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Contaduría y Administración
Accounting & Management

Contaduría y Administración 66 (2), 2021, 1-22

Electricity consumption efficiency and mitigation strategies in Mexico's production structure

Estrategia de eficiencia en el consumo de energía eléctrica y mitigación en la estructura productiva de México

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Received March 1, 2019; accepted May 7, 2020
Available online November 29, 2023

Abstract

This study conducts a multisectoral analysis of the consumption of electricity in Mexico, the intensity and efficiency of electricity consumption, as well as the emission of pollutants by type of electricity generation technology; in order to propose an improvement strategy. The results indicate the existence of 19 key subsectors in the use of electricity power. The greatest intensity in electricity consumption is in the subsectors of water and gas supply by pipelines, manufacturing of products based on non-metallic materials and manufacture of textile input and textiles finishes. The highest CO2 emission corresponds to combine cycle generation, conventional thermoelectric and coal-fired technologies with an emission of 122. Mt of CO2 ; clean energies emit 2.7 Mt of CO2 . Based on these results, a strategy of efficiency in electricity consumption an mitigation for the national production apparatus is proposed.

JEL Code: E2, L94, Q43, Q51, Q54
Keywords: efficiency; multisectoral analysis; electrical power; mitigation

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Peer Review under the responsibility of Universidad Nacional Autónoma de México.

http://dx.doi.org/10.22201/fca.24488410e.2021.2487

http://dx.doi.org/10.22201/fca.24488410e.2021.2487

Resumen

En el presente estudio se realiza un análisis multisectorial del consumo de energía eléctrica en México, de la intensidad y eficiencia en dicho consumo, así como de la emisión de contaminantes por tipo de tecnología de generación de electricidad; con la finalidad de proponer una estrategia de mejora. Los resultados indican la existencia de 19 subsectores claves en el uso de la energía eléctrica. La mayor intensidad en el consumo de electricidad está en los subsectores de suministro de agua y gas por ductos, fabricación de productos a base de materiales no metálicos y fabricación de insumos textiles y acabados de textiles. La mayor emisión de CO2 corresponde a tecnologías de ciclo combinado, termoeléctrica convencional y carboeléctrica con una emisión de 122.7 Mt de CO2 ; las energías limpias emiten 2.7 Mt de CO2 . Con base en estos resultados se propone una estrategia de eficiencia en el consumo de electricidad y mitigación para el aparato productivo nacional.

Código JEL: E2, L94, Q43, Q51, Q54
Palabras clave: eficiencia; análisis multisectorial; energía eléctrica; mitigación

Introduction

According to the United Nations (UN, 2019), climate change is currently an issue of general interest and represents one of the greatest challenges for human beings. The effects of these changes are global and of a magnitude never seen before, so it is necessary to propose strategies to improve mitigation. Climate change is undeniable, according to the University of Cambridge and the World Energy Council (2014, pp. 2–5). Most likely, it is predominantly caused by human activities, such as carbon dioxide emissions.

Electricity generation is one of the main sources of Greenhouse Gas (GHG) emissions and one of the main engines for Mexico's development. Therefore, numerous studies have been conducted to determine energy efficiency measures with a high impact on emissions reduction to implement them without affecting Mexico's economic growth (INECC and UNDP, 2012, p. 22). A multisectoral analysis of electricity consumption in Mexico and the intensity, efficiency, and emission of pollutants by electricity generation technology will serve as a basis for proposing a strategy for improvement.

Review of the literature

The Energy Input-Output analysis describes the consumption and use of energy needed to produce goods and services in each of the sectors of the production structure of a region or country. There are three elementary models of this type of analysis (Guevara et al. 2018, p. 7): the hybrid unit model of Bullard and Herendeen (1975), the direct effect coefficient model based on the direct energy intensity of all sectors

http://dx.doi.org/10.22201/fca.24488410e.2021.2487

(Miller & Blair, 2009), and the multifactor model that explains energy flows according to the energy conversion processes in the economy (Guevara & Domingos, 2017).

Ruíz Nápoles has conducted several studies on low-carbon growth and adoption of mitigation technologies in Argentina and Brazil (Ruiz, 2014a) and has proposed climate change mitigation policies in Mexico (2014b), concluding that the energy sector is the sector that emits the most pollutants and indirectly contributes to greenhouse gas emissions.

