub-period between 1990 and 1998 shows a 39% increase in CO_2 emissions. From an economic perspective, this period was characterized by a significant economic growth with annual rates surpassing 5%. According to this economic growth, and considering the decomposition analysis carried out, the population and the income effects are revealed as the main drivers behind the changes in CO_2 emissions. In fact, these results are in keeping with those of [11,17]. The importance of the income effect has also been highlighted in other countries by Refs. [20,27,47,48] and [22].

Moreover, the RES penetration effect also drives changes in CO2 emissions and shows that the economy moved toward a greater fossil fuel dependency during this first sub-period. Therefore, these results prove that RES did not play a relevant role during this period.

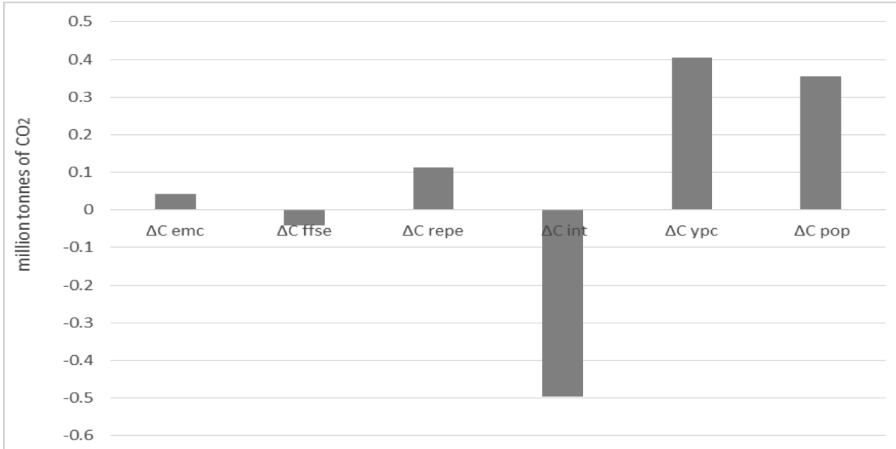
The carbonization effect (D_{emc}) does not show a clear pattern for CO_2 emissions. Sometimes, it reduces CO_2 emissions and in other years it was a driver. This means that no significant changes took place in the quality of fossil fuels. Yet, the fossil fuel substitution effect (D_{ffse}) showed quite interesting results (see Fig. 2). Until 1993, this effect drove changes in CO_2 emissions, mainly due to coal and oil. Later, the share of gas increased while the coal share diminished and the oil share did not show a clear pattern.

During the first sub-period, the intensity effect partially offsets other effects. This finding corresponds with most of the literature [18,21,49] and [11]. This result also coincides with the [17] in which the energy intensity effect decreased from 1990 but not enough to outweigh the joint action of population and income effects.

The beginning of the second sub-period under consideration (1998–2000) was underlined by the economic crisis and also associated with being the year after signing the Kyoto Protocol. The crisis began with a high exchange rate, public spending and strong macroeconomic imbalances. Consequently, Colombia faced a fiscal crisis and high levels of domestic and international private debt. Access to international financial markets was not allowed for Colombia and its GDP registered a strong, 4.3% decrease in 1999 [50]. Colombia asked the International Monetary Fund for loans to recover its international credibility.

During this sub-period, there was a negative change in CO2 emissions due to income, intensity, penetration and substitution effects. These were only partially offset by the carbonization and population effects (see Fig. 3).

The third sub-period analyzed (2000–2012) began with the ratification of the Kyoto Protocol by the Colombian authorities. This



Source: Own elaboration based on Table 2.A

Fig. 1. Additive LMDI-I effects of CO2 emissions changes (1990–2012).
Source: Own elaboration based on Table 2.A

Table 1
The multiplicative chain-linked LMDI decomposition analysis of CO_2 emissions in Colombia (1990–2012).

	D_{tot}	D_{emc}	D_{ffse}	D_{repe}	D_{int}	D_{ypc}	D_{pop}
1990–1991	1.0388	1.0124	1.0025	1.0125	0.9884	1.0032	1.0195
1991–1992	1.0428	0.9782	1.0042	1.0379	0.9738	1.0306	1.0192
1992–1993	1.1119	1.0676	1.0021	0.9936	1.0219	1.0047	1.0188
1993–1994	1.0077	0.9941	0.9958	0.9832	0.9782	1.0390	1.0186
1994–1995	1.0409	1.0199	0.9983	1.0048	0.9672	1.0331	1.0183
1995–1996	1.0146	0.9943	0.9905	1.0057	1.0037	1.0024	1.0181
1996–1997	1.0669	1.0249	0.9887	1.0850	0.9381	1.0161	1.0179
1997–1998	1.0165	0.9562	0.9965	1.0186	1.0413	0.9883	1.0176
1998–1999	0.8830	1.0450	0.9928	0.9517	0.9335	0.9417	1.0173
1999–2000	1.0428	1.0051	0.9988	1.0338	0.9623	1.0268	1.0169
2000–2001	1.0029	0.9975	1.0008	1.0087	0.9795	1.0002	1.0166
2001–2002	0.9641	1.0138	0.9924	0.9774	0.9565	1.0087	1.0162
2002–2003	0.9880	0.9729	1.0078	0.9870	0.9825	1.0229	1.0159
2003–2004	1.0038	0.9934	0.9875	1.0128	0.9592	1.0371	1.0157
2004–2005	1.0231	0.9632	1.0063	1.0133	0.9949	1.0312	1.0154
2005–2006	1.0015	0.9653	0.9956	0.9916	0.9851	1.0510	1.0152
2006–2007	1.0048	1.0238	0.9990	0.9884	0.9296	1.0532	1.0150
2007–2008	1.0148	0.9574	1.0048	1.0077	1.0111	1.0204	1.0147
2008–2009	1.0266	0.9604	1.0002	1.0310	1.0198	1.0021	1.0144
2009–2010	1.0149	1.0044	0.9988	0.9954	0.9775	1.0253	1,0140
2010–2011	1.0989	1.1068	1.0075	0.9839	0.9392	1.0521	1.0136
2011–2012	0.9923	0.9900	0.9934	0.9982	0.9700	1.0285	1.0133

Source: Own elaboration from Ref. [7].

