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Assessing the Impacts of Final Demand on CO_2-eq Emissions in the Mexican Economy: An Input-Output Analysis

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Abstract

The aim of this paper is to analyze the Mexican energy system and its greenhouse gas (GHG) emissions for the year 2012 and to estimate a baseline scenario for 2026 using an input-output analysis. The elasticity of emissions with respect to national demand is calculated in order to identify the total and distributed effects of CO_2 equivalent (CO_2-eq) emissions. In this framework, the analysis evaluates the effects in the economy related to changes in individual sector demands, and, vice versa, the effect on individual sectors due to global changes in national demands. Results show that passenger and freight transport, power generation, iron and steel industry, chemical industry, air transportation and agriculture concentrate the largest potential for mitigation strategies, and also have important distributive effects on the Mexican economy. Results are evaluated under the mitigation strategies of industrial sector proposed by the Fifth Assessment Report of the IPCC.

Keywords

Input-Output, GHG Emissions, Mexico

1. Introduction

Recently, the 21st United Nations Climate Conference (COP21) resulted in a worldwide agreement on climate pointing to the need to contain global temperature rise to under 2˚C, and, if possible under 1.5˚C. In general, the agreement considers a commitment of the parties to decrease emission levels based on their historic, current, and future responsibilities by establishing binding obligations in nationally determined contributions (NDCs), and to pursue domestic measures aimed toward achieving them. In addition, the agreement extended the current goal of mobilizing $100 billion a year in support by 2020 through 2025 with a new higher goal to be set for the period after 2025. In addition, COP21 called for a new mechanism, similar to the Clean Development Mechanism under the Kyoto Protocol, enabling emission reductions in one country to be counted toward another country's NDC [1] [2].

According to Mexico's intended NDC [2], the country has committed to reduce 25% of its greenhouse gases (GHG) and short-lived climate pollutant emissions unconditionally (below "Business as Usual" scenario) by the year 2030. However, Mexico has a General Climate Change Law (GCCL) that establishes an aspirational objective of 30% reduction of emissions by 2020 and 50% by 2050 with respect to the emissions levels in 2000 [3].

There are several methods to evaluate energy consumption and GHG emissions and to identify mitigation opportunities for NDCs. Methods can be divided into bottom-up and top-down. Top-down models evaluate the system from aggregate economic variables, whereas bottom-up models consider technological options or project-specific climate change mitigation policies in a model of energy systems [4].

Input-output analysis is a top-down approach in which the data on production and consumption in all sectors allow a complete allocation of all activities to all products. GHG emissions are the result of economic activity that exists to meet human needs. Economic activity can be defined as all the production processes and the exchanges of goods and services between the productive sectors and the final demand. In that process, there is energy involved and therefore emissions. W. Leontief, a 1973 Nobel Prize winner, proposed input-output analysis [5]. The core of which is a table that shows the flow of goods and services, measured in monetary terms for a given time period, between the productive sectors that compose the economy and the final demand. It is a tool that allows analysis of the economy on a global scale and information of individual sectors at the same time. The main property of this technique is that it encodes the multiplicative effect [6] that comes from economic activity, allowing assessment of both direct and indirect effects.

Literature Review

Recent studies on energy consumption and GHG emissions using input–output analysis include: Alcantara and Padilla who developed input-output subsystems for the service sector in Spain that allowed the decomposition of the CO_2 emissions into five different components: own, demand volume, feedback, internal, and spill-over components [7]; Proops *et al.* [8], who assessed the reduction of CO_2 emissions in a comparative study for Germany and the United Kingdom; Tarancon *et al.* [9], who used an input–output approach combined with a sensitivity analysis to analyze the direct and indirect consumption of electricity by 18 manufacturing sectors in 15 European countries. In addition, Tarancon and del Rio [10] provided a critical overview of sensitivity analyses within input-output techniques applied to energy-related CO_2 emissions. Alcantara *et al.* [11] also analyzed the responsibility of the productive structure of an economic system with respect to the consumption and generation of electricity within an input-output framework.

Also, important studies using input-output models have been developed for China, the largest CO_2 emission country, including three-scale input-output modeling for the urban economy [12]; embodied energy, export policy adjustment, and China's sustainable development: a multiregional input-output analysis [13]; CO_2 emissions of China's food industry [14]; urban carbon transformations: unraveling spatial and intersectorial linkages for key city industries based on multiregional analysis [15]; and China's regional disparities in energy consumption: an input-output analysis [16].

More recently, input-output analysis has been used to estimate embodied emissions in trade. For example, Wiebe *et al.* [17] used input-output matrixes to analyze CO_2 emissions embodied in international trade, covering 48 sectors in 53 countries and 2 regions. Su and Ang [18] analyzed emissions based on competitive and noncompetitive imports. Cortés Borda *et al.* [19] quantified the differences between production-based (territorial) and consumption-based (global) nuclear energy usage in the main 40 economies of the world through the application of a multiregional environmentally extended input-output model. Input-output matrixes are also the basis of the General Equilibrium Models applied for energy and CO_2 emissions [20] [21] that have gained importance for the analysis of climate policy impacts to the economy [22] [23] [24].