Cardenete and Fuentes-Saguar (2014) analyzed the energy sector in Andalusia and its importance from the point of view of final energy consumption, identifying—through the use of a social accounting matrix—the sectors with the greatest responsibility in the emission of pollutants and the highest cost in terms of CO_2 emissions.

Gianialli and Canziani (2014) determined that low carbon development (LCDS) in Peru exhibits great improvement in economic, social, and environmental benefits and in the incorporation of financing and application of internationally available technologies. Betancourt (2015) determines the effects of applying a CO_2 environmental tax in Mexico, emphasizing that implementing fiscal policies and economic instruments with a climate focus will boost low-emission economic development and increase competitiveness. Loizou and Chatzitheodoridis (2015) analyzed the dynamics of the Greek energy sector, determining how the energy sectors contribute fundamentally to the national economy and identifying their backward and forward linkages with the other sectors of the economy.

Livas-García (2015), using the concept of energy requirements of energy through the input-output methodology and structural change analysis, determined the dependence of the Mexican energy system on hydrocarbons. Guevara, Rodriguez, and Domingos (2015) introduced a new energy input-output model, called the final model, which describes energy flows according to energy conversion processes and energy use levels in the economy. On the other hand, Guevara, Souza, and Domingos (2016) presented information on energy transitions in Mexico based on the analysis of useful exergy from 1971-2009. Exergy is a measure of available energy, and useful exergy is the minimum necessary value of work required to produce a given end use, which makes it possible to measure the effective amount of exergy delivered to a final function.

Patiño (2016) analyzes Colombia's production structure, energy efficiency, and CO_2 emissions, identifying and measuring the key elements that contribute to these emissions and their connection with energy consumption. The Ministry of Energy (SENER, 2016) published the determination of the baseline energy consumption and sectoral energy efficiency potentials in Mexico by analyzing the industry, transportation, residential, commercial, non-energy, agriculture, and livestock sectors.

Liu, Chen, Tian, Zheng, and Li (2016) conclude that promoting non-fossil fuel energies will offer an increasing contribution to a low-carbon transition in the medium to long term in China. Arreola-

Marroquín and Ríos (2017) find that the growth rate of energy production and consumption is negatively affected by the growth rate of energy prices. Consequently, economic policies must focus much more directly on increasing energy efficiency and innovation.

Guevara, Córdova, García, and Bouchain (2017) analyze the state and evolution of energy in Mexico before the 2014 energy reform, identify the presence of three decisive elements in the change in primary energy use and consumption, and determine that the energy sector is in a deficient state in terms of its structure and operation. Guevara et al. (2018) determined the correlations between energy and CO_2 emissions in the NAFTA bloc by applying the so-called multifactor energy model. The results show that NAFTA does not have a joint integrated energy system for the three participating countries, although it has helped to reduce energy-related CO_2 emissions.

This literature review showed different studies on energy consumption, energy efficiency, CO_2 emissions, and mitigation in the production structure. Most of them were carried out through input-output analysis and referred to the use and consumption of energy considering hydrocarbons (oil, gas, and derivatives) and electricity as a whole. Consequently, there is no exclusive analysis of the electricity sector. Given the above, the objective of this work is to perform a multisectoral analysis of electricity consumption, intensity, and efficiency, to determine the key subsectors in electricity consumption based on the database of the Input-Output matrix published in October 2017 by the National Institute of Statistics and Geography (INEGI) at 2013 basic prices, and the emission of pollutants by electricity generation technology with data as of 2017, to propose an improvement strategy.

CO_2 emissions by type of source and generation technology

Different sources and technologies are involved in the generation of electricity. Currently, there are several options with very different characteristics, such that the main classification in Mexico distinguishes between conventional and clean energies. The potential for renewable resources and clean energy in Mexico is immense; electricity generation has a significant diversity of technology for its exploitation. Hydroelectric plants are the largest contributors to installed capacity, followed by geothermal, wind, and solar photovoltaic (PV) plants. The latter two sources have grown the most in recent years (ECLAC, 2018, p. 83). The fastest growth rate was presented by wind power, which grew in installed capacity from 3.735 MW in 2016 to 5.077 MW in 2018. Solar PV grew in installed capacity from 389 MW in 2016 to 1646.55 MW in June 2018.

