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Electricity demand of non-residential buildings in Mexico

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ABSTRACT

By now, there is a consensus that non-residential buildings (commercial and public buildings) present important opportunities for reducing cost, fuel inputs and greenhouse gas emissions, especially because of their intensive use of electricity. Till now, however, in emerging economies energy efficiency opportunities in buildings are typically more focused on households. In Mexico, official government statistics suggest that the non-residential sector electricity demand is low compared to the residential and industrial sectors, but previous studies suggest that non-residential electricity use is underestimated due to the reliance of electricity tariff classes, which may not adequately distinguish large commercial buildings from industrial facilities. The analysis presented here follows the same general bottom-up methodology as two recent studies, but enhances them with a more rigorous and up-to-date assessment of electricity drivers of building sub-types from a variety of sources. The result is a more reliable estimate of non-residential electricity demand by building sub-type and climate zone. Non-residential buildings electricity demand in 2017 is found to be 66.9 TWh, which is nearly three times the official estimate of 22.6 TWh in the same year. Such a large discrepancy likely distorts the picture of energy use in the country and may lead to an under-emphasis by government and private sector actors in managing energy use in this important sector.

1. Introduction

By now, there is a consensus that non-residential buildings (commercial and public buildings) present important opportunities for reducing cost, fuel inputs and greenhouse gas emissions, especially because of their intensive use of electricity. Because of the mild or warm climate in Mexico, space heating and water heating use are moderate in non-residential buildings. Therefore, this study focuses on electricity use, while recognizing that the use of other fuels is potentially important. According to data from OECD (2019), in 2016 the Mexican services sector accounted for nearly 65 % of the economy size. Similar economies to Mexico based on the relative size of the services sector and GDP per capita are listed in Table 1. Data on total electricity consumption and relative size in the economy for the services sector was extracted from (OECD, 2019) for the year 2016. The electricity consumption percentage for the services sector relative to total electricity consumption is also reported in Table 1. As can be seen, Mexico is the country in which the services sector has the smallest percentage in electricity consumption among “similar economies”. Data shows that compared to other countries, in Mexico there would be 60 % to more than 200 % less electricity consumption in the services sector. This suggests that electricity consumption from the Mexican services sector might present an underestimation issue.

Since the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris, France in December 2015, attention on modeling the future energy use of nations has grown in importance. The Nationally Determined Contributions (NDC) (Gobierno de la República, México, 2015) as well as the National Energy Transition and Sustainable Energy Use Strategy (SENER, 2014) have set the goal for national reduction of greenhouse gases emissions, and researchers now focus on finding the paths to achieve it. For these reasons, it is important to understand how energy is used at the present time in the different sectors in any economy, so that a precise forecast of energy use can be made. For this purpose, nations keep track of energy use through National Energy Balances (NEB). The Mexican Energy Balance (MEB) is the main reference in the country for tracking energy flows through the economy, and is published every year by the Energy Secretariat (SENER). The MEB contains disaggregated information of final energy use by fuel type for the different economic sectors, namely: residential, transport, agricultural, commercial, public services and industry (see Table 2). The industrial sector is further disaggregated into 15 industrial subsectors which correspond to the highest energy consumers

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Table 1
Relative size and electricity consumption of services sector and GDP per capita for selected countries in 2016.

	Relative size of services sector	Electricity consumption % of services sector	GDP/capita[a] (USD/Hab)
Brazil	73.1 %	27.0 %	13,980
Chile	64.0 %	16.9 %	20,784
Colombia	62.4 %	22.0 %	12,860
Mexico	65.0 %	8.9 %	16,946
South Africa	68.3 %	14.5 %	12,124
Turkey	61.0 %	27.9 %	23,424

[a] GDP in constant USD 2010 prices in PPP.

Table 2
Final energy sectorial consumption per fuel type for 2017, according to SENER (PJ).

	Natural Gas	Electricity	Oil & Coal products[a]	Others[b]	Total
Residential	35.5	213.0	246.5	256.7	751.6
	5%	28 %	33 %	34 %	100 %
Commercial	13.8	81.5	64.4	–	159.7
(NRB)	***9%***	51 %	40 %	–	100 %
Public services	–	28.9	–	–	28.9
	–	100 %	–	–	100 %
Agricultural	–	41.7	140.3	–	181.9
	–	23 %	77 %	–	100 %
Transport	2.2	3.9	2354.1	–	2360
	0.1 %	0.2 %	99.7 %	–	100 %
Specific Industries[c]	425.4	164.8	263.1	–	897.1
	50 %	19 %	31 %	–	100 %
Miscellaneous	257.8	401.9	313.2	6.7	979.6
Industries	26 %	41 %	32 %	***1%***	100 %
Total industry	683.2	566.7	576.2	50.5	1876
	36 %	30 %	31 %	***3%***	100 %

[a] Includes coal, petroleum & coal coke and refined oil products.
[b] Includes solar energy and biomass.
[c] Iron and Steel; Cement and cement products; Petro-chemistry; Chemistry; Mining; Glass and glass products; Pulp and paper; Sugar; Beer brewing; Cars and Trucks manufacturing; Construction; Bottled water and beverages; Rubber products; Fertilizers; Tobacco.

accounting for nearly 54 % of total industrial energy use in 2016. The remaining industrial energy consumption (46 %) is categorized as "Miscellaneous"[1] industries (SENER, 2017). Furthermore, the miscellaneous category is responsible of more than 70 % of industrial electricity consumption, meaning that more than 70 % of industrial electricity consumption is not attributed to a specific industrial activity. The category *"Public services"* accounts only for energy consumed for public street lighting and potable and waste water pumping.

Regarding electrical consumption data, SENER relies on the Federal Commission of Electricity (CFE), which is the governmental institution uniquely charged with generating, transmitting and distributing electrical energy to all sectors[2]. The CFE electricity distribution system is based on a sectorial categorization and is organized by 6 main electrical tariff types as can be seen in Table 3. The major differences between the tariff types are the voltage supply, the power demand and the pricing. The agricultural tariff type is mainly for water pumping with a special tariff for pumping water at night, and is differentiated according the tension levels. The public services tariff is used for public street lighting in the main cities (Mexico City, Monterrey and Guadalajara), public street lighting for the rest of the country and for water pumping. There are 7 electrical tariffs for the domestic sector, which are assigned depending on the average annual temperature where the households are located, and one more for High Domestic Consumers (D.A.C. for its acronym in Spanish). For the Non-Residential Buildings (NRB) sector there are two different tariff types based on the power demand level. The industrial electrical tariffs are subdivided based in the supply voltage: medium and high. For the medium voltage, there is a tariff corresponding to a power demand lower than 100 kW and one for a power demand higher than 100 kW. For the high-voltage supply, the tariffs are differentiated depending on if they are delivered at the transmission or sub-transmission level and are time dependent. This type of tariff corresponds to the energy-intensive industries such as the iron and steel or chemical sectors, among others. Information on the sales of electricity by CFE was obtained and compared with the information reported in the MEB. It was observed that for the agricultural, domestic and public services sectors, both databases reported the same amount of electricity consumption. Statistics for usage in tariffs 2 and 3 (Medium voltage commercial buildings) through 2013 correspond to demand reported as 'commercial' in the MEB. After that, we believe that the difference between sales and the data reported in the MEB accounts for self-electric generation in the commercial sector. According to (Tecener SA de CV, 2015), which is a guide on electric tariffs for micro, small and medium sized businesses, industrial electrical tariffs types can be applied to economic units belonging to the commercial sector. This is mainly because of the definitions of the tariffs, and for very large consumers in the commercial sector that have a power demand higher than 100 kW, industrial tariffs are applied. Indeed, in (GIZ, 2013) it is reported that more than half of surveyed hotels were in tariff types OM or HM, which correspond to medium industries (see Table 3). For this reason, in the MEB there exists a misallocation of electric consumption of NRB into the "Miscellaneous" industrial user category.