In the case of Mexico, there are few analyses based on the input-output analysis related to GHG emissions. For example, Lewis [25] performed an input-output study of carbon dioxide emissions in Mexico linked to trade liberalization and the participation of Mexico in global trade [26]. Because of the lack of such analyses, this paper is novel in developing a top-down model based on input-output analysis for a middle-income country.

In this paper, we use input-output analysis to analyze the Mexican energy system and its GHG emissions for the year 2012 and to estimate a baseline scenario for 2026. The elasticity of emissions with respect to national demand is calculated in order to identify the total and distributed effects of CO_2-eq emissions. In this framework, the analysis also evaluates the effects in the economy related to changes in individual sector demands and, vice versa, the effect on individual sectors due to global changes in national demands.

This paper is divided into four sections: Section 1 is the introduction, Section 2 presents the methodological framework as well as a brief description of the data used, Section 3 presents a discussion of the results, and Section 4 offers some conclusions.

2. Methodological Framework and Data Sources

According to input-output methodology, the economy can be decomposed on n sectors that produce and exchange goods or services. The bigger the number of sectors n, the more accurate and precise the model of the economy is. The input-output basic equation, also known as the Leontief equation is the following:

$$\overline{x} = \boldsymbol{L}\overline{f} \tag{1}$$

where $\overline{x}$ is the total sectorial production, which is the sum of final demand and consumption among all sectors of economy, $\overline{f}$ is the final sectorial demand, and $\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-1}$ is the Leontief matrix, where $\boldsymbol{I}$ is the identity matrix and A is formed by a_{ij} that denotes the amount of product from sector i that is needed to produce one unit of product by sector j in monetary terms.

In order to estimate emissions, let n be the sectors of economy and K the number of different fossil fuel sources. Every sector is represented by $1 \times K$ vector $\overline{\boldsymbol{\Phi}_i}$ and $\overline{\boldsymbol{\Phi}_{ik}}$ represents the amount of fuel k that sector i uses in one year. Let E_k^T be the emission factor of fuel k and technology T. Then $\mathbb{C}$ is the total carbon dioxide emissions (CO_2-eq) of the economy related to fossil fuel combustion:

$$\mathbb{C} = \sum_{i=1}^{n} C_i = \Phi \overline{E} \tag{2}$$

Let γ_i be the emission intensity, defined as the quantity of CO_2-eq per unit of output of sector i. The vector $\overline{\gamma}$ is then the sectorial emission intensity formed by all γ_i (from $i = 1, \cdots, n$). CO_2-eq emissions of sector i will be the multiplication of the emission intensity of sector i by the activity of sector i: $C_i = \gamma_i x_i$. But substituting x_i from Equation (1):

$$C_i = \gamma_i \sum_{j=1}^{n} L_{ij} f_i \tag{3}$$

For the objective of this paper, the change in sectorial emissions due to the changes in final demand is then:

$$\Delta C_i = \gamma_i \sum_{j=1}^{n} L_{ij} \Delta f_i \tag{4}$$

Let us define the elasticity of total CO_2-eq emissions ($\mathbb{C}$) due to changes in final demand of sector j as [7].

$$\boldsymbol{\psi} = \frac{\frac{\Delta \mathbb{C}}{\mathbb{C}}}{\frac{\Delta f_j}{f_j}} \tag{5}$$

From this point we can define a new variable: $s_j = \frac{f_j}{x_j}$ that takes into account the part j of total production that goes directly to final demand. This allows distinguishing between sectors whose production is mainly for satisfying final demand and those whose production is used as inputs by other sectors, therefore:

$$\boldsymbol{\psi} = \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{C_i}{\mathbb{C}} l_{ij} \frac{x_j}{x_i} s_j \tag{6}$$

But considering (1), (6) can be expressed as the multiplication of two matrixes:

$$\boldsymbol{\psi} = \overline{c}\hat{x}^{-1} \boldsymbol{L} \hat{x} \overline{s} \tag{7}$$

This matrix expression gives us the total emission variation of the economy due to a unitary change in final demand of all n sectors. To extract from here the emission variation of sector *i*, due to a change in final demand of sector *j*, we have to remove the sums from expression (6). Let $\hat{c}$ be the diagonal matrix of vector $\bar{c}$ and also

$$\left(1-\boldsymbol{D}\right)^{-1} = \bar{x}'^{-1}\boldsymbol{L}x' \tag{8}$$

Then, the elasticity can be written as:

$$\boldsymbol{\psi} = \hat{c}\left(1-\boldsymbol{D}\right)^{-1}\hat{s} \tag{9}$$

And for *ij*

$$\psi_{ij}^{f} = c_i l_{ij}\frac{x_j}{x_i}s_j \tag{10}$$

The element ψ_{ij}^{f} represents the percentage of increase in CO_2-eq emissions of sectors *i* in response to a 1% increase in final demand of sector *j*. For example, if sector *i* is agriculture and sector *j* is food industry, then ψ_{ij}^{f} would express the percentage of increase in CO_2-eq emissions of agriculture in response to a 1% increase in final demand of the food industry. The matrix modifies the multipliers contained on Leontief's matrix using emission intensities (emissions per monetary unit produced) that referred to the proportion of the total greenhouse gases emitted. Considering the definition of the elements ψ_{ij}^{f}, if we construct a column vector whose elements represent a percentage of increase on sectorial final demand, and multiply them by the matrix $\boldsymbol{\psi}^{f}$, then the result must be the sectorial percentage of increase in CO_2-eq emissions in response to changes of all final demands:

$$\bar{\Delta} := \frac{\Delta\bar{f}}{f}\begin{pmatrix} \dfrac{f_1^1 - f_1^0}{f_1^0} \\ \vdots \\ \dfrac{f_n^1 - f_n^0}{f_n^o} \end{pmatrix} \tag{11}$$

where the 0 super index indicates the final demand in year 0, and 1 indicates the final demand at the end of an arbitrary time period. Let vector $\bar{\boldsymbol{\Delta}}$ be multiplied by matrix $\boldsymbol{\psi}^{f}$ then:

$$\boldsymbol{\psi}^{f}\bar{\Delta} := \frac{\Delta\bar{f}}{f}\begin{pmatrix} \sum_{j=1}^{n}\psi_{1f}^{j}\Delta_1 \\ \vdots \\ \sum_{j=1}^{n}\psi_{1n}^{f}\Delta_n \end{pmatrix} = \overline{\Delta\psi} \tag{12}$$

where Δ_i is the *i*-th element of vector $\bar{\boldsymbol{\Delta}}$. The vector $\boldsymbol{\Delta\psi}$ represents the percentage of increase in CO_2-eq emissions in response to changes in the final demand of all sectors, assuming that the structure of the economy and emission intensity will remain constant. Equation (12) allows calculating base scenarios considering the variation in final demand.

2.2. Total, Distributive, and Structural Effects

From Equation (9), it is possible to analyze different effects that final demand has on emissions levels. The Total Effect (TE) is the sum over *i* (columns of the matrix), and represents the change in emissions for all the economy due to a unitary change in final demand of sector *j*. The Distributive Effect (DE) is the sum over *j* (rows of the matrix) and represents the change in emissions for all the economy due to a unitary change in each of the *j* sectors.

In addition, it is possible to separate each effect into two components [27]: Own Sector Effects (OE) that result from the changes in the final demand of each Own Sector (the diagonal elements of matrix $\Delta\psi$), and Structure Effects (SE) that result from the changes in other sectors of the economy.

2.3. Data Sources

The input-output model constructed in this work comes from a combination of two different databases available in Mexico, in addition to the IPCC emission factors [28]. These are the 2012 input-output matrixes provided by the National Institute of Statistics and Geography (INEGI) [29] with three different levels of sectorial disaggregation (*i.e.*, 19 sectors, 70 subsectors, and 262 branches) and the 2012 National Energy Balance (NEB) [30] with a sectorial disaggregation of 17 producing sectors in addition to the agricultural sector, commercial sector, and transport sector, which subdivides itself into 4 sectors. In total, the NEB provides 26 different sectors. In order to match energy sectors from NEB and economy sectors from the input-output matrix, some sectors were summed up either in energy or I-O matrixes (**Table 1**). CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions are considered. The CO_2-eq for CH_4 and N_2O, are 21 and 298 respectively.

2.4. Final Demand Projection for Year 2026

Final demand is projected to 2026 using Equation (13). The annual rate of growth was projected from 2003 to 2014 to 2026 (3.5% per year). Fuel structure, economy structure, and CO_2-eq intensity are considered constant.

3. Results and Analysis

Table 2 presents CO_2-eq emissions related to Mexican energy consumption and production in 2012 and estimations of a baseline scenario for 2026, as well as the variation in percentage. Changes in final demand carry a total emission increase of 3.4%.

The total CO_2-eq emissions impact matrix was calculated according to Equation (10) and is presented in **Table A1**. **Table 3** presents the TE, and **Table 4** the DE, both for 2012. The diagonal elements of both of **Table 3** and **Table 4** are the percentages of OE in TE and DE, respectively. A large TE (final column of **Table 3**) means that the sector's final demand has a high influence on total emissions, whereas a large DE (final column of **Table 4**) means that an overall change in final demand has a large influence on emissions from the specific sector. For example, a 1% increase in final demand of the coal mining sector would lead to a 0.07% increase of total CO_2-eq emissions (**Table 3**, row 1, final column), whereas

Table 1. Sectors for input-output analysis: sector code.