Since the electricity sector is one of the main contributors to the emission of Greenhouse Gases (GHG), reducing its consumption is essential for achieving the established objectives. There are two ways to reduce electricity consumption: by reducing the activities that consume electricity in absolute terms or by increasing efficiency in the use of electricity in diverse activities. The second case is more feasible since it does not imply a decrease in economic activity, despite not obtaining absolute decreases (Mendiluce and Linares, 2011, pp. 1–3).

According to the National Inventory of Greenhouse Gas and Compound Emissions of the National Institute of Ecology and Climate Change (INECC), conventional technologies for electricity generation contribute 18% of the total emissions of Greenhouse Gases (GHG) at the national level (it is the activity in Mexico with the second-greatest impact on the environment, after transportation), with a volume equivalent to 125 billion tons of CO_2 (SENER, 2018, p. 25).

Table 1 presents emissions produced by a generation source, average emissions per MWh of generation for conventional technologies, and the type of existing technology in 2017.

Table 1
CO_2 emissions by type of technology and generation source 2017

Type of technology	Generation source	Average emissions per MWh (kg of CO_2)	Power plants in operation	Emissions produced (Mt of CO_2)
Conventional			526	122.7
Combined cycle	Natural gas	346	83	57.2
Conventional thermoelectric	Petroleum derivatives	680	59	29.1
Carboelectric	Coal	773	3	23.6
Turbo gas	Natural gas and diesel	509 660	131	7.3
Internal combustion	Diesel, fuel oil, or a blend of both	688	248	2.8
Fluidized bed	Petroleum coke		2	2.7
Clean			270	2.7
Renewable			239	0.3
Hydroelectric	Water		86	0.0
Wind power	Wind		45	0.0
Geothermal	Endogenous steam		8	0.0
Solar	Sun		23	0.0
Bioenergy	Biomass and waste		77	0.3
Other			31	2.4
Nucleoelectric	Uranium or plutonium		1	0
Efficient cogeneration	Primary energy of process		30	2.4
Total			796	125.4

Source: PRODESEN 2018-2032 (SENER, 2018, p. 141)

http://dx.doi.org/10.22201/fca.24488410e.2021.2487

The importance of incorporating Clean Energy Certificates (CEL) into Mexico's electricity structure should be noted. These are certificates issued by the Energy Regulatory Commission (CRE) to authenticate a measured amount of electricity generation through clean energy and that assist in the fulfillment of the obligations associated with the consumption of load centers (CRE, 2017). The regulatory framework in this area provides investors with certain benefits, including tax incentives and promotional certificates such as CELs, which can be traded in the market according to supply and demand.

Energy input-output model applied to electric energy

The final consumption of electricity depends on the sectoral consumption of the production structure of the economy, the energy content, and the production of each sector and the generation of capital. Therefore, it is essential to determine the link between the sectoral economic behavior and the consumption and demand for electric energy (Alcántara and Padilla, 2002, pp. 2–3). A multisectoral analysis of electricity consumption facilitates the application of energy efficiency indicators, which are a valuable instrument for describing in detail how electricity use is affected by certain factors in the different sectors of the economy while facilitating the identification of processes with areas of opportunity for improving energy efficiency and the scope for savings by sector. Based on the well-known Leontief model and the analysis performed by Hartner (2013, p. 109) for electric power using an input-output matrix, the intensity of electricity consumption can be expressed as:

$$CEE_j^{\ t} = \frac{EEF_j^t}{X_j} \tag{1}$$

Where $\mathrm{CEE_j}^{\mathrm{t}}$ is the electrical energy consumption of supplier t for sector j in (kW/pesos), $\mathrm{EEF_j^t}$ is the final electrical energy use of supplier t for sector j in (kW/year), and $\mathrm{X_j}$ is the total production of sector j in (Pesos/year). Therefore, the Leontief inverse matrix $(\mathrm{I} - \mathrm{A})^{-1}$, which is known as the total requirements matrix (R), can be expressed as follows:

$$R = (I - A)^{-1} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} \tag{2}$$