Table 2
Three period-wise LMDI multiplicative decompositions of changes in CO_2 emissions in Colombia.

	D_{tot}	D_{emc}	D_{ffse}	D_{repe}	D_{int}	D_{ypc}	D_{pop}
1990–1998	1.3902	1.0440	0.9803	1.1461	0.9127	1.1220	1.1574
1998–2000	0.9208	1.0523	0.9897	0.9839	0.8983	0.9670	1.0345
2000–2012	1.1382	0.9519	0.9832	0.9943	0.7391	1.3847	1.1951

Source: Own elaboration from Ref. [7].

period coincided with an economic recovery. Additionally, at the beginning of 2000, a strong policy against FARC-based terrorism activity was developed by the Colombian authorities. This offered security for transportation and communications. This policy increased private investment in Colombia by national and international firms.

The security policy was accompanied by two other economic results. First, an effective monetary policy worked out by the Bank of the Republic and, second, high levels of economic growth registered by the mining sector. Regarding the latter, between 2008 and 2012, this sector grew at an annual rate of 14%, thus leading the Colombian economy in 2011 to become the fourth-strongest economy in the Latin American Area in terms of GDP.

For the third sub-period, the population and the income effects acted as the main drivers of changes in the CO_2 emissions as is shown in Fig. 3. These two effects were partially offset by the others.

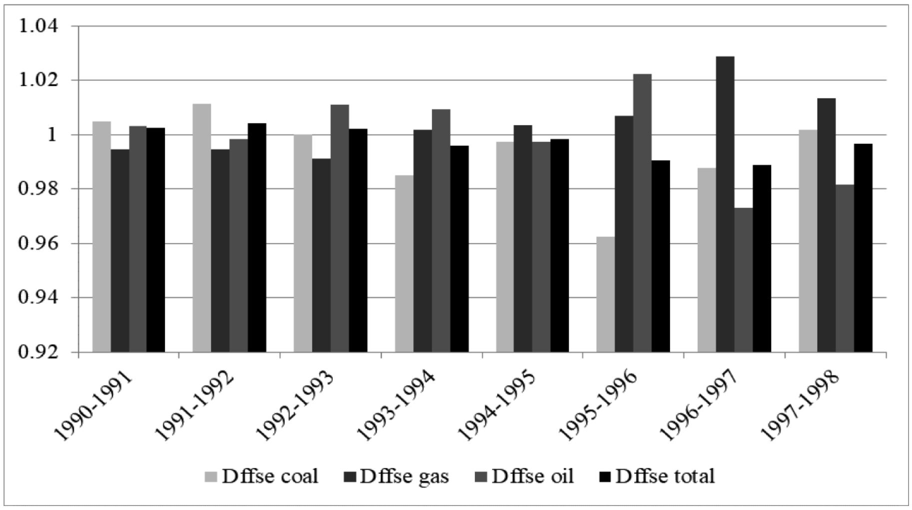
During the third sub-period, few changes can be observed for the role played by RES in Colombia's energy matrix. As of 2009 (the year of the Copenhagen Accord [51]; and onward, the penetration effect acted as a compensating factor for CO_2 emission drivers.

Additionally, the carbonization effect should be considered as it contributed positively to reducing CO2 emissions, showing that better quality fossil fuels were introduced into the fossil fuel matrix. The carbonization effect of fuels shows how the various fuels have influenced the changes in CO2 emissions (see Fig. 4). CO2 emission changes do not follow a regular pattern, but most of the periods show negative changes while positive changes are shown for 2006–2007 and 2010–2011.

During the third sub-period, the substitution effect contributed positively to changes in CO_2 emissions. In fact, between 2000 and 2005, coal and crude oil were the main drivers behind the increase in the CO_2 emissions due to the effects of fossil fuels. Since the 2006–2007 period, the substitution effect showed that although coal and gas contributed negatively, they were offset by the important decrease of crude oil (see Fig. 5).

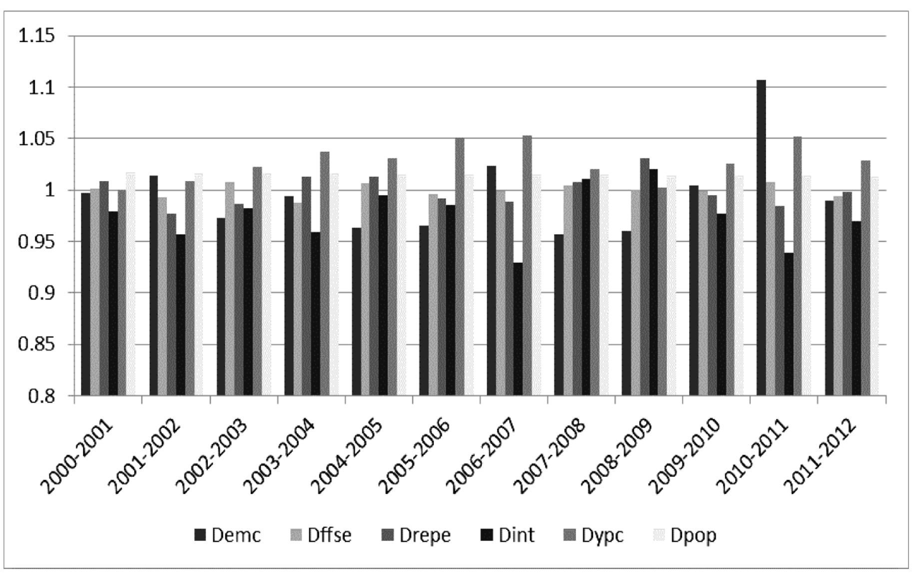
5. Discussion and policy implications

During the period analyzed, CO_2 emissions in Colombia are explained by the effects of population and income. The first effect acts as a driver in all economies where the population increases [17] but the effect of income reveals that the Colombian authorities failed to launch efficient measures to attain decoupling between economic growth and CO_2 emissions. Neither the Rio de Janeiro summit (1992), nor the signing the Kyoto Protocol in 1997