Table 4 shows the historical average annual growth rate of the specific industries, miscellaneous industries and the services sector since the year 2000 (INEGI-BIE, 2019). It can be seen that while the average annual growth rate for the services sector increased over the period, average annual growth rate for the specific industrial sectors decreased. The miscellaneous industrial sectors experienced almost no growth during the period. This is also related to the fact that services sector GDP is not only larger than the industrial sectors (relative to GDP), but is growing in importance in the Mexican economy.

As shown by Table 4, the economic behavior of the services sector which drives non-residential building consumption and the industrial sector (in particular compared to the miscellaneous industrial sectors) is very different. Furthermore, the end uses from both sectors are also very different. Hence, the fact that electric consumption of NRB is miscategorized as "miscellaneous" industrial sectors may have a major impact on the accuracy of energy demand growth projections, and for informed policy decisions targeting energy efficiency in this sector.

The buildings energy sector is well-known as one of the major drivers of energy demand and greenhouse gas emissions worldwide, due to the high reliance of electricity in this sector. In Mexico, where space heating and water heating requirements are moderate, electricity from lighting, refrigeration, air conditioning and other electric appliances and equipment is particularly important. Fortunately, a broad range of opportunities exist to mitigate the negative impacts of electricity in buildings, through energy efficiency of equipment and building envelopes, as well as intelligent controls and occupant behavior. By now, residential building electricity use has been relatively well-studied and energy efficiency programs for major household equipment have a long and successful history, including in Mexico (McNeil & Carreño, 2015) (Sánchez Ramos et al., 2007). Electricity consumption in the non-residential sector, which includes commercial and public buildings, is less

[1] Precisely, these are referred to as "other industrial branches" (*otras ramas industriales*)

[2] This is partially true, since electric self-generation is permitted. Due to the recent energy reform adopted in Mexico in 2012, electrical market is being liberalized. In consequence new tariff schemes are being adopted in the CFE starting from 2018.

Table 3
Summary of the electrical tariff types in Mexico.

Tariff category	Tariffs codes	Voltage supply[a]	Power demand
Agricultural	9, 9 M, 9CU, 9N	Low and Medium	–
Public services	5, 5A, 6	–	–
Domestic	1, 1A, 1B, 1C, 1D, 1E, 1 F, D.A.C.	Low	–
Commercial (NRB)	2,3	Medium	2 (< 25KW); 3 (> 25 kW)
Medium Industry	OM, HM, HMC	Medium	OM (< 100 kW); HM (> 100 kW)
Big Industry	HS, HSL, HT, HTL	Subtransmission and Transmission levels	–

[a] Low: < 1 kV; Medium: 1 kV < V < 35 kV; Subtransmission: 35 kV < V < 220 kV; Transmission: > 220 kV.

Table 4
Historic macroeconomic variables for industry and services sectors, 2000-2017.

	2000 – 2005		2006 – 2011		2012 – 2017	
	Average annual growth rate	Average GDP representation %	Average annual growth rate	Average GDP representation %	Average annual growth rate	Average GDP representation %
Specific industries	2.2 %	36 %	1.9 %	34 %	1.2 %	32 %
Miscellaneous Industries	0.9 %		−0.6%		0.3 %	
Services sector	2.1 %	57 %	2.6 %	59 %	3.3 %	61 %

well-understood. The SIE[3] estimated that electricity consumption in this sector was 22.6 TW h in 2017, or about 9% of all electricity demand in Mexico in that year. As a result, the NRB sector is considered in the Energy Transition Strategy (SENER, 2014) to be a significant, but not dominant sector contributing to final energy use. Industry, on the other hand was estimated to contribute with 157 TWh, or 61 % of electricity demand in Mexico. Accurate assessment of the electricity demand from NRB is critical in order to put this economic sector into proper perspective in national energy consumption. The present work is an attempt to estimate the electricity consumption of the NRB in Mexico, and is a component of a research effort led by Lawrence Berkeley Laboratory's Mexico Energy Initiative collectively known as the Mexico Energy Pathways Initiative (MEPI).

In sections 2.1 to 2.7 we present the data sources and methodologies employed for every building type. In section 2.8 the sectorial results are presented. In section 3, we discuss the results and its implications in the sector, in energy policy and in energy forecasting. Finally, some conclusion remarks are presented in section 4.

2. Methodology and data sources

According to our findings, there are only two previous efforts that tried to estimate the electricity consumption by NRB in Mexico for the years 2009 and 2012 respectively (de Buen Rodríguez, 2009) and (García Kerdan, 2015). The 2009 MEB (SENER, 2010) reports an electricity consumption of the NRB sector of 13.48 TW h, while (de Buen Rodríguez, 2009) estimated NRB consumption in that year to be 22.35 TW h. According to the 2012 MEB (SENER, 2013), the NRB sector consumed 14 TWh in 2012 and (García Kerdan, 2015) estimated this consumption to be 22.53 TWh. Both studies estimate NRB electricity consumption to be around the double of what the MEB reports. Previous studies have attempted to re-evaluate non-residential electricity demand through "bottom-up" estimates combining an Electricity Use Intensity (EUI) with estimates of sub-sector size (floor space, number of establishments, number of hotel rooms, etc.) to arrive at total electricity demand. The EUI [kWh/m^2] is defined for different building types; such as hotels, schools, offices, restaurants, hospitals, shopping centers, among others. As pointed out by both studies, there is very little information about the energy use and floor space for NRB in Mexico. The only source of information for electricity use comes directly from individual energy audits undertaken by the Mexican Electric Energy Saving Trust (FIDE), which were analyzed by both authors and reported in the form of EUI. In particular, (García Kerdan, 2015) utilizes climate zone-specific EUI data, which is important in Mexico due to the climatic diversity in the country. The analysis presented below follows the same general bottom-up methodology as these two recent studies, but enhances them with a more rigorous and up-to-date assessment of electricity drivers of building subtypes from a variety of sources. Table 5 presents the EUI data found in previous studies mentioned above. All building types and climate zones were found in (García Kerdan, 2015) except for theatres which was found in (de Buen Rodríguez, 2009). The reason for selecting the data mentioned above, is that it is the most complete and up-to-date information available. The result is a more reliable estimate of non-residential electricity demand by building sub-type and climate zone. In this work, eight building types in three different climatic regions were analyzed. According to García Kerdan (2015), representative cities were chosen for every climatic zone: Mexico city for the temperate zone, Monterrey for the hot dry zone and Acapulco for the hot humid zone. These climatic zones are defined according to the climatic Köppen classification (Chen & Weiteg Chen, 2013) as follows:

- Hot dry (Monterrey): Average annual temperature around 23 °C with annual precipitation of 500 mm. This would correspond to semiarid climate type (BS) according to the Köppen classification[4].

Table 5
Building types and climate-zone specific EUI data (kWh/m^2-year).

	Hot Dry	Hot Humid	Temperate
Hotels	325.4	281	155.3
Offices	167.8	199.7	109.6
Schools	169.8	98.2	40.5
Hospitals	460.3	393.4	218.5
Restaurants	326.7	336.3	210.3
Department stores	191.9	229.3	115.9
Supermarkets	403.2	443.1	334.8
Theatres	242.8	242.8	242.8

[3] Energetic Information System (SIE for its Spanish acronym).

[4] For more detail about the Köppen climate classifications, climate types and subtypes see (Chen and Weiteg Chen, 2013).

Fig. 1. Climatic regions in Mexico.

- Hot humid (Acapulco): Average annual temperature around 27 °C with annual precipitations of +1000 mm. The hot humid zones mostly correspond to the tropical savannah climate type (Aw), with some zones of tropical monsoon (Am) and tropical rainforest (Af).
- Temperate (Mexico City): Average annual temperature of 18 °C with variable seasonal precipitations and warm temperature in summer. This would correspond to climate types temperate with dry summer or winter (Cs and Cw) and temperate regions with no dry season (Cw).