Sector code	Sector name
1	Coal mining
2	Gas and petroleum extraction
3	Petroleum processing and coking, gas production
4	Electric power generation
5	Agriculture: farming, forestry, animal, husbandry, and fishery
6	Air transport
7	Rail transport
8	Water transport
9	Freight and passenger road transport
10	Petro chemistry
11	Iron and steel basic products
12	Chemical fibers and resins, pharmaceutical products, paintings and adhesives, soaps and cleaners, plastic products, and other chemical products
13	Cane and beet sugar production, chocolates, and candies
14	Cement production and concrete products
15	Ferrous and non-ferrous mining, related mining services
16	Cellulose, paper, and cardboard manufacturing
17	Glass and glass products
18	Carbonated and noncarbonated sweet brewages, water purification, ice production, and beer and distillates manufacturing
19	Fertilizers, pesticides, and agrochemical
20	Car and truck manufacturing
21	Construction
22	Tire and rubber product manufacturing
23	Basic aluminum products
24	Tobacco product manufacturing
25	Wholesale, retail trade, hotels, restaurants
26	Other sectors

when there is a 1% increase of the final demand of all sectors, the emissions of coal mining would increase 0.16% with respect to the previous total emissions (Table 4, row 1, final column). The largest emissions come from the road transport sector. Therefore, a 1% increase in final demand of this sector would lead to a 333% increase of total CO_2-eq emissions (Table 3, row 9, final column), and a 1% increase of the final demand of all sectors will represent an increase of 367% with respect to the previous total emissions (Table 4, row 9, final column).

Figure 1 presents the sectorial relation between DE vs. TE known as the Rasmussen [31] classification discussed in [27] [31] that expresses the degree in which one industry output is used by other industries as an input. In this case, this grouping is based on the comparison of the median values of the sectorial DE and TE in a logarithmic scale. Table 5 shows the meaning of each region.

Table 2. Baseline scenario.

Sector code	Variation of final energy demand 2012-2016 (%)	Variation of emissions 2012-2026 (%)	Emissions 2012 (Tg CO_2-eq)	Share of total emissions	Emissions 2026 (Tg CO_2-eq)	Position in Figure 1
1	−31.25%	0.00%	0.07	0.02%	0.07	VI
2	−2.00%	0.26%	15.18	3.71%	15.22	II
3	7.42%	0.31%	8.39	2.05%	8.41	II
4	−4.52%	6.41%	142.71	34.84%	151.85	II
5	11.40%	0.64%	8.97	2.19%	9.02	II
6	11.14%	0.51%	8.72	2.13%	8.76	II
7	0.00%	0.02%	1.95	0.48%	1.95	IV
8	12.01%	0.09%	2.46	0.60%	2.46	IV
9	3.36%	2.60%	150.38	36.71%	154.28	II
10	−1.31%	0.00%	0.06	0.01%	0.06	IV
11	35.99%	1.03%	13.28	3.24%	13.41	II
12	6.78%	0.16%	4.09	1.00%	4.1	II
13	1.29%	0.07%	3.95	0.96%	3.95	III
14	4.90%	0.07%	9.93	2.43%	9.94	III
15	8.14%	0.11%	1.81	0.44%	1.81	IV
16	18.88%	0.20%	1.98	0.48%	1.98	IV
17	4.71%	0.08%	2.69	0.66%	2.69	IV
18	4.50%	0.04%	3.19	0.78%	3.19	II
19	−4.92%	0.00%	0.04	0.01%	0.04	IV
20	13.48%	0.01%	0.32	0.08%	0.32	I
21	0.03%	0.00%	0.85	0.21%	0.85	I
22	9.14%	0.02%	0.43	0.11%	0.43	Iv
23	−14.47%	0.00%	0.05	0.01%	0.05	IV
24	−13.90%	0.00%	0.02	0.00%	0.02	IV
25	4.15%	0.12%	4.43	1.08%	4.43	II
26	52.58%	2.77%	23.73	5.79%	24.39	II
Total	3.43%	409.66	423.7	100.00%	423.68	

A large discussion of Rasmussen method is developed in [27]. It corresponds to a Classical Multiplier Method [32] [33]. Although there are new developments in the methods developed to analyze interlinkages among industrial sectors, this method is very useful in identifying total and distribution effects, particularly in the analysis of the economic impacts of GHG mitigation [34] [35] [36].

The sectors located in region I of Figure 1 are the construction and automotive sectors. These sectors use inputs of other productive processes, that is to say their consumption is influenced by the demand of other sectors. Consequently, mitigation policies that could affect the magnitude of their production might generate problems in their economic activity. In addition, changes in automotive industries' (automotive production) final demand have a small influence on total