By multiplying this matrix (R) by a diagonal matrix (ê) expressing the electrical energy consumption of the industries on the diagonal (which is given by dividing the electrical energy

http://dx.doi.org/10.22201/fca.24488410e.2021.2487

consumption line by the total production), a matrix containing the total requirements (total production) of electrical energy for the production of one unit for the final demand is obtained. The columns contain the electrical energy input along a product's supply chain, and the sum of the columns indicates the total electrical energy inputs to produce one unit of an industrial product for the final demand.

$$REE = \hat{e} \cdot (I - A)^{-1} = \begin{bmatrix} r_{11}e_1 & r_{12}e_1 & \dots & r_{1n}e_1 \\ r_{21}e_2 & r_{22}e_2 & \dots & r_{2n}e_2 \\ \dots & \dots & \dots & \dots \\ r_{n1}e_n & r_{n2}e_n & \dots & r_{nn}e_n \end{bmatrix} \tag{3}$$

Where REE is the total electrical energy requirements, ê is the diagonal matrix with the electrical energy consumption of the industries on the diagonal and $(\mathrm{I} - \mathrm{A})^{-1}$ is the inverse Leontief matrix. Together with the original equation for total production, the total electrical energy required for the economy is obtained as a function of the final demand matrix (y).

$$REE = \hat{e} \cdot (I - A)^{-1} \cdot y \tag{4}$$

By multiplying the demand as a diagonal matrix, a vector of total electrical energy requirements for the consumption of products produced by all industries within a year is obtained.

$$REE_{pg} = \hat{e} \cdot (I - A)^{-1} \cdot \hat{y} \tag{5}$$

The application of the methodology shows with greater clarity and detail the application of the energy input-output model applied to electric power.

Rasmussen indices

Among the existing methods to identify the key sectors of an economy—essentially those that analyze the weight of each sector to generate carry-over effects, both forward and backward, regardless of their size—are the so-called Rasmussen Indices, whose use is widespread, given that they provide a very appropriate first approach in the analysis of the structure of a real economy (Núñez & Romero, 2016, p. 12).

The capacity to originate backward impacts corresponds to the magnitude that an increase in sector j originates in the other sectors, and the capacity to originate forward impacts is identified as the magnitude to which the economic system weighs on industry i, i.e., the extent to which industry i is affected by an increase in the economic system (Parra & Pino, 2003, p. 19). The general form of the Leontief model is given by the following equation:

$$\boldsymbol{x} = Ly \tag{6}$$

Where x represents the vector of total output for each economy sector, $L = (I - A)^{-1}$ is the matrix of multipliers (Leontief inverse), and y is the vector of final demands. Each value in each sector (column) of L is explained as the effect of an exogenous unit increase corresponding to that sector on the output of each production sector so that the sum of the column equals the total multiplier effect.

Rasmussen indices comparatively relate the effect in each sector to the average effect of all sectors, both by drag (column) and dispersion (row). Thus, if the impact of a sector is greater than the average, its index will be greater than one (Núñez & Romero, 2016, p. 12). In other words, by column, the drag or impact index is defined as:

$$Drag\ Index = U_j = \frac{\bar{m}_j}{\frac{1}{n}\sum m_j} \tag{7}$$

Where $ij = 1, \dots, n$, n is the number of production sectors, and $\bar{m}_j$ is the average impact of the sector or account j on the other sectors. Similarly, by row, the dispersion index is defined as:

$$Dispersion\ Index = U_i = \frac{\bar{m}_i}{\frac{1}{n}\sum m_i} \tag{8}$$

Where: $ij = 1, \dots, n;$ n are the number of production sectors; and $\bar{m}_i$ is the average impact of the sector or account i on the other sectors.

The classification of the sectors is established according to the values obtained for the drag index (total sum of each column) and dispersion index (total sum of each row), which, when compared to the average, classifies each sector of a country's economy. The corresponding criteria are presented in Table 2.

Table 2
Classification of Economic Sectors according to the value of Rasmussen Indices

Sector Type	Interpretation
Key Sectors: Both indexes > 1	These are the sectors most integrated with the other sectors of the economy as a whole.
Driving Sectors: Drag index > 1	These are the sectors that drive growth due to the increase in their production, as they require more inputs from the other sectors.
Strategic sectors: Dispersion index > 1	These are the sectors with the largest supply of inputs, so they could represent a bottleneck in the event of an occasional increase in the economy.
"Independent" sectors: Both indexes < 1	They are poorly integrated into the other sectors of the economy as a whole.

