Energy Input–Output Analysis for México with an extension of the hybrid model.

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Abstract

In 2014, the Mexican government approved an energy reform that allows greater participation of private companies in the energy sector. The purpose of this reform is to improve energy production and consumption trends so to positively affect economic growth and sustainable development. However the repercussions of the reform are difficult to predict without a proper understanding the current state and evolution of energy production and consumption in the country. The work presented here analyzes the structural changes in economic factors that determine the trends of energy production and use in the period 2003-2012. The analysis is carried out with the primary-to-final energy input-output model. The results suggest that the production and use of energy in the Mexican economy has many areas of inefficiency, being the performance of energy conversion technologies in the energy sector and of energy use by non-energy industries the most disappointing. This work set a precedent for future analysis of the repercussions of the energy reform.

1. Introduction

The bold energy reform that the Mexican government approved in 2014 represents one of the most significant regulation changes to the energy sector in the last 60 years (SENER, 2015). Before this reform, the processes of national energy resources exploitation and power generation were controlled by the State. In contrast, with the energy reform, all processes of energy exploitation and generation are opened to private companies (national and foreign). Therefore, it is expected that the proposed regulation will significantly affect the structure of the

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energy sector and the characteristics of energy use and production in the country (SEGOB, 2014).

Furthermore, the energy reform will likely have a large (positive or negative) effect on the economy since Mexico is an oil country, i.e. it has the seventeenth position in oil reserves (EIA, 2013). Consequently, its economy depends heavily on exports of crude oil, e.g. exports account for 37% of government revenues (INEGI, 2015)[2]. A potential, though not-desired, effect of the energy reform could be the reduction of oil-related government revenues, generating a decrease in public spending. Moreover, despite being an oil country, it does not have the industrial capacity to generate its own demand for oil products. This situation causes that the prices of these products to the industry and to final consumers are relatively higher than in the U.S. (EIA,2015). Regarding this, the government hopes for more investment from private companies that boost the construction of new refineries and reduce fuel prices (SEGOB, 2014). On the other hand, the energy reform also aims to increase the number of private power companies on the basis that increase competition in the electricity sector leads to a reduction of electricity prices, which improve the competitiveness of the local industry, and to broader development of renewable electricity.

The negative and positive impacts of such reform are difficult to predict without a proper understanding of the current state and evolution of energy production and consumption in the country prior the energy reform is needed. In this respect, the paper is focused on the analysis of the structural changes in economic factors that determine the trends of energy consumption and production in the country with especial emphasis on the energy sector structure. The analysis is approached with extension of the hybrid energy input-output model by Guevara *et al* (2014).

The paper is structured as follows. Section 2 presents the methodology and section 3 describes the data. In Section 4, we discuss the results of this study. Finally, Section 5 presents the general conclusions of this work.

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2. Methodology

The selected energy input-output model to account for energy flows in the Mexican economy is the primary-to-final model (PF-EIO model) developed by Guevara *et al*. (2014) and Guevara (2014). This model is equivalent to the hybrid-unit model (Bullard, 1975) though, in opposition to the latter, the PF-EIO model offers a detailed description of the transactions and conversion processes of the energy sector.

The PF-EIO model is composed by three sub-models (described below) that are then coupled into a complete model of total energy output (Eq [4]).

1. The energy sector sub-model in physical units

$$\boldsymbol{q}^E = \boldsymbol{Z}^E\boldsymbol{i} + (\boldsymbol{C}^E\boldsymbol{e} + \boldsymbol{r})\boldsymbol{i} \qquad \text{Or} \qquad \boldsymbol{q}^E = \boldsymbol{L}^E(\boldsymbol{C}^E\boldsymbol{e} + \boldsymbol{r})\boldsymbol{i} \qquad [1]^3$$

   where

   - Vector $\boldsymbol{q}^E$ is the total output by product of the energy sector (total energy use)
   - Matrix $\boldsymbol{Z}^E$ is the interindustry transactions between energy industries
   - Matrix $\boldsymbol{L}^E$ is the total primary-to-final energy requirements. This matrix accounts for the structure and efficiency of the energy sector
   - Matrix $\boldsymbol{C}^E$ is the composition of energy demand by the rest of the economy
   - Vector $\boldsymbol{e}$ is the total direct energy demand by non-energy industries
   - Vector $\boldsymbol{r}$ is the final energy demand (or residential energy demand)