Table 3. Total effect (TE) among all sectors of the economy (%).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	TE (10^3)
1	16.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0.07**
2	2.0	89.0	42.0	-	1.0	3.0	3.0	-	1.0	38.0	-	2.0	1.0	1.0	1.0	1.0	1.0	1.0	5.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	**19.30**
3	2.0	1.0	48.0	-	1.0	3.0	3.0	-	1.0	2.0	-	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	**15.60**
4	69.0	7.0	5.0	98.0	20.0	2.0	4.0	2.0	2.0	34.0	12.0	36.0	5.0	14.0	48.0	38.0	21.0	28.0	50.0	33.0	26.0	39.0	45.0	19.0	73.0	49.0	**131.00**
5	-	-	-	-	66.0	-	-	-	-		-	-	9.0	-	-	-	-	2.0	-	1.0	1.0	4.0	-	7.0	1.0	4.0	**14.60**
6	1.0	-	-	-	-	90.0	-	-	-	1.0	-	1.0	-	-	1.0	-	-	1.0	1.0	3.0	1.0	1.0	2.0	4.0	1.0	3.0	**14.30**
7	-	-	-	-	-	-	85.0	-	-		-	-	-	-	-	-	-	-	1.0	1.0	-	-	-	-	-	-	**4.65**
8	-	-	-	-	-	-		97.0	-	1.0	-	-	-	-	-	-	-	-	2.0	1.0	-	-	-	-	-	-	**4.80**
9	5.0	3.0	4.0	1.0	6.0	2.0	2.0		95.0	18.0	1.0	14.0	4.0	1.0	6.0	4.0	3.0	7.0	20.0	35.0	11.0	9.0	16.0	7.0	5.0	11.0	**333.00**
10	-	-	-	-	-	-	-	-	-	2.0	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	**2.92**
11	2.0	-	-	-	1.0	-	-	-	-	-	84.0	1.0	-	1.0	1.0	-	-	-	1.0	2.0	14.0	3.0	1.0	1.0	1.0	5.0	**12.20**
12	-	-	-	-	1.0	-	-	-	-	-	-	40.0	-	-	1.0	-	-	1.0	-	4.0	1.0	3.0	-	-	1.0	1.0	**14.50**
13	-	-	-	-	-	-	-	-	-	-	-	-	78.0	-		-	-	5.0	-	-	-	-	-	-	-	-	**9.86**
14	-	-	-	-	-	-	-	-	-	1.0	-	-	-	82.0	7.0	-	-	-	1.0	-	34.0	-	-	-	-	-	**1.99**
15	-	-	-	-	-	-	-	-	-	1.0	1.0	-	-	-	30.0	-	-	-	5.0	-	1.0	-	1.0	-	-	1.0	**5.60**
16	-	-	-	-	-	-	-	-	-	-	-	1.0		-	-	54.0	-	-	-	-	-	1.0	-	1.0	-	1.0	**1.06**
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	72.0	9.0	-	4.0	1.0	-	-	-	1.0	-	**3.94**
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	43.0	-	-	-	-	-	-	-	-	**17.60**
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.0	-	-	-	-	-	-	-	**0.41**
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.0	-	-	-	-	-	-	**11.20**
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.0	-	-	-	-	-	**61.50**
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36.0	-	-	-	-	**1.94**
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29.0	-	-	-	**0.31**
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	55.0	-	-	**0.07**
25	1.0	-	-	-	-	-	-	-	-	1.0	-	1.0	-	-	-	-	-	-	1.0	2.0	1.0	-	1.0	-	13.0	1.0	**63.50**
26	1.0	-	-	-	1.0	-	1.0	-	-	1.0	-	1.0	1.0	-	3.0	-	1.0	2.0	2.0	5.0	3.0	1.0	2.0	2.0	3.0	21.0	**254.00**

emissions, but the changes in the final demand of other sectors have large impacts on emissions, demonstrating the important influence of this sector on economic activity. A reduction in its final demand would have large impacts on economy and small impacts on emissions.

In Region II we can find the following sectors: road transport, electric power generation, brewages, chemistry, agriculture, iron and steel, commerce, oil and gas extraction, air transportation, and other sectors. Changes in final demand of these specific sectors have a large influence on total emissions, and changes in final demand of other sectors also have large impacts on emissions of these specific sectors. A demand reduction in these sectors will have a large influence on emissions, but also might have a large influence on economic activity.