Source: Input-Output Accounting and a comparative-structural analysis of the Mexican economy (Núñez and Romero, 2016, p. 13)

Energy intensity

Energy intensity is the amount of energy used per output delivered by subsector and end-use. It is usually obtained as energy consumed divided by an economic indicator, which can be the gross domestic product (GDP), or value added by sector. This concept is established through different components, among which are: energy efficiency, type of base industry, exchange rate, cost of energy services, country size, and type of climate and its behavior (IEA, 2015, pp. 17-18) and is applied as an indicator of sustainable economic growth. The European Union has also chosen it as one of the fourteen structural indicators through which the progress achieved within the framework of the Lisbon Strategy is assessed (Mendiluce, 2010, p. 24).

Energy efficiency

Energy efficiency, understood as an energy resource, has the extraordinary capacity to contribute to energy security, economic growth, and the improvement of health and well-being. Distinctively, it constitutes a resource in decreasing greenhouse gas emissions (IEA, 2015, p. 3). Mexico has a program called "Energy Efficiency Statistics, Modeling, and Indicators," and its objective is to integrate and update energy efficiency statistics and indicators, through which the understanding of energy end uses in the different consumption sectors can be improved (Conuee, 2018, pp. 2–3).

An energy efficiency indicator is defined as the set of measures established to reduce, while remaining economically viable, the amount of energy needed to cover the energy requirements of the services and goods requested by society, while also guaranteeing the appropriate level of quality (DOF, 2015). According to Mendiluce and Linares (2011, p. 3), the appropriate procedure to evaluate Energy

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Efficiency (EE), in macroeconomic terms, is through Energy Intensity (EI). As mentioned above, this EI indicator determines the link between energy consumption and the volume of economic activity and is calculated as the ratio of energy consumption to gross domestic product (GDP). It is therefore the inverse of energy efficiency (EE). Thus, in order to improve energy efficiency, it is essential to reduce energy intensity.

$$EI = \frac{energy\ consumption}{GDP} \tag{9}$$

$$EE = \frac{GDP}{energy\ consumption} \tag{10}$$

Mitigation

Mitigation is defined as:

> "Technological changes and replacement that reduce resource input and emissions per unit of output. Although various social, economic and technological policies would reduce emissions, mitigation, as it relates to climate change, is the implementation of policies aimed at reducing greenhouse gas emissions and enhancing sinks" (IPCC, 2008, p. 84).

Although Mexico's per capita carbon emissions are not high, energy and carbon intensity are high compared to other OECD countries. Therefore, for Mexico to have the conditions to achieve its greenhouse gas emissions reduction target, it will be paramount to implement appropriate pricing, remove unproductive subsidies, and optimize the country's energy efficiency (OECD, 2015, p. 19).

Methodology

Database

The most recent Mexican Input-Output Matrix (IOM) published by INEGI in 2017, specifically the domestic symmetric product-to-product matrix, total economy, domestic origin, at 2013 basic prices for 79 subsectors (INEGI, 2017), was used for this paper.

http://dx.doi.org/10.22201/fca.24488410e.2021.2487

Obtaining the key sectors in electricity consumption

A simplistic example of calculation using the most detailed disaggregation available will be applied to illustrate the methodology used to obtain the key subsectors in electricity consumption without going into the detail of the various tariffs by type of sector and amount of consumption. That is, the electricity consumption of three sectors is considered, which has a direct relationship with the price tariff and quantity of consumption, as shown in Table 3, considering the information concerning the symmetrical matrix of Input-Output, product-to-product, total economy, domestic and imported origin, at 2013 basic prices for 19 subsectors, published by INEGI (2017). The target is the row corresponding to electricity consumption aggregated to three sectors; therefore, these values are placed, and the GDP row is excluded.

Table 3
Simplified IOM 2013 aggregated to three sectors, domestic by type of activity including electricity consumption, prices in Millions of pesos at 2013 basic prices.