2. The sub-model of the rest of the economy in monetary units

$$\boldsymbol{x}^S = \boldsymbol{L}^S\boldsymbol{f} \qquad [2]$$

[3] A bold lower case letter ($\boldsymbol{x}$) corresponds to a vector. Bold capital letter ($\boldsymbol{Z}$) describes a matrix or sub-matrices. Non-bold Latin letters (x_i an z_{ij}) represent matrix entries, vector elements, scalars and indexes. A vector with a hat ($\hat{\boldsymbol{x}}$) represents a diagonal matrix, whose diagonal elements are the elements of vector $\boldsymbol{x}$. $\boldsymbol{i}$ is a vector of ones of a consistent length (or summation vector).

Where

- Vector $\boldsymbol{x}^S$ is the output of the rest of the economy (i.e. non-energy industries)
- Matrix $\boldsymbol{L}^S$ is the total non-energy requirements of the rest of the economy. It corresponds to the economy-wide inverse Leontief matrix without energy -industries rows and columns.
- Vector $\boldsymbol{f}$ is final non-energy demand

3. The direct energy intensity of the rest of the economy, i.e. the energy use by non-energy industries per unit of their economic output

$$\boldsymbol{T}^{ES} = \hat{\boldsymbol{e}}\widehat{\boldsymbol{x}^S}^{-1} \qquad [3]$$

The final form of the PF-EIO model is

$$\boldsymbol{q}^E = \boldsymbol{L}^E \boldsymbol{C}^E \boldsymbol{T}^E \boldsymbol{L}^S \boldsymbol{f} + \boldsymbol{L}^E \boldsymbol{r} \qquad [4]$$

whose elements are described in detailed:

a. $\boldsymbol{L}^E$ is the matrix of size $n_C \times n_C$ of total primary-to-final energy requirements, which accounts for the structure and efficiency of the energy sector (units TOE/TOE). Note: n_C is the classification of energy products.
b. $\boldsymbol{C}^E$ is the matrix of size $n_C \times n_S$ of the composition of energy demand by the rest of the economy (units TOE/TOE). Note: n_S is the classification of non-energy industries of the rest of the economy in the energy sector's sub-model
c. $\boldsymbol{T}^{ES}$ is the matrix of size $n_S \times m_S$ of the direct energy intensity of the rest of the economy (units TOE/MXN$). Note: m_S is the classification of non-energy industries in the rest of the economy's sub-model
d. $\boldsymbol{L}^S$ is matrix of size $m_S \times m_S$ of the total non-energy requirements of the rest of the economy (units MXN$ /MXN$).
e. $\boldsymbol{f}$ is the vector of length m_S of the non-energy final demand (units MXN$).

f. $\boldsymbol{r}$ is the vector of length n_C of the final energy demand (units TOE).

Furthermore, PF-EIO models in Eq. [4] were constructed for the Mexican Economy in 2003, 2008 and 2012. These models describe the state of several variables of the economic system (i.e. $\boldsymbol{L}^E$, $\boldsymbol{C}^E$, $\boldsymbol{T}^E$, $\boldsymbol{L}^S$, $\boldsymbol{f}$, and $\boldsymbol{r}$) at a specific point of time. To understand the evolution of these factors with respect to the total energy use by the country, these variables are compared across years. The comparison is performed by an element-wise division of corresponding factors between two different years, i.e. 2003-2008 and 2008-2012. For example, the total primary-to-final energy requirements matrix in 2008-2012 would be compared as $\left[\frac{L_{ij}|_{12}}{L_{ij}|_{08}}\right]$. Therefore, if there is an increase in an entry of one of the variables between 2008 and 2012, this ratio is greater than one.