The per-area electricity consumption of building types shows a strong impact of climate, primarily due to intensive use of air conditioning in warmer regions. In most building types, intensity in the hot regions are roughly twice as high as in the temperate regions[5]. This effect roughly mirrors the residential sector, where air conditioning is still rare in the temperate zones, but intensive during the summer months in the North and Southeast of the country. In the non-residential sector, one would expect the effect to still be strong, but mitigated by the use of air conditioning in public spaces even in the temperate Central Zone. The climatic regions are defined by federative entity (state)[6] assuming that every state corresponds to a unique climatic region. Even though in general this is not accurate, this approximation allows for mapping to other data, which are generally provided at the state level. According to the map shown in Fig. 1, the following correspondence between federative entities and main climatic regions was made:

- **Hot dry**: Baja California, Baja California Sur, Sonora, Sinaloa, Nayarit, Chihuahua, Coahuila, Durango, Nuevo León and Tamaulipas.
- **Hot humid**: Veracruz, Tabasco, Campeche, Yucatán, Quintana Roo, Guerrero, Oaxaca, Chiapas and Colima.
- **Temperate**: Aguascalientes, San Luis Potosí, Zacatecas, Jalisco, Guanajuato, Michoacán, Querétaro, Hidalgo, Estado de México, Morelos, Tlaxcala, Puebla and Ciudad de México.

[5] The exception is theaters, where regional data were not available.
[6] Mexican Federal Entities include 32 states.

The values of the electricity use by type of building and region were obtained using several methodologies, accordingly with the available data. However, in most cases electricity use is the product of the EUI and the estimated floor space.

$$E_{ij} = EUI_{ij} \times S_{ij} \quad (1)$$

Where i is the building type and j is the climatic region. The activity variable S_{ij}, represents floor space (in square meters). This variable is found directly from data sources, or derived from number of employees (for office buildings), occupied hotel rooms (for hotels) or number of students (for schools). Data sources and derivations of floor space are described in the following sections for each building types. The EUI for each building type was obtained directly from (García Kerdan, 2015) summarized in Table 5.

2.1. Stores and supermarkets

The number of establishments as well as occupied floor space for this category was directly available from the 2017 annual report of the National Association of Self-service and Departmental Stores (ANTAD for its Spanish acronym) (Asocioación Nacional de Tiendas de Autoservicio y Departamentales, 2017). It was found that in Mexico in 2017 there was a total floor space occupied by supermarkets of 15 million m^2, which consumed 5.7 TWh of electricity. There was also 13.7 million m^2 of department stores, which consumed 2.2 TWh of electricity. Combined they occupy 28.7 million m^2 and consume 7.9 TWh of electricity (see Fig. 2). The figure clearly shows the impact of electricity consumption for air conditioning in the hot regions, which we expect to be dramatically higher than the temperate zones. The effect is prominent in department stores, but less in supermarkets, where the impact of refrigeration is expected to be significant, and less climate-dependent.

2.2. Hotels

The German Agency for Technical Cooperation (GIZ) has presented an energy consumption analysis that aimed to develop a methodology for benchmarking the energetic performance of hotels in Mexico. The

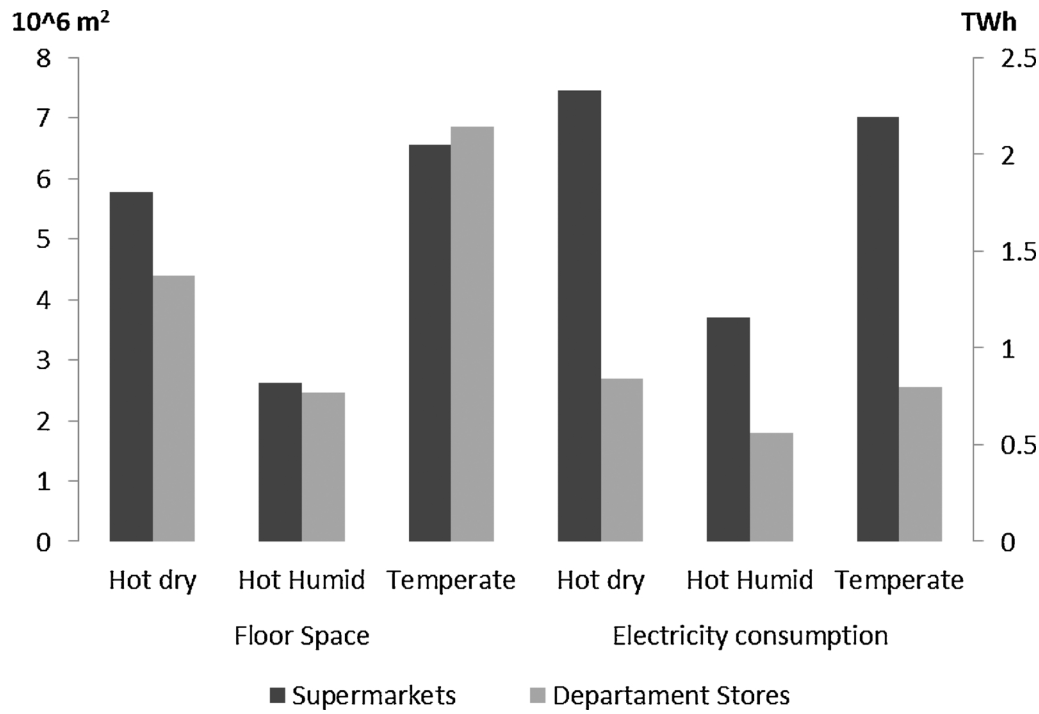

Fig. 2. Electricity consumption for stores and supermarkets in Mexico, 2017.

sample was composed by 323 hotels, mainly 2 and 3 stars, even though the sample contains 1, 4 and 5 stars hotels as well (GIZ, 2013). They present electricity consumption intensity by occupied room per day, per hotel category and climatic region. For those hotel categories in a specific climatic region that didn't had available data, the average for that climatic region was taken. The statistical compendium published by the Tourism Secretary (SECTUR) contains the number of available rooms in each state and the occupancy rate (Secretaría de Turismo, 2017). In Fig. 3 electricity consumption results are presented by number of hotel stars and by climatic region. It was found that total electricity consumption for hotels is 6.6 TWh.

2.3. Restaurants

According to the Restaurants and Seasoned Foods Industry National Chamber (CANIRAC for its Spanish acronym) the restaurant sector is composed of classes belonging to the subsector 722 of NAICS[7] except for the classes 7223 and 7224 (Cámara Nacional de la Industria de Restaurantes y Alimentos Condimentados, 2014), accounting for a total of nine types of restaurants (see Fig. 4). Based on the Economical Units National Directory (DENUE for its Spanish acronym) published by INEGI[8] (Instituto Nacional de Estadística y Geografía, 2016), it was possible to determine the existing number of establishments of each class of restaurant by climatic region in 2016. An average annual growth rate of 4.5 % found in (Cámara Nacional de la Industria de Restaurantes y Alimentos Condimentados, 2014)[9] was used to update to 2017 the numbers obtained previously. An estimation of the size of the restaurants by type was made, with which it was possible to give an approximation of total floor space. Electricity consumption by restaurant type was calculated using Eq. (1). These estimates result in 45.5 million m^2 of restaurant floor space and a total electricity consumption of 12.1 TWh.

2.4. Hospitals

Fig. 5 shows the estimations made with data taken from an energy efficiency study on hospitals commissioned by the General Energy Efficiency and Sustainability Directorate of SENER. The aim of that work was to assess energy use of hospitals in Mexico and to propose demand reduction measures (Creuhueras Díaz, et al., 2015). This document contains information on the number of Medical Attention Units (MAUs) in every climatic region, the average floor space by MAU and the average yearly electricity consumption by the attention level (services provided) of the MAU in every climatic region. With this, it was possible to calculate the EUI by level of attention and by climatic region and the total floor space. Attention level is divided in three categories, in which the level 1 corresponds to small clinics providing only basic services. Level 2 MAUs are generally large regional hospitals providing all types of care. Level 3 MAUs are understood to be specialty hospitals. Data on the number of MAUs corresponds to the year 2014. In order to have updated information on the number of MAUs, the MAU per person in 2014 by federal entity was assumed constant and used to calculate the number of MAUs according to the population in 2017. It was found that hospitals occupy a total floor space of 86 m^2 and consume 17.3 TW h of electricity.