Activities	Primary Sector	Industrial Sector	Services Sector	Final Demand	Total production
Primary Sector	64 515	421 732	5 170	288 325	779 742
Industrial Sector	117 098	3 021 320	746 758	9 753 926	13 639 102
Services Sector	55 740	1 853 896	1 805 456	9 508 711	13 223 804
Value added	542 389	8 342 154	10 666 420	2 009 673	21 560 636
Total production	779 742	13 639 102	13 223 804	21 560 636	49 203 284
Electricity consumption	6 404	174 008	101 947	80 209	362 568

Source: created by the authors based on Mexico's Input-Output Matrix at 2013 basic prices (INEGI, 2017)

Based on these data, a simple analysis shows that the impact of the electricity industry on the national production structure is as follows: of the total electricity consumption corresponding to production processes, 61.63% is destined to the industrial sector, 36.11% to the services sector, and 2.27% to the primary sector. Since the units of this Input-Output matrix are indicated in millions of pesos, the analysis will be applied directly to these data, bearing in mind that the results obtained are handled in percentages of the amounts in millions of pesos. The diagonal matrix with the electricity consumption is given by the division of the electricity consumption line by the total production, that is:

$$\hat{\boldsymbol{e}} = \begin{bmatrix} 0.01686 & 0.00000 & 0.00000 \\ 0.00000 & 0.01443 & 0.00000 \\ 0.00000 & 0.00000 & 0.00951 \end{bmatrix}$$

The Leontief inverse matrix for three sectors is given by:

$$\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}} = \begin{bmatrix} 1.097702 & 0.044191 & 0.003387 \\ 0.220870 & 1.308282 & 0.085661 \\ 0.125646 & 0.209605 & 1.171884 \end{bmatrix}$$

Then, calculating the electricity consumption multiplier matrix, $\hat{\boldsymbol{e}} \cdot (\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}}$, gives the following:

$$\hat{\boldsymbol{e}} \cdot (\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}} = \begin{bmatrix} 0.009015 & 0.000363 & 0.000028 \\ 0.002828 & 0.016691 & 0.001093 \\ 0.000969 & 0.001616 & 0.009034 \end{bmatrix}$$

Which corresponds to the matrix of electric energy multipliers (REE), so the total impact and the distributed index are shown in Table 4, in which the sum of columns and rows is presented.

Table 4
Total drag and distribution effects of electricity consumption in the 3 primary sectors

Activities	Primary Sector	Industrial Sector	Services Sector	Total distribution effect
Primary Sector	0.009015	0.000363	0.000028	0.009406
Industrial Sector	0.002818	0.016691	0.001093	0.020602
Services Sector	0.000969	0.001616	0.009034	0.011619
Total drag effect	0.012802	0.018670	0.010155	

Source: created by the authors based on Mexico's Input-Output Matrix at Basic Prices 2013 (INEGI, 2017)

Applying the Rasmussen Indices described above, the drag and distribution indices for electricity consumption for the 3 primary sectors are obtained, as shown in Table 5.

Table 5
Drag and distribution indices for electricity consumption in the 3 primary sectors

Activities	Electricity consumption multiplier matrix			Total dispersion impact	Distribution index
	Primary Sector	Industrial Sector	Services Sector		
Primary Sector	0.009015	0.000363	0.000028	0.009406	0.677885301
Industrial Sector	0.002818	0.016691	0.001093	0.020602	1.48474654
Services Sector	0.000969	0.001616	0.009034	0.011619	0.837368159
Total drag impact	0.012802	0.018670	0.010155	0.041627	
			Medium effect:	0.013876	
Drag index	0.922612	1.345519	0.731868		

Source: created by the authors based on Mexico's Input-Output Matrix at Basic Prices 2013 (INEGI, 2017)

Therefore, according to Table 5, the industrial sector can be identified as the key sector for electricity consumption in Mexico. To verify the application of Equation (5), the final demand is included in the Input-Output data:

$$\mathrm{REE_{pg}} = \hat{e} \cdot (\mathrm{I} - \mathrm{A})^{-1} \cdot \hat{y}$$

The following results were obtained:

$$\mathrm{REE_{pg}} = \begin{bmatrix} 0.009015 & 0.000363 & 0.000028 \\ 0.002828 & 0.016691 & 0.001093 \\ 0.000969 & 0.001616 & 0.009034 \end{bmatrix} * \begin{bmatrix} 288{,}325 \\ 9{,}753{,}926 \\ 9{,}508{,}711 \end{bmatrix} = \begin{bmatrix} 6{,}404 \\ 174{,}008 \\ 101{,}947 \end{bmatrix}$$

The result indicates that the electricity consumption values obtained agree with those presented in Table 3.