Source: Own elaboration from IEA (2015)

Fig. 2. The fossil fuel substitution effect in Colombia (1990–1998) 1.04 etc.
Source: Own elaboration based on Table 2.A

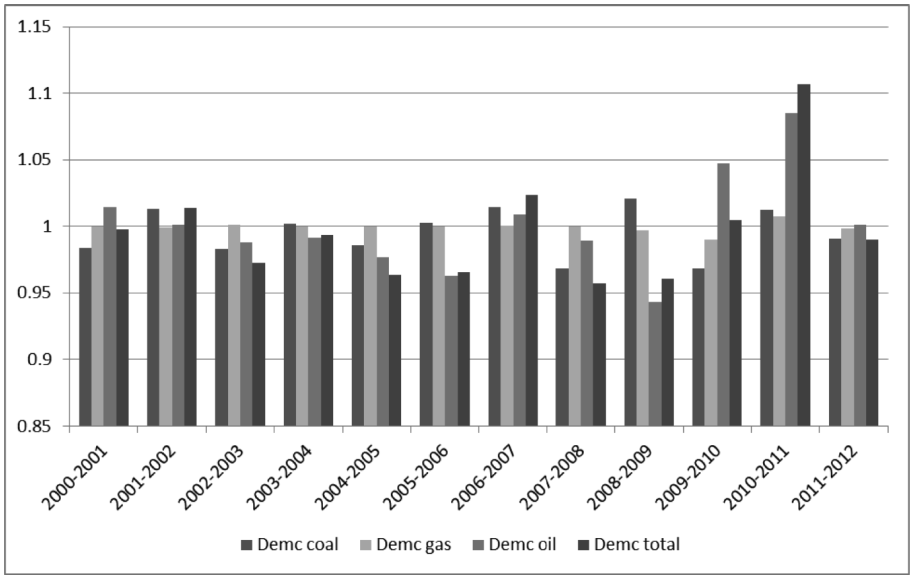


Source: Own elaboration from IEA (2015)

Fig. 3. The multiplicative chain-linked LMDI decomposition analysis of CO_2 emissions in Colombia (2000–2012) 1.15, etc.
Source: Own elaboration based on Table 2.A

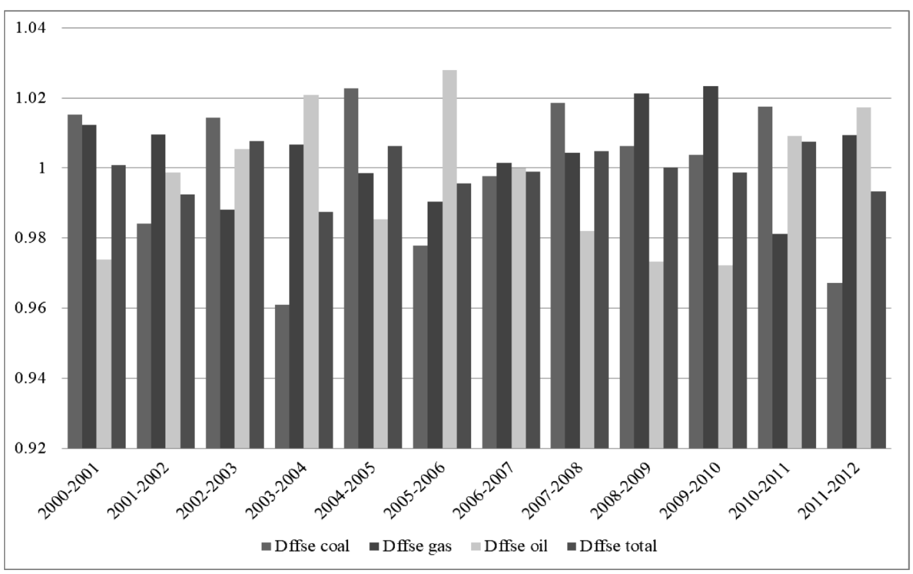
induced Colombia to take steps in this regard. Official documents approved years later have recognized that the emission mitigation measures were extremely limited. For example [52], includes a direct criticism of the measures against pollution prior to 2005 in Colombia. This document recognized that despite information available up to 2005 on CO_2 emissions levels and their consequences, legislation and national standards adopted at the beginning of the 80s were still in force. Additionally, before 2005 Colombia did not have national guidelines for the formulation of coordinated, efficient and equitable strategies aimed at preventing and controlling CO_2 emissions. As a result, local and sectoral actions have developed in isolation. Together with the aforementioned document [53], is also extremely critical and states that in this country they have failed to understand Climate Change as a topic of economic and social development, nor have they integrated it into the planning and investment processes of the productive and territorial sectors. This resulted in losses in economic and competitiveness terms. It also caused an increase in the vulnerability of the country to the Climate Change and a low capacity to respond to extreme weather events.

The status of Colombia in the Kyoto Protocol appears as a non-Annex I country (without mandatory obligations to mitigate CO2 emissions). This, together with the fact that the Protocol was not ratified by the Colombian authorities until 2000, is in line with the



Source: Own elaboration from IEA (2015)

Fig. 4. The carbonization effect in Colombia (2000–2012) 1.15, etc.
Source: Own elaboration based on Table 2.A



Source: Own elaboration from IEA (2015)

Fig. 5. The substitution effect in Colombia (2000–2012) 1.04, etc.
Source: Own elaboration based on Table 2.A

fact that economic growth and CO2 emissions remained coupled.