Table 4. Distributive effect (DE) among all sectors of the economy (%).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	DE (10^3)
1	7.0	-	-	14.0	-	-	-	-	1.0	-	17.0	1.0	-	-	-	-	-	1.0	-	1.0	16.0	-	-	-	6.0	35.0	**0.16**
2	-	46.0	18.0	2.0	-	1.0	-	-	11.0	3.0	-	1.0	-	-	-	-	-	1.0	-	-	3.0	-	-	-	2.0	11.0	**37.10**
3	-	1.0	37.0	3.0	1.0	2.0	1.0	-	22.0	-	-	1.0	-	-	-	-	-	1.0	-	1.0	6.0	-	-	-	3.0	21.0	**20.50**
4	-	-	-	37.0	1.0	-	-	-	2.0	-	-	2.0	-	-	1.0	-	-	1.0	-	1.0	5.0	-	-	-	13.0	36.0	**348.00**
5	-	-	-	-	44.0	-	-	-		-	-	-	4.0	-	-	-	-	2.0	-	-	2.0	-	-	-	1.0	45.0	**21.90**
6	-	-	-	-	-	60.0	-	-	1.0	-	-	-	-	-	-	-	-	-	-	1.0	1.0	-	-	-	2.0	32.0	**21.30**
7	-	-	-	-	-	-	83.0	-	1.0	-	-	1.0	-	-	-	-	-	-	-	1.0	2.0	-	-	-	1.0	8.0	**4.76**
8	-	-	-	-	-	-	-	77.0	1.0	-	-	1.0	-	-	-	-	-	1.0	-	2.0	3.0	-	-	-	1.0	11.0	**6.00**
9	-	-	-	-	-	-	-	-	87.0	-	-	1.0	-	-	-	-	-	-	-	1.0	2.0	-	-	-	1.0	7.0	**367.00**
10	-	5.0	2.0	6.0	1.0	-	-	-	2.0	43.0	-	8.0	-	-	-	-	-	1.0	-	1.0	3.0	-	-	-	5.0	21.0	**1.39**
11	-	-	-	-	-	-	-	-	-	-	32.0	-	-	-	-	-	-	-	-	1.0	26.0	-	-	-	2.0	38.0	**32.40**
12	-	-	-	-	2.0	-	-	-	-	-	-	59.0	-	-	-	-	-	2.0	-	4.0	6.0	-	-	-	5.0	20.0	**9.99**
13	-	-	-	-	-	-	-	-	-	-	-	-	80.0	-	-	-	-	9.0	-	-	-	-	-	-	-	10.0	**9.64**
14	-	-	-	-	-	-	-	-	-	-	-	-	-	7.0	2.0	-	-	-	-	-	85.0	-	-	-	1.0	5.0	**24.30**
15	-	-	-	-	1.0	-	-	-	1.0	1.0	3.0	1.0	-	-	38.0	-	-	-	-	-	14.0	-	-	-	1.0	38.0	**4.41**
16	-	-	-	-	-	-	-	-	1.0	-	-	2.0	-	-	-	12.0	-	1.0	-	1.0	4.0	-	-	-	5.0	72.0	**4.82**
17	-	-	-	-	-	-	-	-	-	-	-	1.0	-	-	-	-	43.0	23.0	-	6.0	6.0	-	-	-	5.0	14.0	**6.57**
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	97.0	-	-	-	-	-	-	2.0	1.0	**7.79**
19	-	-	-	-	27.0	-	-	-	-	-	-	-	2.0	-	-	-	-	1.0	31.0	-	6.0	-	-	-	2.0	29.0	**0.09**
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.0	-	-	-	-	-		**0.78**
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	98.0	-	-	-	-	1.0	**2.07**
22	-	-	-	-	-	-	-	-	1.0	-	-	-	-	-	-	-	-	-	-	4.0	9.0	67.0	-	-	4.0	15.0	**1.06**
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.0		68.0	-	1.0	20.0	**0.13**
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.0	-		**0.04**
25	-	-	-	-	-	-	-	-	1.0	-	-	1.0	-	-	-	-	-	1.0	-	2.0	4.0	-	-	-	75.0	14.0	**10.80**
26	-	-	-	-	-	-	-	-	1.0	-	-	-	-	-	-	-	-	1.0	-	1.0	3.0	-	-	-	3.0	90.0	**57.90**

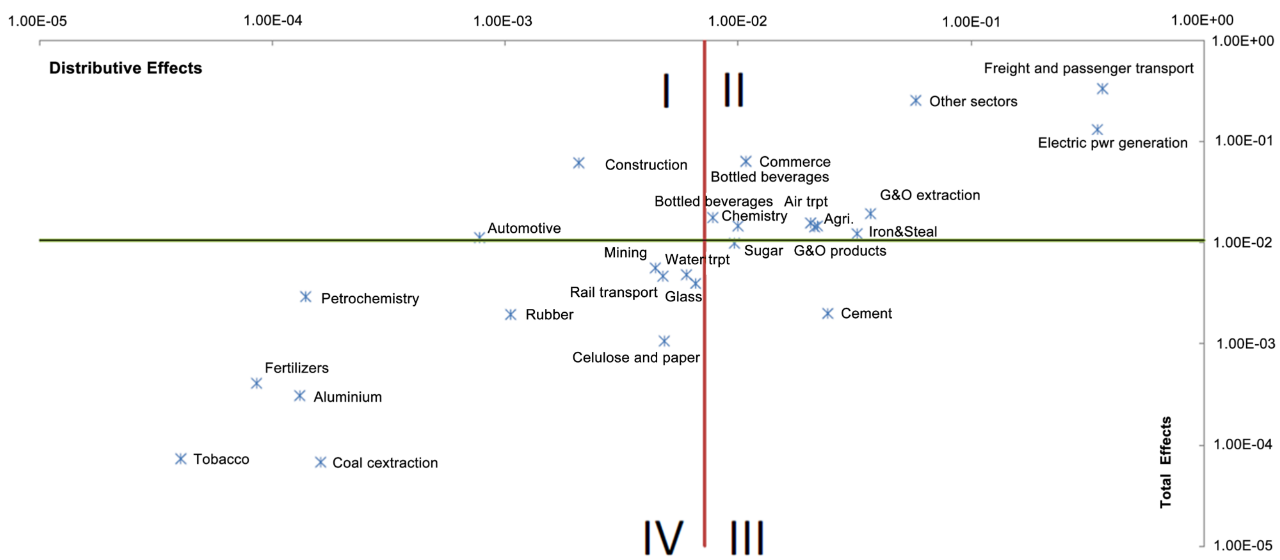

Figure 1. Distributive effects vs. total effects.

Table 5. Regions in **Figure 1**.