2.5. Schools

The General Energy Efficiency and Sustainability Directorate of SENER commissioned an energy efficiency study for public schools. This study only includes elementary and mid-level public schools (Crehueras Díaz et al., 2015b, 2015c). The final report provides information on the average annual electricity consumption per school, subdivided into several subcategories. It considers general and indigenous public elementary schools and several other categories for mid-level schools such as general, remote-teaching and indigenous among others. Electricity consumption in corresponding private schools

[7] North American Industry Classification System

[8] For his acronym in Spanish, is the Statistics and Geography National Institute.

[9] This annual growth rate was found in (Cámara Nacional de la Industria de Restaurantes y Alimentos Condimentados, 2014).

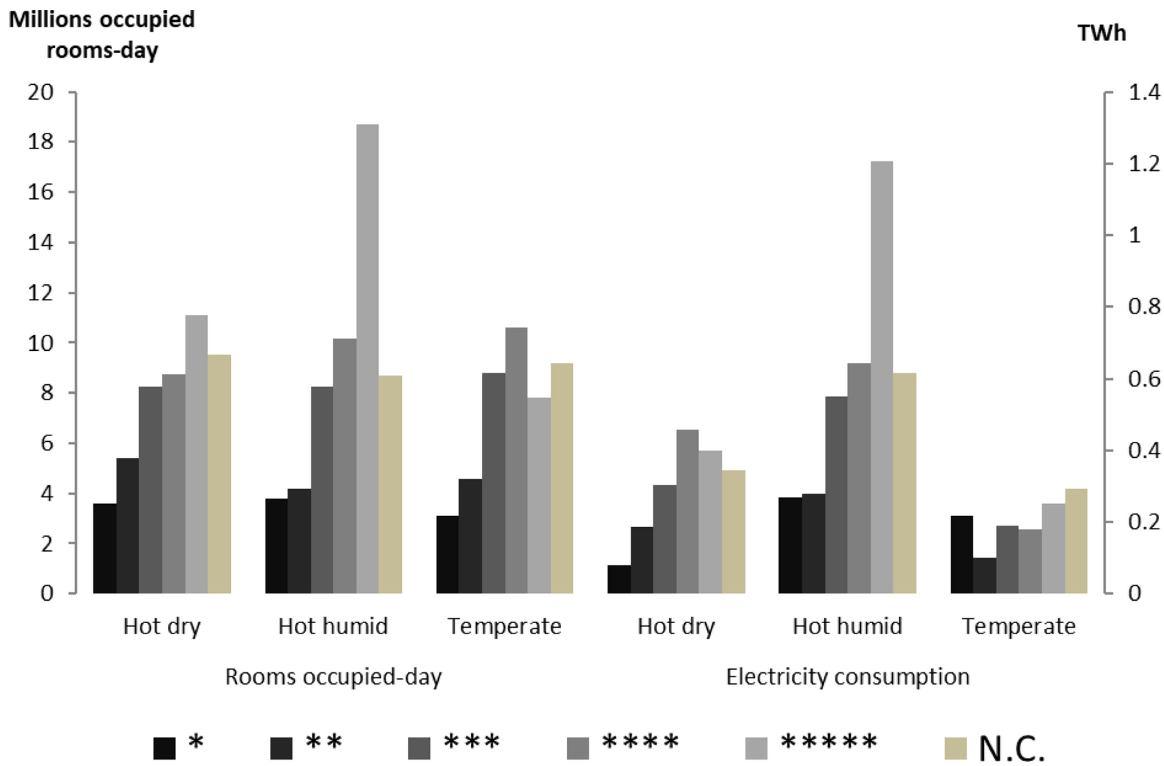

Fig. 3. Electricity consumption for hotels by number of stars in Mexico, 2017[14].

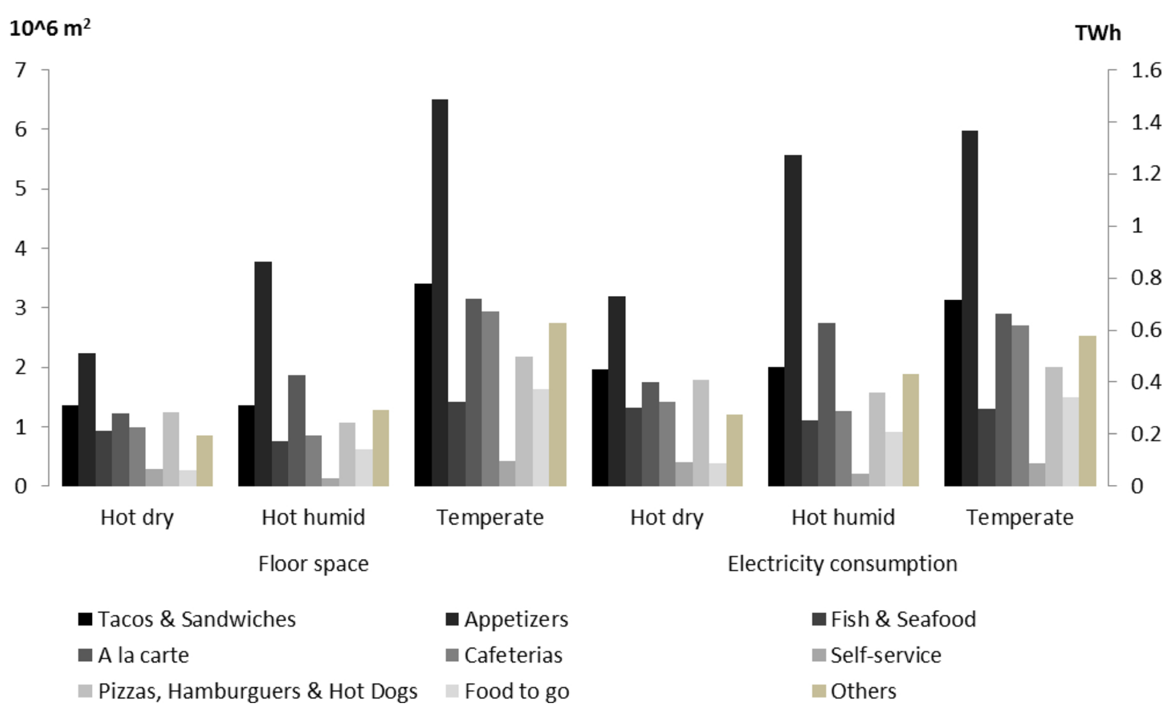

Fig. 4. Electricity consumption for restaurants in Mexico, 2017.

was assumed to be 20 % higher than in their public counterparts. For the preschool, high school and universities, an intensity based on the electricity consumption per student was used, and obtained based on the data found in (Juárez, 2015). Combining this with data on the number of schools per educational level and the number of students obtained from the Public Education Secretary (SEP for its Spanish acronym) for the 2016 – 2017 school year, yeilding 6.7 TWh of electricity, as shown in Fig. 6.

2.6. Offices

Data on the employee occupancy per surface unit was found in (Escobedo Izquierdo, 2005) and (Islas Cortés, Gutierrez García, & Alvarez, 2014). Both studies report similar numbers, but the second was taken as a reference since it is more recent. The number of employees working in offices was extracted from the statistical yearbook from INEGI (Instituto Nacional de Estadística y Geografía, 2017). This