It was only as of 2010 that the Colombian economy showed signs of moving toward a low-carbon economy, as a consequence of the various measures launched by the authorities. Regarding these measures, three milestones were achieved: i) the Act 697 (Act 697 of 2001) on energy efficiency and RES; ii) the introduction of fiscal incentives as of 2003 oriented toward achieving decoupling and iii) the approval of [52].

As the first milestone, the Act 697 granted priority to the use of RES for zones that were not interconnected. It established exemplary obligations for public bodies in terms of energy efficiency.

Table 3
Renewable Energy Sources in the Colombia's electricity matrix (2000–2012). GWh.

	2000	2005	2012
Hydropower	32,074	39,803	47,582
Wind	0	49	55

Source: [7].

Together with this Law is the creation in 2001 of the Inter-sectorial Commission for the Rational Use and Efficiency of Energy and Unconventional Energy Sources—known by its Spanish acronym

Table 4
Main fossil fuels final consumption (2000–2012).

	2000	2005	2012
Coal (kt)	3413	2459	1,501[a]
Natural Gas (TJ)	75,515	131,594	174,892
Oil products (Ktoe)	10,840	10,595	12,106

[a] However, final consumption of Coking coal moved from 0 (2000) to 867 kt in 2012.
Source [7].

CIURE—the objective of which was to coordinate the execution of policies and promote RES programs [54].

Nevertheless, the promotion of RES in Colombia, in comparison with the efforts of neighboring countries, lacked an obligatory penetration objective during those years. According to [55]; while Chile, Mexico and Argentina established that unconventional renewable energy sources (other than hydro-electricity) were to cover 10% of the power supply, Colombia had no laws establishing mandatory objectives. We strongly recommend the setting up of mandatory targets to deploy RES in Colombia's energy mix. The presence of RES in Colombia's energy mix continues to be associated with hydropower. As shown in Table 3, until 2012, the only RES other than hydropower in the country's energy mix was wind, which began operations in 2004, although by comparison it represented 0.001% of the mix.

Consequently, the change in the value of the penetration effect (C_{repe}) at the end of the period analyzed is attributable to new hydro-electrical power plants that began production operations.[1]

Tax incentives oriented toward attaining decoupling constituted a second milestone. As of 2003, fiscal incentives were established for industrial investments concerned with reducing polluting emissions. These fiscal incentives were introduced in Value Added Tax and in personal income tax as well as business taxes. These incentives sought to attain a compatibility between economic growth and air quality. In other words, decoupling between economic growth and polluting emissions. It could be said that this is the first time that the Colombian authorities have pointed out the need to decouple CO_2 emissions and economic growth. In light of our major findings we recommend the insertion of tax benefits into Colombia's programs for energy efficiency improvements for those companies that prove reductions in their energy intensity ratios.

Also, in 2003, the 2003–2006 Strategic Plan for the Transportation Sector was implemented. Several cities in Colombia began to develop plans to improve collective transportation and the bicycle use [56].

The latest milestone at the beginning of the road towards a low-carbon economy was CONPES 3344, approved in 2005 [65]. This included measures against CO_2 emissions such as the usage of natural gas in vehicles and biodiesel. Specifically, in the case of fossil fuels, awareness has been seen among the Colombian authorities in the use of cleaner fuel. On the one hand, in 2000, these authorities already limited the emissions of suspended particles for diesel vehicles[2] [57]. Then again, the firm ECOPETROL, one of Colombia's main operators national deposits [58]; n.d.), entered, in 2011, the Dow Jones Sustainability Index [59]. When it comes to the third milestone, there has been a process to substitute coal for natural gas. This change has decreased CO_2 emissions for that period. The C_{ffse} value captures the substitution effect in Colombia's fossil fuel mix. This change is backed by IEA statistics (2015) which, for the period 2000–2012, show a decreased use of coal. This, for the most part, has been substituted for natural gas, while the use of petroleum products has remained relatively stable (with only an 11.6% growth between the beginning and the end of the period). Table 4 offers detailed information. Acting on the transportation sector, we are convinced that there is room for policy measures to promote the use of Flexible Fuels Vehicles and Electrical Vehicles in Colombia.

Based on this data, we can observe that the results of the factorial decomposition for the 2000–2012 period show that there is an increase in CO_2 emissions (14%), although this has been induced by the effect of population and per capita income. These have been compensated, in part, by the effects of carbonization, substitution, penetration and energy intensity.

6. Conclusions

Low levels of energy consumption and a high share of clean electricity production explains that Colombia comprises a small share of Latin America's GHG emissions. Consequently, based on the principle of common but differentiated responsibilities in the fight against climate change that inspires international agreements, it would be Colombia's task to undertake a major mitigating effort. Notwithstanding, its elevated economic growth rate since the onset of the 21st century makes Colombia's economy one of the most important of Latin America, in which case, its contribution to the battle against climate change must be more active. In the light of the results obtained for the 1990–2012 period, Colombia's political orientation toward decoupling between CO2 emission and economic growth are correct. However, efforts on decoupling were not at all effective.

Decomposition analysis, in addition to being a powerful explanatory tool, offers valuable assistance in assessing drivers of CO_2 emissions changes. The results obtained from LMDI analysis provide useful policy guidance for the Colombian authorities. The change in the value of C_{emc} suggests that an environmental law that prohibits the use of heavy crude oil with elevated sulfur contents has been successful, to a certain degree, in reducing CO_2 emissions. The recommendation must be to continue designing measures that improve the standard quality of the fuel used in transportation. This more demanding legislation would have a major impact on the air quality of the cities that are the main source of emissions. This result would also be aided by reforms in ownership tax that progressively establishes a levy on older vehicles. The reform would be enhanced by financial investments to renovate the car fleet.

The change in C_{ffse} recommends continuing to support the use of natural gas in a double sense. On the one hand, there is the need to improve natural gas storage and distribution infrastructures; on the other, the use of natural gas for residential use in cooking needs to be promoted to substitute biomass, which is highly contaminant and detrimental for heath.