3. Data

Energy flows data from the Ministry of Energy's balances (SENER, 2015) were used to build the energy sector sub-model according to the commodity-by-industry approach to input-output analysis (Miller,2009; EUROSTAT,2008). In this approach, energy data is arranged into supply and use tables, which consist of $n_C = 41$ energy products, $n_T = 16$ energy industries and $n_S = 23$ non-energy industries of the rest of the economy of direct energy demand.

The sub-model of the rest of the economy was built with the domestic input-output tables at current prices from INEGI (2015). The 2003 and 2008 tables have a classification of $m = 253$ industries (of which, $m_S = 55$ are non-energy industries). The 2012 table has a classification of $m = 800$ industries (of which, $m_S = 55$ are non-energy industries). Because of the different classification system, the 2012 table was harmonized into the 2003 and 2008 table's classification through aggregations. Furthermore, to perform a temporal comparison, it was necessary to convert the data from current to constant prices (Dietzenbacher, 2012; Miller,2009). This was done by deflating/inflating the entire dataset with the appropriate chain indices (Dietzenbacher, 1998; Jackson,2004)

Finally, as it is done by Guevara et al (2014), the matrix of direct energy intensity ($\boldsymbol{T}^{ES}$) is built so that it performs the necessary transformations between the SENER's and INEGI's classifications (n_S vs. m_S).

4. Results

The results of the comparisons are presented in the form of heat maps for each of the variables of the PF-EIO model

$\boldsymbol{q}^E$ – *Total energy use by energy product*

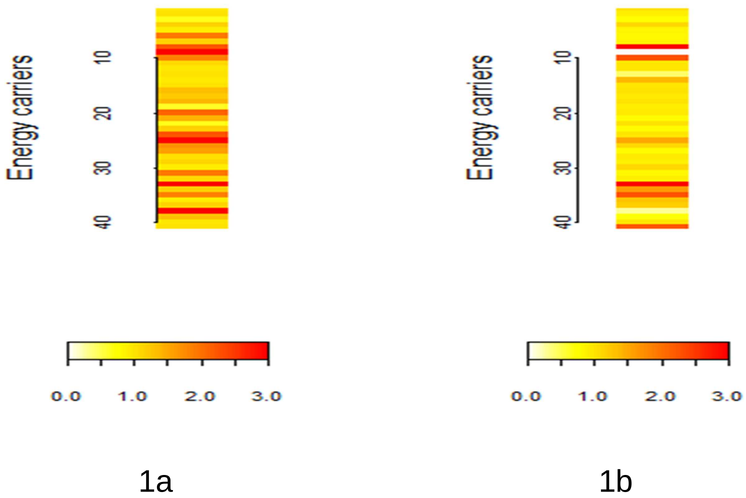
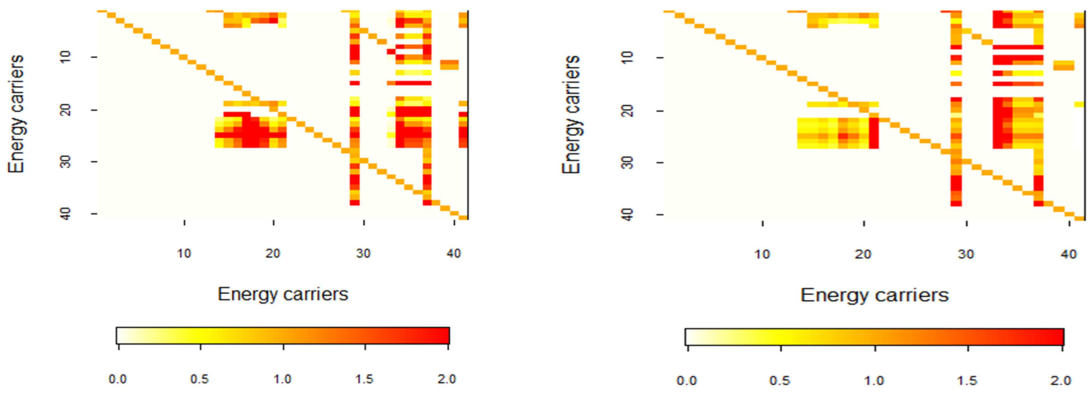