Regions	Distributive Effects	Total Effects
I	Small changes in final demand of the specific sector have a small influence on total emissions	Large changes in final demand of other sectors have large impacts on emissions of the specific sector
II	Large changes in final demand of the specific sector have a large influence on total emissions	Large changes in final demand of other sectors have large impacts on emissions of the specific sector
III	Large changes in final demand of the specific sector have a large influence on total emissions	Small changes in final demand of other sectors have small impacts on emissions of the specific sector
IV	Small changes in final demand of the specific sector have a small influence on total emissions	Small changes in final demand of other sectors have small impacts on emissions of the specific sector

The sugar industry and the cement industry are the sectors in Region III. Changes in final demand of these specific sectors have a large influence on total emissions, but changes in final demand of other sectors have small impacts on emissions of these specific sectors. In Region IV are less relevant sectors in terms of final demand and emissions. A reduction in CO_2-eq emissions of these sectors will not have an important impact on overall emissions, because the share in the distribution of emissions is low.

Another important observation from **Figure 1** is how construction and cement (in region III) are linked. It is possible to connect a line with both sectors that crosses the mean values (the center of the graphic). TE of the construction sector that affects the cement sector is the same amount as the DE of the cement sector received from the construction sector. Hence, if the final demand of sector 21 decreases, the emissions from sector 14 will also decrease. This relation also means that if the cement for construction is substituted with other materials, emissions from sector 14 will decrease.

5. Concluding Remarks

In this paper, an input-output methodology is developed to analyze energy-related GHG emissions of the Mexican economy. The paper also analyzes total and distributive effects that final demand has on emissions levels. It also identifies Own Sector Effects (OE) that result from the changes in the final demand of each Own Sector (the diagonal elements of matrix $\Delta\psi$), and Structure Effects (SE) that result from the changes in other sectors of the economy.

According to IPCC's fifth assessment report [37], the main mitigation strategies for the industrial sector are 1) reduction of emission intensity expressed as the ratio of GHG emissions to energy use; 2) reduction of energy intensity, measured as unit energy consumption in physical units (or in this case monetary units); 3) increase in material efficiency, which is the amount of material required to produce one product; and 4) reduction of product service intensity, which is the level of service provided by a product.

These strategies can be applied to sectors that appear in Region II and III to obtain the largest reduction in GHG emissions. Strategies 3) and 4) are related to a reduction in material or product production and will have an important effect on the economy, particularly in those sectors that appear in Region II. The alignment of strategies to fulfill the goals of the NDC requires additional analysis. Additional work is necessary to evaluate policies. The results presented in this paper are a useful tool for a GEM for the Mexican economy.