The penetration plans for non-conventional RES in Colombia is more focused on promoting mini-hydraulic plants (around 10 MW). This is to be expected in a country with important hydraulic

[1] As of the year 2000, four generation groups of the firm Urrá I entered into production. Another example was the production of La Vuelta Plant with an 11.8 MW capacity in 2004. These data lead us to conclude that despite efforts, the future of renewable energy in Colombia continues to depend upon hydroelectricity, as the construction of a transmission line with Panama is underway, which will connect Colombia with Central America.

[2] It must be underlined that improvements have been made in the quality of the crude oil used in Colombia during this latter period. The world liquid hydrocarbon market classifies crude oil based on density. Crude oil quality is inversely related to its degree of sulfur. The lesser the sulfur, the sweeter the crude, and the higher its API degree. The American Petroleum Institute gravity, or API gravity, is a measure of how heavy or light a petroleum liquid is compared to water: if its API gravity is greater than 10, it is lighter and floats on water; if less than 10, it is heavier and sinks. The production of crude oil in Colombia varies in quality and quantity.

resources. Nevertheless, the risk of occasional drought recommends public support of other, non-conventional RES technologies that do not depend upon rainfall. In line with the above, such weather phenomenon as "La Niña" and droughts could cause the electricity generated by the hydro-electrical plants to be insufficient to cover the demand, which would increase together with economic growth. The best options are wind and solar power.

Colombia must continue to move along the road of improved energy efficiency. This pathway includes measures for pricing carbon (tradable allowances and tax carbon measures) that could improve energy-saving behaviors. The results allow us to conclude that the efficiency and energy savings policies prove to be effective and should focus upon three sectors: industrial, transportation and residential sectors. Within the industrial sector, mining needs special attention, as it greatly contributes to Colombia's economic growth.

Regarding the effect of income as one of the usual drivers of CO_2, this might receive greater attention from Colombia's authorities. Two types of measures have revealed themselves to be the most effective: the first is to enhance the energy efficiency labeling of appliances [64]. This is an inexpensive measure for authorities, and easy for consumers to understand. A second measure is to support a publicly funded program to substitute old, energy intense appliances in favor of new, more efficient models. In this sense, measures such as labeling of appliances based on their level of efficiency or energy consumption have proven to be effective.

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Annex A

The effects of the multiplicative LMDI-I analysis are calculated as follows:

$$D_{emc} = \exp\left(\sum_i w_i \cdot \ln\left(\frac{CF^T}{CF^0}\right)\right) \quad (1.A)$$

$$D_{ffse} = \exp\left(\sum_i w_i \cdot \ln\left(\frac{F^T}{F^0}\right)\right) \quad (2.A)$$

$$D_{repe} = \exp\left(\sum_i w_i \cdot \ln\left(\frac{ER^T}{ER^0}\right)\right) \quad (3.A)$$

$$D_{\text{int}} = \exp\left(\sum_i w_i \cdot \ln\left(\frac{I^T}{I^0}\right)\right) \quad (4.A)$$

$$D_{ypc} = \exp\left(\sum_i w_i \cdot \ln\left(\frac{Q^T}{Q^0}\right)\right) \quad (5.A)$$

$$D_{pop} = \exp\left(\sum_i w_i \cdot \ln\left(\frac{P^T}{P^0}\right)\right) \quad (6.A)$$

$$w_i = \frac{L\left(C_i^0, C_i^T\right)}{L\left(C^0, C^T\right)} = \frac{\frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0}}{\frac{C^T - C^0}{\ln C^T - \ln C^0}} \quad (7.A)$$

The effects of the additive LMDI-I analysis are calculated as follows:

$$\Delta C_{emc} = \sum_i w_i \cdot \ln\left(\frac{CF^T}{CF^0}\right) \quad (8.A)$$

$$\Delta C_{ffse} = \sum_i w_i \cdot \ln\left(\frac{F^T}{F^0}\right) \quad (9.A)$$

$$\Delta C_{repe} = \sum_i w_i \cdot \ln\left(\frac{ER^T}{ER^0}\right) \quad (10.A)$$

$$\Delta C_{\text{int}} = \sum_i w_i \cdot \ln\left(\frac{I^T}{I^0}\right) \quad (11.A)$$

$$\Delta C_{ypc} = \sum_i w_i \cdot \ln\left(\frac{Q^T}{Q^0}\right) \quad (12.A)$$

$$\Delta C_{pop} = \sum_i w_i \cdot \ln\left(\frac{P^T}{P^0}\right) \quad (13.A)$$

$$\text{The weight being: } w_i = L\left(C_i^0, C_i^T\right) = \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \quad (14.A)$$

Table 1.A
Accumulated values of multiplicative chain-linked LMDI decomposition analysis of CO_2 emissions in Colombia (1990–2012).

	D_{tot}	D_{emc}	D_{ffse}	D_{repe}	D_{int}	D_{ypc}	D_{pop}
1990–1991	1.0388	1.0124	1.0025	1.0125	0.9884	1.0032	1.0195
1990–1992	1.0833	0.9902	1.0069	1.0508	0.9625	1.0339	1.0391
1990–1993	1.2045	1.0570	1.0091	1.0442	0.9836	1.0387	1.0586
1990–1994	1.2138	1.0509	1.0047	1.0267	0.9622	1.0793	1.0783
1990–1995	1.2635	1.0716	1.0032	1.0315	0.9306	1.1149	1.0980
1990–1996	1.2819	1.0680	0.9918	1.0373	0.9342	1.1174	1.1177
1990–1997	1.3677	1.0952	0.9801	1.1254	0.8765	1.1354	1.1376
1990–1998	1.3902	1.0440	0.9803	1.1461	0.9127	1.1220	1.1574
1990–1999	1.2276	1.0970	0.9675	1.0908	0.8524	1.0568	1.1772
1990–2000	1.2801	1.1062	0.9630	1.1278	0.8200	1.0852	1.1974
1990–2001	1.2838	1.1007	0.9663	1.1375	0.8034	1.0853	1.2170
1990–2002	1.2377	1.1177	0.9573	1.1118	0.7686	1.0947	1.2365
1990–2003	1.2228	1.0846	0.9672	1.0975	0.7551	1.1197	1.2562
1990–2004	1.2274	1.0783	0.9548	1.1112	0.7251	1.1606	1.2749
1990–2005	1.2558	1.0349	0.9645	1.1260	0.7212	1.1967	1.2947
1990–2006	1.2577	0.9999	0.9597	1.1164	0.7108	1.2571	1.3139
1990–2007	1.2637	1.0272	0.9553	1.1037	0.6608	1.3238	1.3338
1990–2008	1.2824	0.9763	0.9675	1.1119	0.6685	1.3502	1.3527
1990–2009	1.3165	0.9421	0.9636	1.1461	0.6818	1.3527	1.3718
1990–2010	1.3360	0.9459	0.9639	1.1405	0.6673	1.3856	1.3897
1990–2011	1.4682	1.0498	0.9668	1.1229	0.6258	1.4594	1.4106
1990–2012	1.4569	1.0424	0.9592	1.1203	0.6084	1.4980	1.4269