Figure 1. Heat map of element-wise ratio $\boldsymbol{q}^E_{Y2}/\boldsymbol{q}^E_{Y1}$. The red color means that there was an increase in production renewable energy by three or more times

Figure 1a shows the comparison of the $\boldsymbol{q}^E$ vector between 2003 and 2008. There is a clear increase in the use of certain energy products: Some renewable energy sources, like geothermal energy, wind power, biogas and firewood (indexes 6-10). The second red strip belongs to imported oil products, which tells us that the Mexican economy used more imported oil derivatives in 2008 than in 2003. Finally the total requirements for grid electricity (index 37) significantly increased.

On the other hand, Figure 1b shows an increase in demand for renewable energy products such as biogas and solar energy between 2008 and 2012. It also shows the rise in electricity generated through biogas and solar photovoltaics technologies (index 34-35). In addition, figure 1b reports an increase in the use of imported oil products for non-energy use .

$\boldsymbol{L}^E$ – Total primary-to-final energy requirements



2a

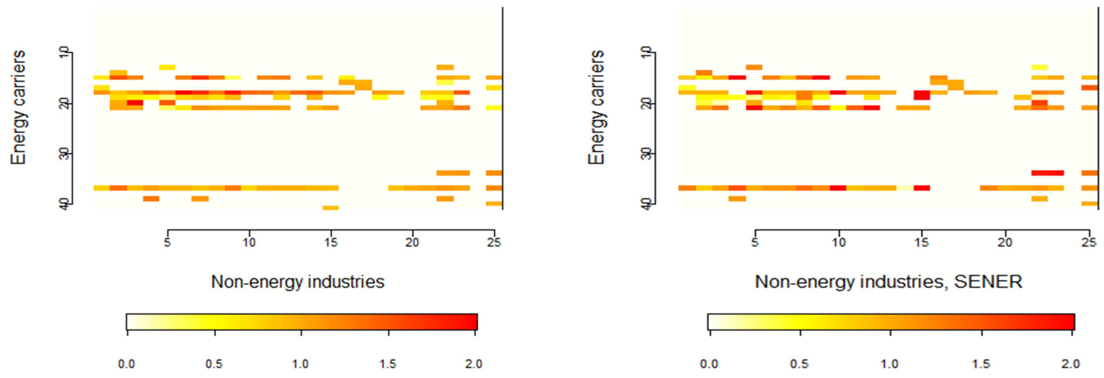
2b

Figure 2. Heat map of element-wise ratio $\boldsymbol{L}^E_{Y2}/\boldsymbol{L}^E_{Y1}$.

Figure 2a shows the $\boldsymbol{L}^E$ matrix (i.e. primary requirements to satisfy intermediate and final energy demand) from 2003 to 2008. The rows of the matrix represent the flows of energy products to energy conversion technologies in the columns. The zone around the center of the matrix (columns 14-22) correspond to oil refinery technology, which used more imported oil derivatives to their processes. This implies that more imports of oil derivatives were needed to satisfy a unit of final and intermediate demand for these products (Neither there were new refineries nor the current refineries produced more). Thermoelectric power technologies (column 28) became less efficient in this period since they increased their energy inputs per unit of thermoelectricity generated. The same happened with some renewable power technologies (columns 32-37) that increased the use of oil derivatives in their processes.