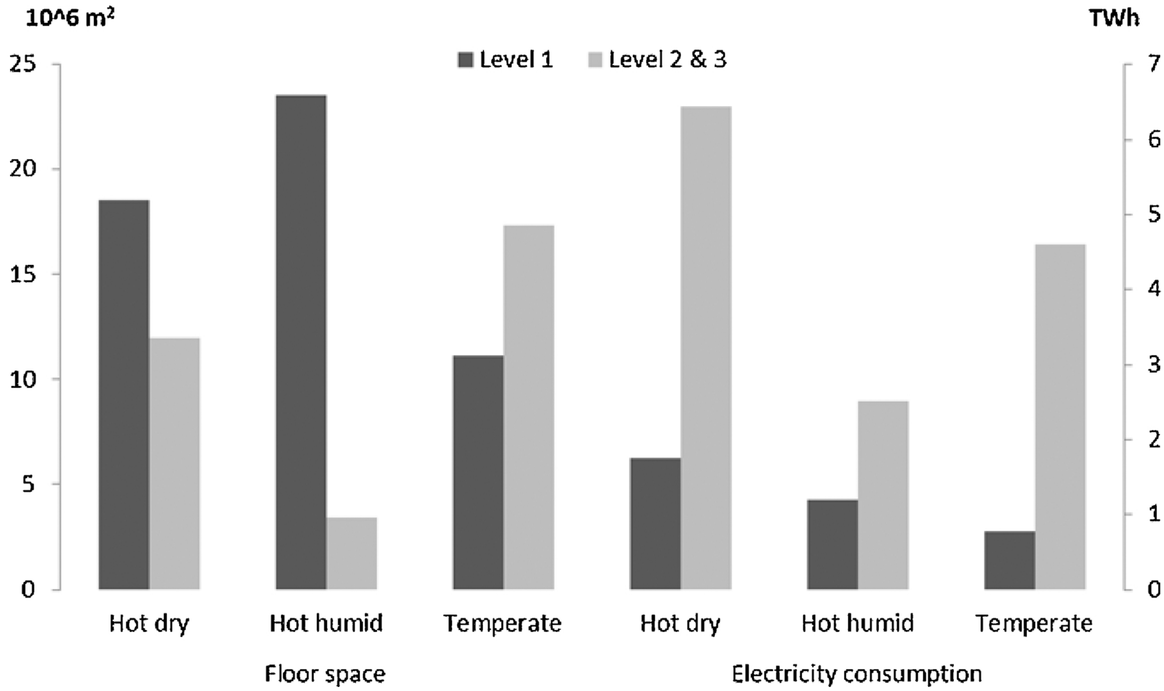

Fig. 5. Electricity consumption for hospitals in Mexico, 2017.

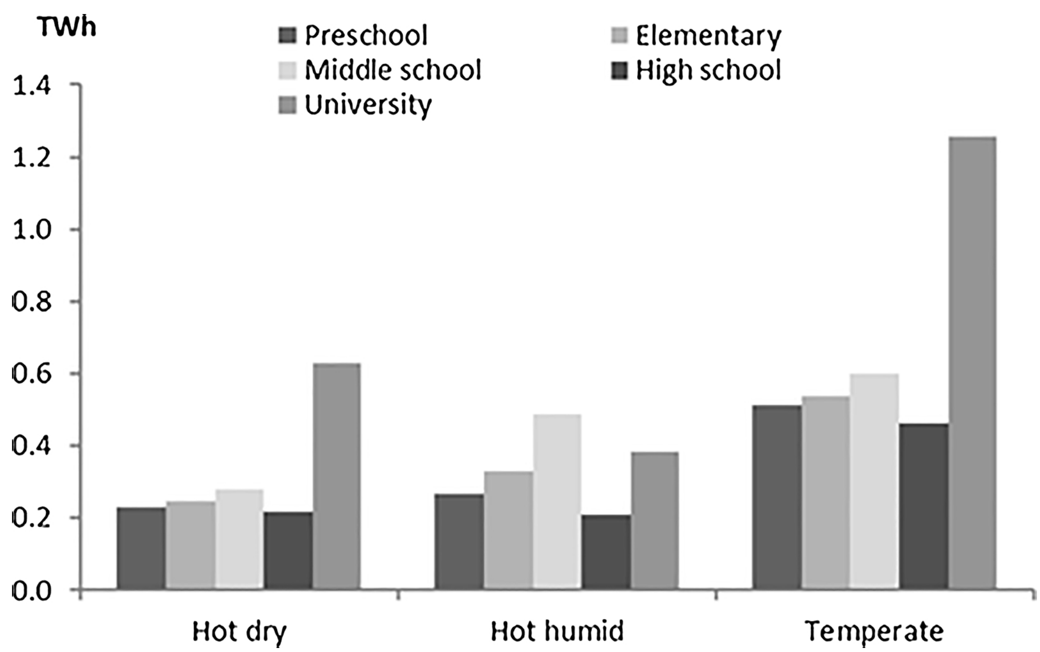

Fig. 6. Electricity consumption for schools in Mexico, 2017.

Table 6
Determination of the floor space occupied by offices in Mexico, 2017.

	Population distribution by climatic region	Employees working in offices	Number of employees per 100 m^2	Floor space (10^6 m^2)
Hot dry	27.91 %	1,269,354	4.86	26.12
Hot humid	19.17 %	1,032,170		21.24
Temperate	52.92 %	2,945,908		60.62
Total	100 %	**5,247,432**	–	**107.97**

information is only available at a national level, and it does not exist by state, making the distribution by climatic regions impossible to determine directly. Instead, a population distribution by climatic region was calculated based on the 2010 population census undertaken by the INEGI (Instituto Nacional de Estadística y Geografía, 2010). Table 6 presents numbers related to the floor space calculation for offices are presented. Results are that office buildings host more than 5 million employees and occupy a total floor space of nearly 108 million m^2.

Using Eq. (1) it was possible to estimate that the electricity consumption for offices as presented in Fig. 7is 15.5 TWh.

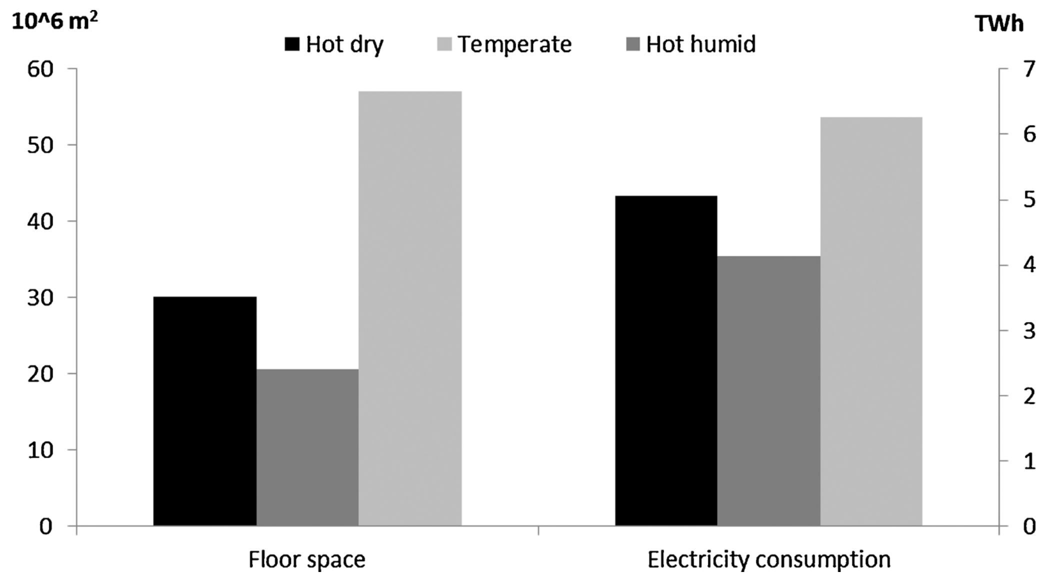

Fig. 7. Electricity consumption for offices in Mexico, 2017.