Source: Own elaboration.

Table 2.A
Inter-annual chain-linked additive LMDI-I effects of CO2 emissions changes in Colombia in million tonnes of CO_2 between 1990 and 2012.

	Δ C	ΔC emc	ΔC ffse	ΔC repe	ΔC int	ΔC ypc	ΔC pop
1990–1991	0.0239	0.0123	0.0025	0.0124	−0.0117	0.0032	0.0193
1991–1992	0.0620	−0.0220	0.0041	0.0372	−0.0265	0.0301	0.0190
1992–1993	0.0438	0.0654	0.0021	−0.0064	0.0216	0.0047	0.0187
1993–1994	0.0192	−0.0059	−0.0042	−0.0169	−0.0220	0.0383	0.0184
1994–1995	0.0229	0.0197	−0.0017	0.0047	−0.0334	0.0325	0.0182
1995–1996	0.0377	−0.0057	−0.0095	0.0056	0.0037	0.0024	0.0179
1996–1997	0.0592	0.0246	−0.0113	0.0816	−0.0639	0.0160	0.0177
1997–1998	0.0699	−0.0447	−0.0035	0.0184	0.0405	−0.0118	0.0174
1998–1999	−0.1520	0.0441	−0.0073	−0.0495	−0.0688	−0.0601	0.0171
1999–2000	0.0435	0.0051	−0.0012	0.0332	−0.0384	0.0264	0.0168
2000–2001	0.0093	−0.0025	0.0008	0.0087	−0.0208	0.0002	0.0164
2001–2002	−0.0400	0.0137	−0.0077	−0.0228	−0.0445	0.0087	0.0161
2002–2003	0.0111	−0.0275	0.0077	−0.0131	−0.0176	0.0226	0.0158
2003–2004	0.0329	−0.0066	−0.0126	0.0127	−0.0417	0.0364	0.0155
2004–2005	0.0596	−0.0375	0.0063	0.0132	−0.0051	0.0307	0.0153
2005–2006	0.0485	−0.0354	−0.0044	−0.0085	−0.0151	0.0497	0.0151
2006–2007	−0.0165	0.0235	−0.0010	−0.0116	−0.0730	0.0519	0.0149
2007–2008	0.0626	−0.0436	0.0047	0.0076	0.0110	0.0202	0.0146
2008–2009	0.0784	−0.0404	0.0002	0.0305	0.0196	0.0021	0.0143
2009–2010	0.0249	0.0044	−0.0012	−0.0046	−0.0228	0.0250	0.0139
2010–2011	0.0018	0.1015	0.0075	−0.0162	−0.0627	0.0507	0.0135
2011–2012	0.0173	−0.0100	−0.0067	−0.0018	−0.0305	0.0281	0.0132
1990–2012	0.4813	0.0416	−0.0416	0.1136	−0.4969	0.4041	0.3555

Source: Own elaboration.