In contrast between 2008 and 2012 (Figure 2b), oil refinery technologies did not become as inefficient as in the previous period and the imported oil derivatives requirements were reduced in these technologies. However the inefficiency grew again in thermoelectric power technologies and in some renewable power technologies (columns 34-35) such as the biogas-to-electricity technology.

$\boldsymbol{C}^E$ – Composition of intermediate energy demand



3b

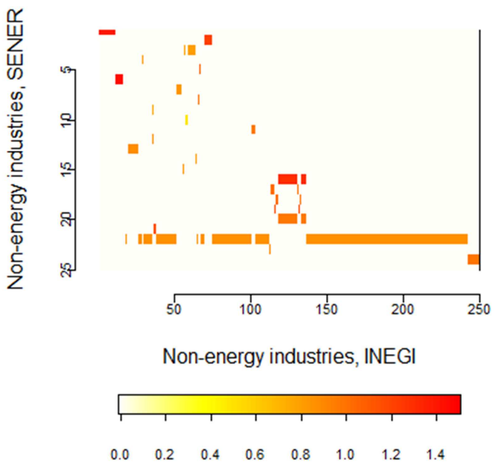
3a

Figure 3. Heat map of element-wise ratio $\boldsymbol{C}_{Y2}^E/\boldsymbol{C}_{Y1}^E$.

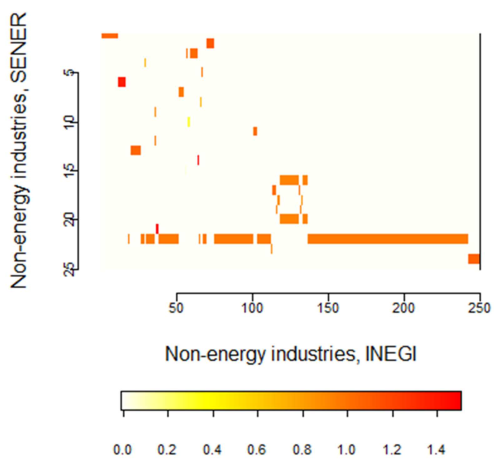
The Figure 3a shows the $\boldsymbol{C}^E$ matrix, which shows the share of each energy product in the intermediate demand of non-energy industries (rows correspond to energy product shares and columns to non-energy industries). The comparison between 2003 and 2008, shows a higher share for Kerosene and LPG (rows 17 and 23) in the energy demand of some non-energy industries except in agriculture, steel, chemical and sugar (columns 1-4). In addition, there was a reduced demand share of fuel oil (row 19) in most non-energy industries.

A higher demand share for Kerosene, LPG and electricity (rows 17, 23 and 37) continued to increase from 2008 to 2012 (Figure 3b). Moreover, the demand share of fuel oil and petroleum coke (rows 19-20) decreased in most industries