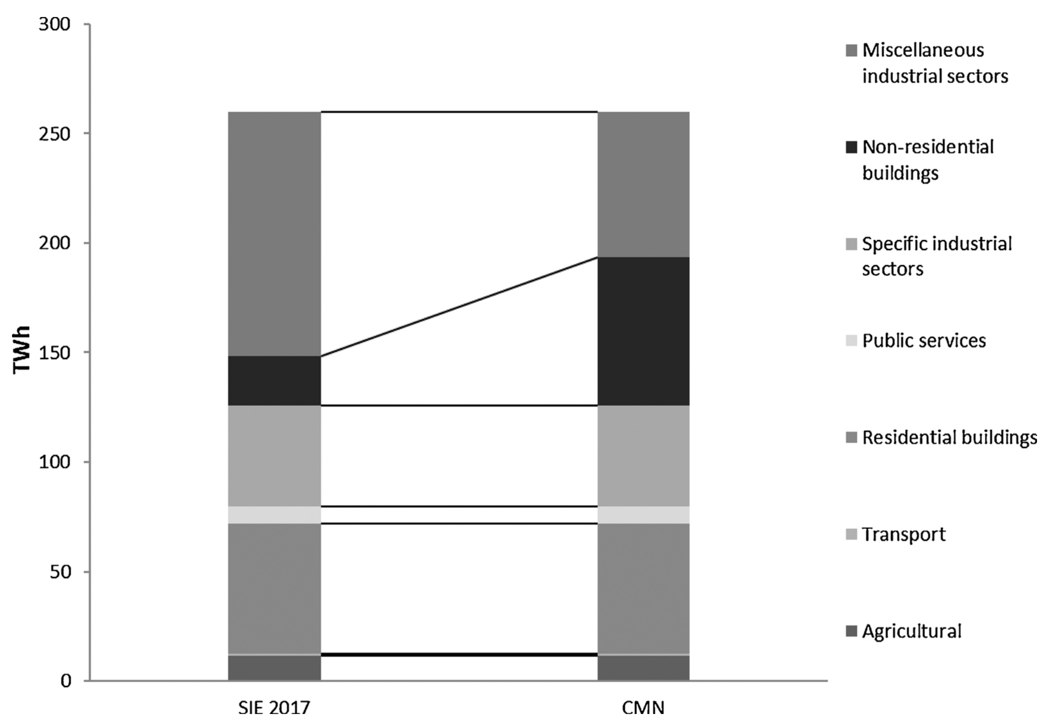

Fig. 8. Electricity consumption for theatres in Mexico, 2017.

2.7. Theaters

The Cinematographic Industry National Chamber (CANACINE for its Spanish acronym) published an account of the number of screens by state, making possible the determination of the number of screening rooms available in each climatic region. In order to estimate the size of a screening room, we considered an average of 250 spectators per room, with a space of 375 m^2, plus a 200 m^2 per movie room accounting for halls, corridors and bathrooms, giving a total space of 575 m^2 per movie room. The EUI for theatres was taken from (de Buen Rodríguez, 2009), and the results are shown in Fig. 8. Theatres consume 0.9 TWh of electricity and occupy a total floor space of 3.9 million m2.

2.8. Sector results

Table 7 summarizes the methodologies used to determine the occupied floor space and electricity consumption. It shows the specific methodology used in every building type and displays the parameter employed to determine the occupied floor space as well as the source of that parameter. It also shows the specific subcategories considered.

Table 7
Space floor and electricity use calculations methodology summary.

Building Category	Parameter	Source of parameter	Considered subcategories	Area characterization	Electricity use characterization
Hotels	Number of rooms	Statistical compendium, Tourism Secretary (Secretaría de Turismo, 2017)	1, 2, 3, 4 & 5 stars & uncategorized hotels	Occupancy rate, available rooms-days	Electricity use by occupied room-day (Paredes Rubio, Erick, & Juan, 2013)
Restaurants	Number of restaurants by type	Economical Units National Directory (Instituto Nacional de Estadística y Geografía, 2016)	Tacos & sandwiches Appetizers Fish & seafood Cafeterias Self Service Pizzas, Hamburgers & Hot Dogs Food to go Others	Floor space estimation by restaurant type	EUI by climatic region (García Kerdan, 2015)
Offices	Number of employees in offices	Statistical yearbook INEGI 2017 (Instituto Nacional de Estadística y Geografía, 2017)	Executives and official workers Office workers	Employee per m^2 (Islas Cortés et al., 2014)	EUI by climatic region (García Kerdan, 2015)
Shops	Built area	ANTAD 2017 (Asocioación Nacional de Tiendas de Autoservicio y Departamentales, 2017)	Department stores Specialized	Direct	EUI by climatic region (García Kerdan, 2015)
Supermarkets	Built area	ANTAD 2017 (Asocioación Nacional de Tiendas de Autoservicio y Departamentales, 2017)	Self-service stores	Direct	EUI by climatic region (García Kerdan, 2015)
Hospitals	Number of medical attention units	Estudio de Eficiencia Energética en Hospitales (Creuhueras Díaz Santigo et al., 2015c)	Attention level 1 Attention level 2 Attention level 3	Average floor space by Medical Attention Unit (Creuhueras Díaz Santigo et al., 2015c)	Calculated EUI based on average electricity consumption by MAU and average floor space by MAU by climatic region
Schools	Number of schools	Historical series SEP, schoolar cycle 2016 – 2017 (Secretaría de Eduación Pública, 2016-2017)	Public elementary General Indigenous Private elementary Public middle school Remote-school General Technical Communitarian For workers Migrant Private middle school		Average consumption by school (Crehueras Díaz et al., 2015a)
	Number of students	Historical series SEP, schoolar cycle 2016 – 2017 (Secretaría de Eduación Pública, 2016-2017)	Preschool High school Universities		Average consumption by student (Juárez, 2015)
Theatres	Number of screens	CANACINE (Cámara Nacional de la Industria Cinematográfica, 2017)		Floor space estimation per movie room considering 250 spectators	General EUI (de Buen Rodríguez, 2009)

Finally, it shows how the parameter was used to ultimately determine floor space and how electric consumption was obtained, based on the area characterization results.

Results are summarized in Table 8. Total electricity consumption was found to be 66.9 TW h with an estimated floor space of 272 million m^2, accounting only for restaurants, offices, shops, supermarkets, theatres and hospitals. The major consumer was found to be the hospital buildings followed by offices and restaurants.

Table 8
Summary results for floor space and electricity consumption in NRB in Mexico, 2017.

	Floor Space (10 m^2)	EUI (kWh/m^2-year)	Electricity consumption (TWh)
Hotels	144,556,614[a]	54.88[b]	6.6
Restaurants	45.5	291.1	12.1
Offices	108.0	159.0	15.5
Shops	13.7	179.03	2.2
Supermarkets	15.0	393.7	5.7
Theatres	3.9	242.75	0.9
Hospitals	86.0	459.62	17.3
Schools	–	–	6.7
Total	**272.0**	–	**66.9**

[a] Occupied rooms-day.
[b] kWh/occupied rooms-day.

3. Discussion and implications

3.1. Subsector comparisons

The methodology above results in an estimated NRB electricity demand in 2017 that is roughly three times the reported consumption of the sector in that year. This result is consistent with misidentification of many non-residential customers as belonging to the industrial sector, as in previous studies. However, due to the size of the discrepancy, further consideration is warranted.

First, key drivers and results are compared to previous studies in Table 9. The corresponding values for past studies are a self-made projection to the year 2017, and actual estimated values for their respective year can be consulted directly at the source. The table shows an overall electricity demand in the current study that is 2.3–2.5 times as high as the previous studies. The table shows also that the

Table 9
Comparison of electricity consumption in buildings with previous studies.

	Floor Space (10^6 m^2)			Unitary consumption (kWh/m2-year)			Total consumption (TWh)		
	ODB[b]	IGK15	CMN	ODB	IGK	CMN	ODB[c]	IGK16	CMN
Warehouses	5	–	–	148.32	–	–	0.7	–	–
Hotels	19.3	17.7	–	310.6	253.9	54.88[a]	6	4.5	6.6
Restaurants	2	3.5	45.5	310.6	291.1	291.1	0.6	1	12.1
Offices	6.3	5.1	108	158.91	159.03	159.03	1	0.8	15.5
Shops	21.1	10.9	13.7	189.91	179.03	179.03	4	2	2.2
Supermarkets	–	15.7	15		393.7	393.7	–	6.2	5.7
Theatres	3	–	3.9	242.75	–	242.75	0.7	–	0.9
Hospitals	6.2	5.7	86	335.57	357.4	459.62	2.1	2	17.3
Schools	128.6	124	–	90.11	102.83	D.N.A	11.6	12.8	6.7
Total	**187.3**	**186.7**	**255.56**	–		–	**26.1**	**29.2**	**66.9**

D.N.A.: Does Not Apply, since electricity consumption for schools was calculated on a per-student or per-school basis.
ODB: (de Buen Rodríguez, 2009).
CMN: Current work (Chatellier-McNeil).
IGK: (García Kerdan, 2015).
[a] Units correspond to unitary electricity consumption per occupied room-day.
[b] Electricity consumption reported corresponds to projections for the year 2017 based on the electricity consumption per unit of sectorial value added for the respective estimation's year made in 2009 and 2012 by ODB and IGK respectively.
[c] Floor space reported corresponds to projection for the year 2017. They were calculated considering the projected value for electricity consumption (see footnote 15) and the respective unitary consumption considered by ODB and IGK.