References

[1] United Nations, Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1998.
[2] Joint Center Research, Emission Database for Global Atmospheric Research (EDGAR) Release Version 4.1, 2010.
[3] UPME, Sistema de información Minero-energético colombiano Retrieved from UPME, 2015. www.simec.gov.co (Accessed September, 2015).
[4] Colombian Parlament, Act 629 of 2000. Diario Oficial, 44,272 Published December 27 th 2000, 2000. Available at: http://www.sinchi.org.co/index.php?option=com_content&view=article&id=40&Itemid=2156 (Accesed September 2015).
[5] CONPES 3242, Estrategia institucional para la venta de servicios ambientales de mitigación del cambio climático, Departamento Nacional de Planeación, 2003. Available at: https://www.minambiente.gov.co/images/normativa/conpes/2003/Conpes_3242_2003.pdf (Last accessed July 2015).
[6] Organisation for Economic Co-operation and Development (OECD), Estudios económicos de la OCDE, Colombia evaluación económica, Available at:, 2013 http://www.oecd.org/eco/surveys/Colombia_Overview_ESP%20NEW.pdf (Last Accessed April 2015).
[7] IEA. International Energy Agency, Key Statistics for Countries, 2015. http://www.iea.org/countries/non-membercountries/colombia/ (Accessed December 2015).
[8] B.J. Ruiz, V. Rodríguez, Renewable energy sources in the Colombian energy policy, analysis and perspectives, Energy Policy 34 (2006) 3684–3690.
[9] D.A. Alonso, M.P. Vides, M. Londoño, Amenazas y Riesgos Ambientales en las Zonas Costeras Colombianas, Medellín, in: G.H. Ospina-Salazar, A. Acero (Eds.), INVEMAR, Informe del Estado de los Ambientes Marinos y Costeros en Colombia, fourth ed. vol. 2002, 2001, p. 178 (Serie de Publicaciones Periódicas/INVEMAR; No. 8).
[10] R.R. Torres-Parra, J.C. Gómez-López, F. Afanador-Franco, Variación del nivel medio del mar en el Caribe colombiano, Bol. Científico CIOH 24 (2006) 64–74.
[11] S. Calderón, A.C. Álvarez, A.M. Loboguerrero, S. Arango, K. Calvin, T. Kober, K. Daenzer, K. Fisher-Vanden, Achieving CO2 reductions in Colombia: effects of carbon taxes and abatement targets, Energy Econ. (2015), https://doi.org/10.1016/j.eneco.2015.05.010.
[12] R. Delgado, Cadena Monroy, A.I. Espinosa, C. Peña, M. Salazar, A case study on Colombian mitigation actions, Clim. Dev. 6 (2014a) 12–24. Special Issue on mitigation actions in five developing countries - Supplement 1.
[13] R. Delgado, C. Matajira, C. Álvarez, A.I. Cadena Monroy, S. Calderón, Modeling the Implications of Socio-economic of Mitigation Actions in Colombia. Part 2 – Results and Findings. Working Paper for CDKN Project on Linking Sectoral and Economy-wide Models, Energy Strategic Research Centre, Universidad de los Andes, Bogotá, Colombia, 2014b. Available at: www.erc.uct.ac.za.
[14] Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), Visión general del inventario nacional de emisiones de gases de efecto invernadero, 2009. Available at: http://www.cambioclimatico.gov.co/documents/40860/214237/capitulo1.pdf/dc4d6c8e-5bce-42b5-8ea2-e413ae824735 (Last Accessed August 2015).
[15] Programa de las Naciones Unidas para el Desarrollo (PNUD), Nuevos escenarios de cambio climático, 2011. Available at: http://documentacion.ideam.gov.co/openbiblio/bvirtual/022965/documento_nacional_regional.pdf (Last Accessed September 2015).
[16] Organisation for Economic Co-operation and Development (OECD), Evaluaciones del desempeño ambiental Colombia, 2014. Available at: http://www.oecd.org/env/country-reviews/Evaluacion_y_recomendaciones_Colombia.pdf (Last Accessed May 2015).
[17] IEA. International Energy Agency, CO2 emissions from Fuel Combustion Highlights 2014, 2014. Available at: https://www.iea.org/publications/freepublications/publication/CO2EmissionsFromFuelCombustionHighlights2014.pdf (Accessed May 2015).
[18] T. O'Mahony, Decomposition of Ireland's carbon emissions from 1990 to 2010: an extended Kaya identity, Energy Policy 59 (2013) 573–581.
[19] J.M. Cansino, A. Sánchez-Braza, M.L. Rodríguez-Arévalo, Driving forces of Spain's CO2 emissions: a LMDI decomposition approach, Renew. Sustain. Energy Rev. (2015) 749–759, https://doi.org/10.1016/j.rser.2015.04.011.
[20] K. Jeong, S. Kim, LMDI decomposition analysis of greenhouse gas emissions in the Korean manufacturing sector, Energy Policy 62 (2013) 1245–1253.
[21] C. Ma, D.I. Stern, Biomass and China's carbon emissions: a missing piece of carbon decomposition, Energy Policy 36 (2008) 2517–2526.
[22] S. Ren, H. Yin, X. Chen, Using LMDI to analyze the decoupling of carbon dioxide emissions by China's manufacturing industry, Environ. Dev. 9 (2014) 61–75.
[23] W.W. Wang, M. Zhang, M. Zhou, Using LMDI method to analyze transport sector CO_2 emissions in China, Energy 36 (2011) 5909–5915.
[24] R. Li, R. Jiang, Moving low-carbon construction industry in jiangsu province: evidence from decomposition and decoupling models, Sustainability 9 (6) (2017) 1013, https://doi.org/10.3390/su9061013.
[25] X.-T. Jiang, R. Li, Decoupling and decomposition analysis of carbon emissions from electric output in the United States, Sustainability 9 (6) (2017) 886, https://doi.org/10.3390/su9060886.
[26] X.-T. Jiang, J.—T. Dong, X.-M. Wang, R.-R. Li, The multilevel index decomposition of energy-related carbon emission and its decoupling with economic growth in USA, Sustainability 8 (9) (2016) 857, https://doi.org/10.3390/su8090857.
[27] L.C. Freitas, S. Kaneko, Decomposition of CO2 emissions change from energy consumption in Brazil: challenges and policy implications, Energy Policy 70 (2011) 1495–1504.
[28] C. Sheinbaum, B.J. Ruíz, L. Ozawa, Energy consumption and related CO2 emissions in five Latin American countries: changes from 1990 to 2006 and perspectives, Energy 36 (2011) 3629–3638.
[29] G.R. Timilsina, A. Shrestha, Factors affecting transport sector CO_2 emissions growth in Latin American and Caribbean countries: an LMDI decomposition analysis, Int. J. Energy Res. 33 (4) (2009) 396–414.
[30] R. Hoekstra, J. Van den Bergh, Comparing structural and index decomposition analysis, Energy Econ. 25 (1) (2003) 39–64.
[31] B. Su, B.W. Ang, Structural decomposition analysis applied to energy and emissions: some methodological developments, Energy Econ. 34 (2012) 177–188.
[32] B.W. Ang, K.H. Choi, Decomposition of aggregate energy and gas emission intensities for industry: a refined Divisia index method, Energy J. 18 (3) (1997) 59–73.