T^{ES} – Direct energy intensity



4a



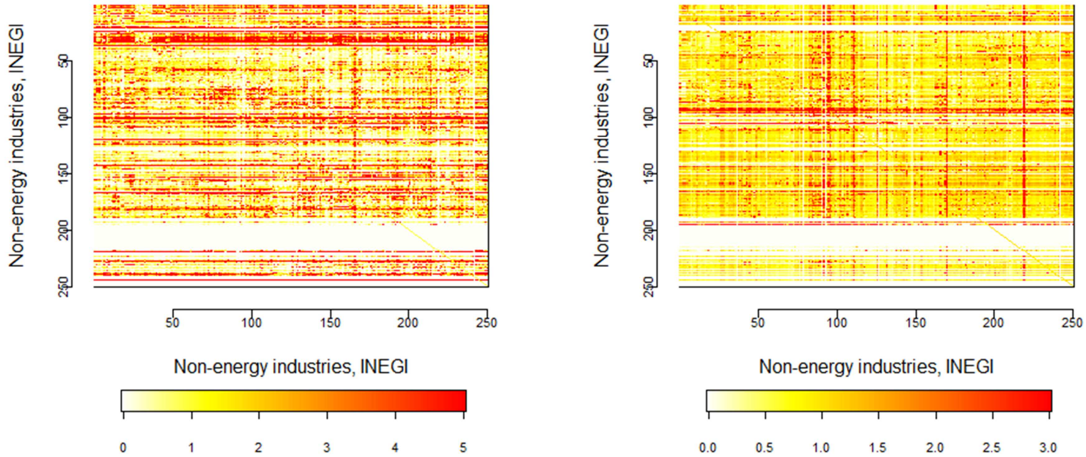
4b

Figure 4. Heat map of element-wise ratio $\boldsymbol{T}_{Y2}^{ES}/\boldsymbol{T}_{Y1}^{ES}$.

The $\boldsymbol{T}^{ES}$ matrix shows us the direct energy intensity of non-energy industries (rows show the aggregated sectors of non-energy industries while columns the branches of these sectors). Between 2003 and 2008 (Figure 4a), the primary industries (row 1) became less efficient as well as the iron and steel, chemical, mining and land transport industries (rows 2, 3, 6 and 16). Disappointingly, few industries became more efficient, e.g. automotive and rubber industries (row 11 and 15). The changes between 2008 and 2012 were less significant, standing out the inefficient trend of the mining industry (row 6) and the improvements in the automotive industries (row 11).

$\boldsymbol{L}^{S}$ – Total non-energy requirements of the rest of the economy

Matrix L^{S} shows the changes in interindustry non-energy monetary transactions in the period 2003-2008 (Figure 5a). In the heat map, there is a red horizontal stripe around rows 20-30, which mainly consists of construction industries. This implies that there was a higher demand for construction services in 2008 compared to 2003. Another significant increases were in the demand for electronic equipment, auto parts and automobiles (around row 100) and for public services (rows 243-250). In addition, only few products were consumed less by most industries, e.g. wood industries and telecoms services (rows 49-51 and 144-151).

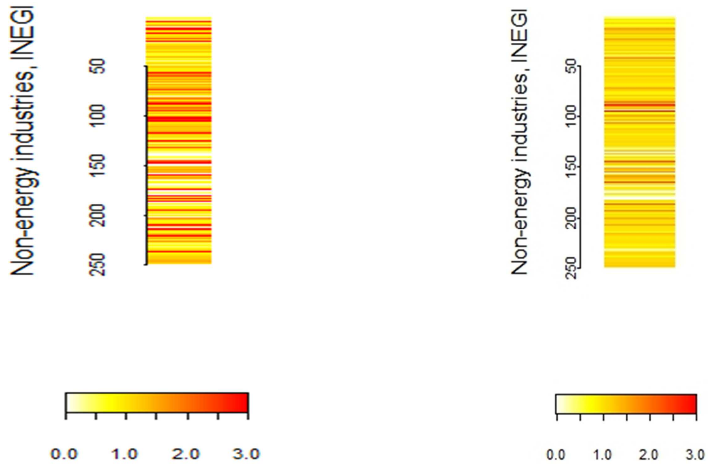


5a 5b

Figure 5. Heat map of element-wise ratio $\boldsymbol{L}_{Y2}^{S}/\boldsymbol{L}_{Y1}^{S}$.

Between 2008 and 2012 (Figure 5b), the changes were not significant, i.e. the total requirements hardly change in most industries. However there was an increase in the intermediate demand for electronic equipment and automobiles (around row 100) and utilities (rows close to 200). On the other hand, it is clear that industries of electronic equipment (columns 91-100) increased their demand of most input per unit of their products to final demand.