Obtaining the intensity and efficiency of electricity consumption

Equations (9) and (10) are applied to obtain these values. Table 6 shows electricity consumption and Gross Domestic Product (GDP) in millions of pesos at 2013 basic prices.

http://dx.doi.org/10.22201/fca.24488410e.2021.2487

Table 6
Intensity and efficiency in electricity consumption according to IOM 2013 aggregated to three sectors, domestic by type of activity, prices in millions of Pesos at 2013 basic prices.

Activities	Electricity consumption	GDP	Intensity in electricity consumption	Efficiency in electricity consumption
Primary Sector	6 404	476 794	0.0134	74.4532
Industrial Sector	174 008	5 141 987	0.0338	29.5504
Services Sector	101 947	10 033 297	0.0102	98.4171

Source: created by the authors based on Mexico's Input-Output Matrix at Basic Prices 2013 (INEGI, 2017)

Results

Obtaining the key subsectors in electricity consumption for 79 subsectors

Applying the proposed methodology, 19 key subsectors in electricity consumption were identified, and are presented in Table 8. Of these 19 key subsectors, 14 correspond to the industrial sector (marked in bold in Table 7) and 5 to the services sector. On the other hand, only 7 sectors identified as having the highest electricity consumption are key subsectors (indicated with * in Table 7).

Table 7
Key subsectors in electricity consumption

#	NAICS CLASS CODE	SUBSECTOR	Drag index	Distribution index
1	222*	Water and piped gas supply	9.734121	11.851983
2	327*	Manufacture of products based on non-metallic minerals	4.877220	5.296454
3	313	Textile input manufacturing and textile finishing	3.218297	3.985156
4	212*	Mining of metallic and non-metallic minerals, except oil and gas	2.331348	3.890318
5	326*	Plastic and rubber industry	2.211306	2.818198
6	331*	Basic metal industries	2.185495	2.560128
7	332*	Manufacture of metal products	2.121818	2.164235
8	322	Paper industry	1.684613	2.054574
9	321	Wood industry	1.635226	1.717021

10	323	Printing and related industries	1.870621	1.518164
11	721	Temporary lodging services	1.288929	1.389916
12	311*	Food industry	1.104060	1.277370
13	339	Other manufacturing industries	1.318026	1.249550
14	512	Film and video industry and sound industry	1.311059	1.219548
15	337	Manufacture of furniture, mattresses, and blinds	1.772252	1.174112
16	314	Manufacture of textile products, except garments	1.631148	1.164285
17	813	Associations and organizations	1.117352	1.047678
18	511	Publishing of newspapers, magazines, books, software and other materials	1.168013	1.008165
19	493	Warehousing services	1.185662	1.007305

Source: created by the authors based on Mexico's Input-Output Matrix at 2013 basic prices (INEGI, 2017)

Obtaining the intensity and efficiency of electricity consumption

As in the example of 3 sectors, Equation (9) is applied to obtain the intensity of electricity consumption, obtaining the main subsectors shown in Table 8.

Table 8
Subsectors with the highest intensity of electricity consumption

#	NAICS CLASS CODE	SUBSECTOR	Intensity in electricity consumption
1	222	Water and piped gas supply to final consumers	0.3298228
2	327	Manufacture of products based on non-metallic minerals	0.2731411
3	313	Textile input manufacturing and textile finishing	0.1692285
4	326	Plastic and rubber industry	0.1532228
5	332	Manufacture of metal products	0.1096351
6	323	Printing and related industries	0.0908286
7	322	Paper industry	0.0902579
8	331	Basic metal industries	0.0855081
9	329	Other manufacturing industries	0.0789066
10	335	Manufacture of electrical accessories, appliances, and electrical power generation equipment	0.0718251

Source: created by the authors based on Mexico's Input-Output Matrix at 2013 basic prices (INEGI, 2017)

According to the consumption of electrical energy and the Gross Domestic Product corresponding to each subsector, the 5 main subsectors in consumption intensity are: Water supply and

http://dx.doi.org/10.22201/fca.24488410e.2021.2487

piped gas supply to the final consumer, manufacture of products based on non-metallic minerals, manufacture of textile inputs and textile finishing, plastics and rubber industry, and manufacture of metal products.