[33] B.W. Ang, F.Q. Zhang, K.H. Choi, Factorizing changes in energy and environmental indicators through decomposition, Energy 23 (6) (1998) 489–495.
[34] B.W. Ang, F.L. Liu, A new energy decomposition method: perfect in decomposition and consistent in aggregation, Energy 26 (6) (2001) 537–548.
[35] B.W. Ang, Decomposition analysis for policymaking in energy: which is the preferred method? Energy Policy 32 (2004) 1131–1139.
[36] B.W. Ang, N. Liu, Negative-value problems of the logarithmic mean Divisia index decomposition approach, Energy Policy 35 (1) (2007a) 739–742.
[37] B. Commoner, M. Corr, P. Stamler, The Closing Circle: Nature, Man, and Technology, Knopf, New York, 1971.
[38] R. York, E. Rosa, T. Dietz, Bridging environmental science with environmental policy: plasticity of population, affluence, and technology, Soc. Sci. Q. 83 (1) (2002) 18–34.
[39] Y. Kaya, Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios, Paris talk, 1990.
[40] Y. Kaya, Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios, IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris, 1989.
[41] B. Metz, O. Davidson, P. Bosch, R. Dave, L. Meyer, Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, New York, 2007.
[42] K. Yamaji, R. Matsuhashi, Y. Nagata, Y. Kaya, An integrated system for CO2/energy/GNP analysis: case studies on economic measures for CO_2 reduction in Japan, in: Presented at the Workshop on CO_2 Reduction and Removal: Measures for the Next Century, Austria: International Institute for Applied Systems Analysis, Laxenburg, 1991.
[43] W. Leontief, D. Ford, Air pollution and the economic structure: empirical result of input-output computations, in: A. Brody, A.P. Carter (Eds.), Input-output Techniques: 9–30, North-Holland Publishing Company, Amsterdam-London, 1972.
[44] A. Rose, S. Casler, Input-output structural decomposition analysis: a critical appraisal, Econ. Syst. Res. 8 (1) (1996) 33–62.
[45] B.W. Ang, N. Liu, Energy decomposition analysis: IEA model versus other methods, Energy Policy 35 (2007b) 1426–1432.
[46] Universidad Nacional de Colombia, Agencia de Noticias, 2014. http://www.agenciadenoticias.unal.edu.co/ndetalle/article/energia-nuclear-una-puerta-que-colombia-no-puede-cerrar.html (Accessed, September 2015).
[47] W. Wang, X. Liu, M. Zhang, X. Song, Using a new generalized LMDI (logarithmic mean Divisia index) method to analyze China's energy consumption, Energy 67 (2014) 617–622.
[48] L. Wu, W. Zeng, Research on the contribution of structure adjustment on carbon dioxide emissions reduction based on LMDI method, Procedia Comput. Sci. 17 (2013) 744–751.
[49] J. Schleich, W. Eichhammer, U. Boede, F. Gagelmann, E. Jochem, B. Schlomann, H.J. Ziesing, Greenhouse gas reductions in Germany – lucky strike or hard work? Clim. Policy 1 (2001) 363–380.
[50] S. Kalmanovitz, Recesión y recuperación de la economía colombiana, Nueva Soc. 192 (2004) 99–116.
[51] UNFCCC, Copenhagen Accord, 2009. http://unfccc.int/meetings/copenhagen_dec_2009/items/5262.php (Accessed December 2015).
[52] CONPES 3344, Lineamientos para la formulación de la política de prevención y control de la contaminación del aire, Departamento Nacional de Planeación, 2005. Available at: https://www.minambiente.gov.co/images/normativa/conpes/2005/Conpes_3344_2005.pdf (Last accessed, August 2015).
[53] CONPES 3700, Estrategia institucional para la articulación de políticas y acciones en material de cambio climático en Colombia, Departamento Nacional de Planeación, 2011. Available at: http://oab.ambientebogota.gov.co/es/documentacion-e-investigaciones/resultado-busqueda/conpes-3700-estrategia-institucional-para-la-articulacion-de-poli-ticas-y-acciones-en-materia-de-cambio-climatico-en (Accessed September 2015).
[54] Ministerio de Minas y Energía (MinMinas), Mecanismos e instrumentos financieros para proyectos de eficiencia energética en Colombia, 2011. Available at: http://www.si3ea.gov.co/LinkClick.aspx?fileticket=8%2BgUyAt%2BRXA%3D&tabid=90&mid=449&language=es-CO (Last Accessed May 2015).
[55] J. Benavides, Retos y oportunidades de las energías renovables en Colombia, Available at: Obs. energía Renov. América Lat. el Caribe (2011) http://www.renenergyobservatory.org/uploads/media/Anexo_22._Estudio.Retos_y_Oportunidades.Colombia.pdf (Last Accessed May 2015).
[56] Center for Clean Air Policy, A Vertical NAMA for Sustainable Urban Development, Available at:, 2014 http://www.ccap.org/docs/resources/1116/A%20Vertical%20NAMA%20for%20Sustainable%20Urban%20Development.pdf (Last access, July 2015).
[57] Decreto 1552. https://www.acp.com.co/images/pdf/serviciosinformacion/normatividadvigente/decretosambientales/Emisiones.pdf, 2000.
[58] Open Oil (n.d.). Almanaque del Petróleo en Colombia. Available at http://openoil.net/oil-almanacs/(Accessed September 2015).
[59] Ecopetrol, Por quinto año consecutivo, Ecopetrol hace parte del índice mundial de sostenibilidad del Dow Jones, 2015. http://www.ecopetrol.com.co/wps/portal/es/ecopetrol-web/nuestra-empresa/sala-de-prensa/boletines-de-prensa/Boletines%202015/Boletines%202015/Quinto-periodo-consecutivo-en-indice-mundial-sostenibilidad-Dow-Jones.
[62] Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), Informe del estado del medio ambiente y los recursos naturales renovables, Available at:, 2011 http://documentacion.ideam.gov.co/openbiblio/bvirtual/022649/InformeTomo1.pdf (Last Accessed August 2015).
[64] Ministerio de Minas y Energía (MinMinas), Reglamento Técnico de Etiquetado - RETIQ, para fines de uso racional y eficiente de energía, 2015. http://www.minminas.gov.co/historico-de-eventos?idEvento=8737.
[65] Plan Energético Nacional 2006-2025, Available at: http://www.upme.gov.co/Docs/PLAN_ENERGETICO_NACIONAL_2007.pdf, 2007 (Accessed September 2015).