f *– Final non-energy demand*

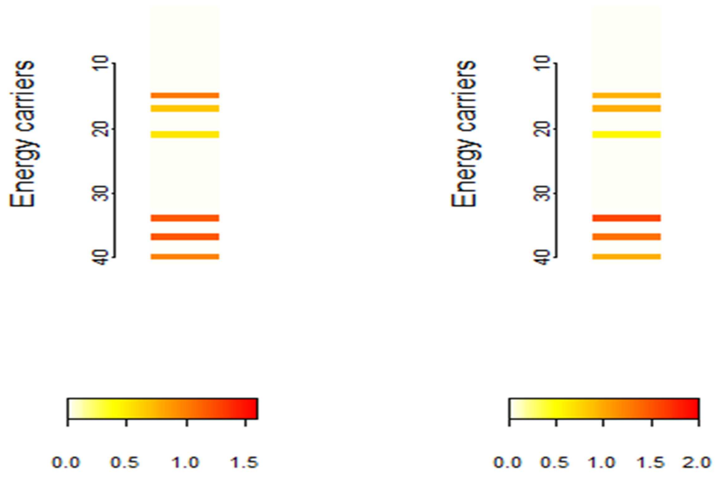


6a 6b

Figure 6. Heat map of element-wise ratio $\boldsymbol{f}_{Y2}/\boldsymbol{f}_{Y1}$.

The vector $\boldsymbol{f}$ shows the final demand for non-energy products. In the heat map of 2003-2008 (Figure 6a), the final demand of certain industries was significantly increased, especially of primary industries (index 1-11), pulp and paper (index 52-54), automotive (index 101-103), telecom services (index 148-151) and some services (index 210-222). Conversely, between 2008 and 2012, the demand increase was not significant for most non-energy products, being electric equipment (index 91-100) and financial services (index 152-160) the industries with the highest increase in this period.

r *– Final energy demand*



7a 7b

Figure 7. Heat map of element-wise ratio $\boldsymbol{r}_{Y2}/\boldsymbol{r}_{Y1}$.

$\boldsymbol{r}$ is the vector of energy demand in the residential sector. The heat map 2003 - 2008 (Figure 7a) shows that there is an increased demand for LPG, solar PV electricity, grid electricity and firewood (indexes 15, 34, 37 and 40) while the residential demand for natural gas decreased (index 21). The same trend was observed in the period 2008-2012 (except for LPG, index 15).

5. Conclusions

The present work presents a descriptive analysis of the changes of several factors that determine the level of energy production in Mexico over the period 2003-2012.

The most significant result was the disappointing performance of energy conversion technologies in the energy sector. Most national conversion technologies increased their energy requirements per unit of secondary energy carrier demand which implies that either their processes became less efficient or that they were unable to satisfy the domestic energy demand hence relying more in energy imports. Moreover, even some renewable energy technologies such as biogas-to-electricity and geothermal power used more fossil fuel inputs to their production processes. In addition, there was an increase in renewable energy production though almost negligible in absolute terms.

The results are also disappointing regarding intermediate energy demand of the rest of the economy. First non-energy industries did not significantly change their mix of energy demand hence they did not favor more efficient carriers such as renewable electricity and natural gas. Second the economic efficiency of energy carrier use (i.e. direct energy intensity) did not experience improvements in most sectors, including strategic sectors such as agriculture, iron steel and transport, but the opposite. Regarding residential energy demand increased over the entire period. Unfortunately, the lack of adequate infrastructure led to more consumption of LPG instead of the more efficient and more environmental-friendly natural gas.

Furthermore, the non-energy transaction in the rest of the economy had also a negative impact on the trend of energy consumption since most non-energy industries increased their demand of non-energy inputs per unit of final demand (i.e. more inputs to produce the same) between the 2003 and 2008. Moreover, final non-energy demand significantly increased.

These results suggest that the production and use of energy in the Mexican economy has many areas of inefficiency. Particularly, the energy sector and the characteristics of intermediate energy demand seem to have been in a precarious situation for many years and need adequate intervention. However the adequateness of the bold energy reform would be tested on the basis of how much it can address these inefficiencies.

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