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Appendix

Table A1. CO_2-eq emission impact matrix for the year 2012 (10^{-6}%).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	10.699	0.2932	0.6988	22.721	0.7686	0.1225	0.0794	0.0243	1.6244	0.2106	27.751	1.2275	0.1615	0.0884	0.6974	0.0756	0.1621	1.1139	0.0463	1.2512	25.432	0.2936	0.0308	0.0039	9.6334	56.433
2	1.3116	17082	6547.6	603.64	181.19	365.42	129.14	6.8587	3988.7	1101.8	25.433	327.21	81.145	12.998	43.774	10.714	38.272	194.92	21.606	144.39	1165.3	26.338	3.1743	0.6203	720.59	4232.3
3	1.4385	135.63	7531.8	536.38	184.79	419.39	147.88	7.6512	4558	46.144	24.755	144.83	83.551	14.244	44.126	10.347	32.001	186.33	12.404	136.48	1251.8	20.844	3.0239	0.6485	699.14	4241.3
4	46.292	1278.5	733.78	128532	2983.5	279.33	203.6	83.021	5316.8	993.19	1510.3	5299.7	532.36	273.79	2695.7	404.18	812.93	4899.9	202.38	3709.5	16167	748.66	138	14.131	46125	124376
5	0.0656	15.955	11.873	8.1427	9676.2	12.484	8.6507	2.6119	99.976	7.3909	3.9986	72.441	857.05	0.7659	27.096	1.0232	4.2587	382.28	1.3018	108.46	339.17	77.396	0.9106	5.1366	325.95	9838
6	0.7519	16.391	15.005	69.8	66.044	12837	14.528	1.9521	139.3	15.964	11.669	94.912	27.324	1.6785	31.825	1.4551	9.5398	92.218	4.6253	284.13	317.55	13.649	5.6981	2.8756	457.56	6747.1
7	0.0612	8.4428	10.1	13.327	16.112	3.7065	3958.9	0.3096	47.823	8.8046	2.9215	33.416	6.5719	0.4028	4.9285	0.6671	1.6996	18.504	3.8678	66.749	105.4	2.9514	0.8466	0.0793	49.749	391.9
8	0.1031	14.348	17.136	22.645	27.896	6.3316	2.7391	4649.8	81.247	14.927	4.9529	56.263	11.224	0.6858	8.3362	1.125	2.876	31.452	6.5128	112.21	178.46	4.9907	1.4132	0.1337	83.883	662.61
9	3.622	512.69	606.65	874.8	848.09	241.74	108.86	23.604	317806	528.53	180.37	2015.4	398.14	25.072	341.74	39.667	119.88	1151.3	81.258	3889.5	6793.9	177.95	48.922	4.7558	3280.6	26987
10	0.0039	6.4222	2.8651	7.9402	1.1924	0.2032	0.0871	0.0139	3.1856	59.836	0.2284	10.48	0.5026	0.0398	0.3111	0.1002	0.599	1.8812	0.6139	1.4112	4.6441	0.4625	0.0315	0.0033	6.4792	29.753
11	1.6529	20.959	16.051	16.164	83.05	15.843	11.988	3.2958	133.48	10.321	10272	95.856	22.292	14.623	80.698	1.3135	6.0396	85.429	2.2771	214.3	8392.6	59.659	2.3081	0.4801	528.47	12316
12	0.1643	4.8449	6.4942	5.0569	181.51	3.1908	2.0826	0.6079	39.034	6.8304	3.5118	5882.1	35.309	0.4396	29.297	2.6835	7.5629	198.39	1.716	441.38	639.83	48.689	0.9294	0.2093	458.24	1991.7
13	0.0075	1.8351	1.3081	1.1472	15.998	1.2677	0.8714	0.2634	10.261	2.702	0.4293	7.8459	7674.4	0.0802	2.7219	0.1041	2.9742	847.67	0.1555	11.176	32.785	0.5954	0.0954	0.041	46.718	981.27
14	0.0834	63.097	40.742	14.606	11.937	3.7508	4.5841	0.3566	52.465	15.221	28.909	14.794	3.929	1628.8	416.91	0.46	4.0152	11.94	5.5675	16.822	20640	2.1876	0.6893	0.0506	147.1	1121.9
15	0.2536	8.5155	6.8852	7.7641	31.72	2.3886	1.6371	0.4483	22.779	43.004	115.43	30.746	5.0827	6.8054	1697.5	0.9033	11.903	19.321	21.738	21.826	629.71	2.1645	2.0933	0.0737	63.506	1659
16	0.0478	6.1479	4.8486	10.34	16.058	5.261	3.3369	0.9532	62.882	3.543	1.8973	87.549	8.4621	0.391	11.395	577.25	7.1294	35.267	0.7767	47.265	183.36	19.418	0.4953	0.9707	244.05	3483
17	0.0262	2.6103	2.2669	2.5997	10.452	1.5782	1.0212	0.3057	20.749	3.9124	0.8722	52.314	9.3422	0.1366	3.4416	0.2067	2848.4	1529.1	0.483	422.27	395.16	1.2011	0.2347	0.049	339.54	924.72
18	0.0087	0.5338	0.4238	0.8755	7.8696	0.2703	0.1404	0.0481	3.0964	0.741	0.2217	4.4679	1.1142	0.0309	0.388	0.0501	0.1414	7531.8	0.0743	4.1253	12.11	0.2567	0.0489	0.01	134.64	85.532
19	0.0002	0.0426	0.0319	0.0258	23.113	0.0324	0.0227	0.0067	0.2692	0.0218	0.0117	0.1886	2.0508	0.0021	0.0737	0.0029	0.0114	0.9271	26.768	0.2927	5.2966	0.1864	0.0026	0.0123	1.7428	24.656
20	0	0.0004	0.0004	0.0006	0.0006	0.0002	0.0001	0	0.2025	0.0003	0.0001	0.0014	0.0003	0	0.0003	0	0.0001	0.0009	0.0001	776.22	0.0049	0.0001	0	0	0.0027	0.0353
21	0.0009	0.0702	0.0545	0.6065	0.1713	0.0449	0.3023	0.0084	1.8466	0.0914	0.1827	0.366	0.1469	0.0133	2.3549	0.0122	0.0372	0.276	0.036	0.4796	2032.5	0.0589	0.0126	0.0013	4.7345	28.018
22	0.0055	0.3561	0.2793	0.3352	2.8886	0.244	0.1673	0.0484	6.4707	0.2061	0.1384	2.2146	0.5265	0.0188	0.7068	0.0274	0.0952	1.4104	0.0409	38.831	97.394	706.58	0.0272	0.0075	41.925	154.64
23	0.0002	0.0425	0.0317	0.0294	0.0906	0.0333	0.0247	0.007	0.2745	0.0186	0.0124	0.154	0.039	0.0032	0.0864	0.0028	0.0151	0.1767	0.0037	0.3719	13.531	0.0195	89.333	0.0009	0.8914	26.161
24	0	0.0002	0.0002	0.0003	0.0037	0.0001	0.0001	0	0.0016	0.0002	0.0001	0.0124	0.0006	0	0.0002	0.0021	0.0001	0.0012	0	0.0027	0.0054	0.0003	0.0001	40.384	0.0602	0.0513
25	0.5008	24.332	20.352	36.598	51.053	11.779	5.2843	1.9582	149.91	21.477	11.712	96.141	24.619	1.2665	11.797	2.5629	6.5492	66.492	3.7895	202.15	389.88	9.5527	2.5954	0.2747	8113.6	1539.5
26	0.3384	83.781	62.437	40.634	175.07	66.109	45.818	13.839	526.04	32.965	20.98	207.99	75.566	4.0371	142.66	5.0301	20.787	342.9	6.7423	541.15	1644.8	19.737	4.7377	1.8148	1665.1	52176