Table 10
Macroeconomic data for Mexico and USA.

	Mexico	USA
Population (millions)	123.5	326.0
GDP (USD billions, PPP, current prices 2017)	2425	19,485
GDP per capita (USD, PPP, current prices 2017)	19,630	59,774
VA Restaurants (USD billions, current prices 2017)	26.4	299.3
VA Offices[a] (USD billions, current prices 2017)	115.3	4,695.6
Number of employees in restaurants (millions)	1.35	4.60
Number of employees in office (millions)	5.25	33.76

[a] Includes: Telecommunications; IT and other information services; Financial and insurance activities; Legal accounting, head offices, management consultancy activities; Advertising and market research; Office administrative and support activities; Public administration and defense, compulsory social security.

estimations of activity (floor space) account for much more of the discrepancy than EUI. Specifically, while floor space estimates for hotels, shops, supermarkets, theatres and schools are somewhat similar, they differ by between a factor of 8 and 22 for restaurants, offices and hospitals. For this reason, comparison with another data point is useful to validate our estimate.

For this purpose, a comparison has been made with the United States. Data on the occupied floor space and number of employees by building type was obtained from the Commercial Building Energy Consumption Survey (Energy Information Administration, 2012) for the year 2012. The factors to be taking into account are macroeconomic measures such as the Gross Domestic Product (GDP) in Power Purchasing Parity (PPP), population, sectorial Value Added (VA), which were obtained from the OECD stats site (OECD) for the year 2017, and are presented in Table 10. The table shows that the Mexican economy was about an 8th of the size of the U.S., but there were about 30 % as many restaurant workers and about 15 % as many office workers.

Table 11
Available floor space per employee (m^2/employee).

	Restaurants	Offices
USA	61.98	43.90
Mexico	33.60	17.44

Using data from Table 10, Table 11 calculates the implied available floor space per employee for restaurants and offices. We find by this method about half as many restaurant employees per unit floor area in Mexico and about 40 % of office employees.

This can be compared to previous work by the authors in which a logistic functional form is developed to relate the number of employees per square meter of building space as a function of GDP per capita for the commercial sector using a global data sample (McNeil et al., 2013). BUENAS is a bottom–up stock accounting model that predicts energy consumption for each type of equipment in each country according to engineering-based estimates of annual unit energy consumption.

Applying the GDP per capita values in Table 10 to this model, yields 37.5 m^2/employee for Mexico and 68.9 m^2/employee for the U.S., or about half as many employees per unit floor area in Mexico compared to the United states. While this model does not distinguish between building subsectors, the predictions and ratio between them are roughly consistent with our findings and give some confidence about the reasonableness of the results.

A similar comparison can be made in the hospital subsector. According to the data found in (Creuhueras Díaz, et al., 2015), the average size of a Medical Attention Unit (MAU) is calculated to be 3180 m^2, giving a total floor space of approximately 86 million m^2, or 0.7 m^2 per capita. Meanwhile, there is 1.2 m^2 of hospital space in the U.S. per capita (Energy Information Administration, 2012), or about 1.7 times more hospital space per habitant than in Mexico, which seems reasonable given the relative level of economic development of the two countries.

Finally, we note that not all the NRB are included in the above calculations. For example, prisons, transports hubs, and recreational buildings that are not theatres are not represented here. These buildings were not included due to lack of data on the energy intensities and floor space occupation. Hence, the electricity consumption estimated here for NRB would be higher considering those other types of buildings.

3.2. Policy implications

The method described in the previous sections results in an estimate of 66.9 TWh for NRB in Mexico in 2017, compared with 22.6 TW h from SIE, a difference of 198 %. Under the hypothesis of misidentification of some commercial building electricity customers as Miscellaneous Industrial Sectors, we conclude that actual electricity consumption in

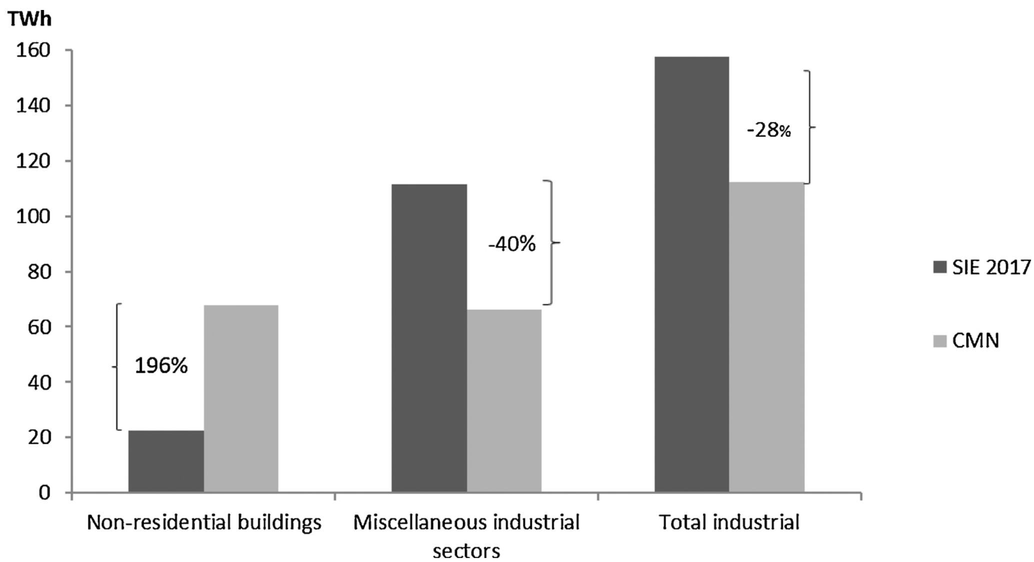

Fig. 9. Sectorial consequences in the electricity energy balance for Mexico, 2017.

miscellaneous Industrial sectors is 67.3 TWh, rather than 111.6 TWh, as reported by SIE. The remainder of the industrial category, which we categorize as 'Specified Industrial Sectors' remains unchanged because it corresponds to more precise information about electricity consumption for those particular sectors. Sectorial consequences of the reallocation are shown in Fig. 9. Meanwhile, Table 10 and Fig. 10 show that around 40 % of the electricity consumption identified as miscellaneous industry is actually non-residential building electricity consumption, corresponding to 28 % of total industrial electricity consumption. This means that electricity accounts for only 17 % of industrial energy consumption, down from 30 %. Finally, whereas industry was thought to be the largest electricity-consuming sector in Mexico with 157.4 TW h and 61 % of total electricity; the results presented here imply total industrial electricity consumption of only 113 TW h or 44 % of the total. Together, residential and NRB electricity consumption is estimated to be 126 TW h, meaning that the buildings sector is actually the largest electricity consumer in Mexico, with 49 % of total electricity consumption (Table 12).

Table 12
Comparative values for sectorial electricity consumption in Mexico (TWh).

	SIE 2017		CMN	
Agricultural	11.6	4%	11.6	4%
Transport	1.1	0.4%	1.1	0.4%
Residential buildings	59.2	23 %	59.2	23 %
Public services	8.0	3%	8.0	3%
Non-residential buildings	22.6	9%	66.9	26 %
Specific industrial sectors	45.8	18%	45.8	18%
Miscellaneous industrial sectors	111.6	43%	67.3	26 %
Total	259.9	100 %	259.9	100 %

Reallocation of electricity consumption from industry to buildings has important policy implications, since consumption patterns, efficiency opportunities and programs are highly distinct between the sectors. For instance, Mexican non-commercial buildings are likely responsible for strong growth of air conditioning use in the country, even in temperate areas. This end use provides particular challenges opportunities to manage electricity demand through regulations and market-based programs directed at both equipment efficiency and building envelopes. Furthermore, much of the remaining electricity use in buildings is concentrated in lighting and refrigeration systems, which are key subjects of efficiency standards and advanced controls.