Equation (10) is applied to obtain the main subsectors with the highest electricity consumption efficiency, presented in Table 9.

Table 9
Subsectors with the highest efficiency in electricity consumption

#	NAICS CLASS CODE	SUBSECTOR	Efficiency in electricity consumption
1	238	Specialized works for construction	1,167
2	237	Construction of civil engineering works	762
3	521	Central Banking	581
4	211	Oil and gas extraction	524
5	482	Rail transportation	512
6	484	Freight transportation	506
7	483	Transportation by water	497
8	236	Building	422
9	531	Real Estate Services	404
10	112	Breeding of animals	323

Source: created by the authors based on Mexico's Input-Output Matrix at 2013 basic prices (INEGI, 2017)

Conclusions

The contribution of this study in relation to other works that address this topic is that it exclusively analyzes the electricity sector, identifying 19 key subsectors in electricity consumption, which means it can be considered the first study of its kind in Mexico. In addition, it identifies the subsectors with the highest intensity in electricity consumption. Given that final electricity consumption is a function of sectoral consumption, energy content, production in each sector, and capital generation, the results obtained make it possible to determine the link between sectoral economic behavior and electricity consumption and demand, which can be used to propose scenarios for improving efficiency in electricity consumption and mitigation.

Of the 19 key subsectors identified in electricity consumption, 14 correspond to the industrial sector and 5 to the services sector. Of the main subsectors identified with the highest intensity in electricity consumption, 8 are key subsectors in the consumption of this supply, as follows: water supply and piped gas supply to the final consumer, water bottling and piped gas supply to the final consumer, plastics and rubber industry, manufacture of metal products, printing and related industries, paper industries, basic metal industries and manufacture of accessories, electrical appliances, and electrical power generation equipment.

Given that the key subsectors and those with the highest intensity of electricity consumption are present throughout Mexico, they require special supervision—to reduce their intensity, increase their efficiency, and reduce emissions of polluting gases—until the causes of their high electricity consumption are determined and clean technologies for generating energy are promoted and installed. For the consumption efficiency program to be feasible and significant, it must be developed with the participation of the government and the companies that make up the key and most intensive subsectors.

Considering the immense potential of existing resources in Mexico and that electricity generation has a significant diversity of technology for its exploitation, it would be useful to have a "more aggressive" program for analyzing the incorporation and substitution of clean energy generation plants. In Mexico, no governing body is dedicated exclusively to this objective, but rather, this activity is distributed among different areas of the Ministry of Energy (SENER), the Federal Electricity Commission (CFE), and some of the country's universities. Recently, greater importance has been given to the creation and operation of the wholesale electricity market, with the study of the application of Mexico's immense natural resources in electricity generation from clean energy being a higher priority.

In 2017, there was an installed capacity of 434 MW of distributed generation. Therefore, performing a technical-economic feasibility analysis to estimate the potential generation increase with this method and other non-polluting ones would be useful. In consideration of the large amount of emissions produced by the 3 coal-fired power plants (23.6 Mt of CO_2), it is necessary to work on a short-term retirement program—since the retirement of 1400 MW is scheduled for 2029—replacing them with another type of generation technology (preferably clean energy), since on average they emit 773 kg of CO_2 per MWh generated, a value above the average emissions, compared to 346 kg of CO_2 per MWh generated by the combined cycle technology, a value lower than the average for the electricity sector.

The Electricity Sector Development Program (PRODESEN) and the 2018-2032 electricity sector outlook indicate the retirement of generation units and the increase of generation capacity with clean energy, but there is no program to replace conventional power plants with clean energy plants. In other words, no future planning envisions the substitution of power plants with higher pollutant emissions by clean energy ones or those with lower pollutant emissions.

An inventory of the location of the production centers with the highest electricity consumption intensity and of the key subsectors in electricity consumption will allow the replacement of conventional power plants by clean energy plants or those with lower greenhouse gas emissions or alternatively, the relocation or incorporation of production centers in areas with greater clean energy capacity. This project must involve the participation of the government and the companies that constitute the main industrial production centers.

Acknowledgments

To the Consejo Nacional de Ciencia y Tecnología (CONACYT) for their valuable support for this research.

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