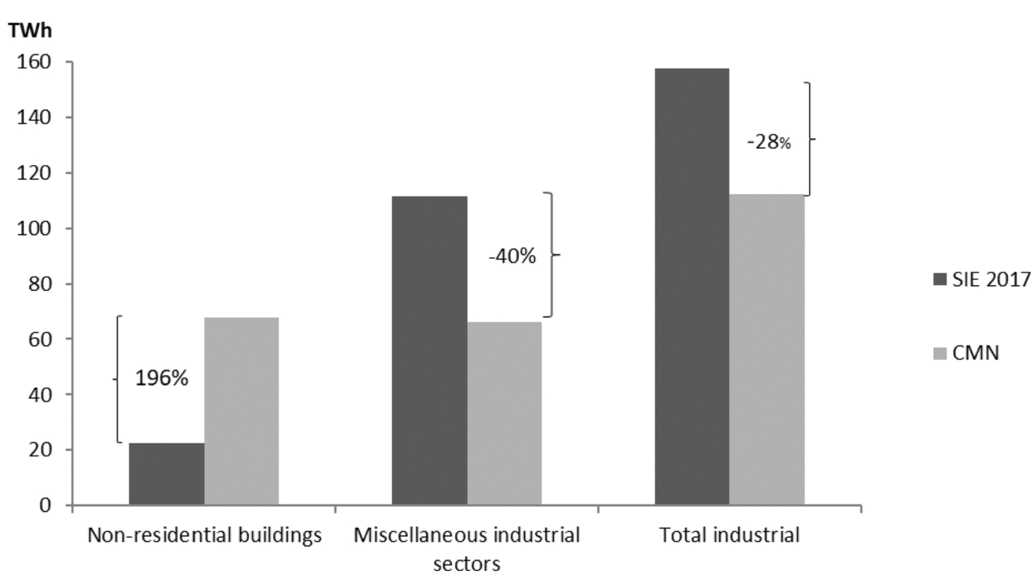

Fig. 10. Consequences in the electricity balance for selected sectors, Mexico 2017.

Industries, on the other hand primarily use electricity through motors and motor systems, including pumps and compressors, and may be more easily managed through energy management programs and private sector voluntary commitments.

3.3. Energy forecasting

An example of energy forecast with a policy assessment for Mexico can be found in (Altamirano et al., 2016), which presents an action plan for meeting the targets laid out in Mexico's commitment of reducing emissions by 22 % by 2030. That study used official sources for energy information, and in their baseline scenario, total emissions are estimated to grow from 709 Mt CO_2-eq in 2015 to 1009 Mt CO_2-eq in 2030 (46 %). They propose several mitigation actions for every sector in an unconditional and a conditional scenario in order to achieve the emissions targets of 758 Mt CO_2-eq and 623 Mt CO_2-eq respectively. The findings are that among all proposed mitigation actions, the biggest reductions potentials are in industrial energy efficiency, methane capture and a carbon tax. In particular for the building sector two actions regarding cooling and lighting are proposed. For cooling they suggest 30 % and 50 % reductions and for lighting 10 % and 20 % reductions in energy use relative to the baseline for unconditional and conditional scenarios respectively. Assuming a 3.4 % annual growth rate during the period as in (Ordoñez, Wolfgang, & Martin, 2016) and according to our findings, energy use for cooling in the NRB will grow from around 28 TWh in 2017 to 43.6 TWh in 2030, and for lighting from around 17.8 TWh in 2017 to 27.5 TWh in 2030. An emission factor of 0.582 tCO_2-eq/MWh from (CRE, 2017) was cosidered. Taking the respective reduction actions in the unconditional scenario, cooling and lighting would save around 15.8 TW h of electricity, which is equivalent to 9.2 Mt CO_2-eq emissions[10] or 3.7 % of the overall emission reductions for the unconditional scenario. For the conditional scenario it was found that a reduction of 27.3 TW h could be achieved, avoiding around 16 Mt CO_2-eq, representing 4.1 % of the overall emission reductions for the conditional scenario. Both of these reduction potentials represent 15%–27% of one of the biggest reduction potential, which is industrial energy efficiency that ranks first and third in the unconditional and conditional scenarios respectively. This shows that the impacts of the results presented here are not negligible, since acceptable potential reductions in the NRB sector could be achieved with a relatively simple and cost-effective solution.

Recently, the Bariloche Foundation and the National Commission for Efficient Use of Energy (CONUEE) supported by the European Union Energy Initiative (EUEI) and the German Agency for Technical Cooperation (GIZ), published a report that proposes a series of energy efficiency measures for the industrial sector in Mexico (Bouille et al., 2018) for the horizon 2030. In particular they propose some measures for the miscellaneous Industrial sector, as we know now; a portion of the electricity consumption from that sector corresponds to some NRB. The potential energy savings from these measures are compared to a baseline scenario previously made by GIZ (Ordoñez et al., 2016). The objective here is to demonstrate the potential impacts the results presented here could have on a baseline projection and on the resulting savings potentials. For this, the baseline scenario provided in (Ordoñez et al., 2016) was replicated using the same assumptions and data used in that work. Then another baseline scenario was modeled using the same assumptions as the original baseline scenario, with the difference that in the second baseline scenario the results presented here on electricity consumption were used. That also means that the sectorial energy mix for industry and commercial sectors are also modified.

For the original baseline scenario, (Ordonez et al.) used a top-down econometric methodology based on historical data to describe the energy use as a function of macroeconomic variables for each different sector. For the case of industry and NRB sectors, the energy use only depends on GDP, modeled through a straight-line equation with the GDP as the independent variable. Enough information is provided in order to replicate the energy use forecast for the period $2015-2030$. GDP was set to grow at a Compound Average Annual Growth Rate (CAAGR) of 4.1 %, considering a CAAGR of 3.4 % for industry and 5.1 % for the commercial sector. The resulting CAAGR for energy use in both sectors are 2.8 % and 3.4 % for the industrial and NRB sectors, respectively. The share of the sectorial energy mix is considered to be constant (Ordoñez et al., 2016). Fig. 11 shows the energy mixes used for the industrial and NRB sectors. The GIZ calculated the electricity share in sectorial energy mix to be 34 % in industry and 37.7 % in NRB sector[11]. For the second baseline scenario, electricity use share was changed to 26 % for industry and 75 % for NRB sector[12].

Fig. 11 shows the results obtained in form of a difference between electricity baseline scenarios for the period 2017–2030 for industrial and NRB sectors. There are two main implications. The first, is that under/over estimation of electricity use is likely to grow over time, attributable to the different economic behaviors and energy mixes of the sectors implied (see Fig. 11). The average annual difference of electricity use is calculated to be 229 PJ for NRB and -242 PJ for industrial sectors. Compared to the original model, this represents an average underestimation of 106 % of total energy consumption for the NRB sector, and an almost constant average overestimation of 9% of total energy consumption for the industrial sector. Sectorial energy mix is not affected since it is considered to be constant over time[13]. This also implies that NRB sector is likely to continue to be apparently negligible in terms of potential electricity savings, making it a less appealing sector than it should be for energy policy makers. On the other hand, the "miscellaneous industrial sector" is going to appear as a more interesting sector focus the efforts for saving electricity.

The second implication is that energy efficiency and energy savings potentials are going to be overestimated for industry and underestimated for NRB sector. To illustrate that, some energy saving measures proposed in (Bouille et al., 2018) for industrial miscellaneous sector where analyzed. In particular for electricity use, they suggest four measures impacting electricity use, namely: thermal isolation for refrigeration equipment, improvement of energy efficiency for pumps, compressors and fans, efficient lighting and cogeneration. The energy savings potentials are assessed relative to the total energy demand for that sector in 2030. Thermal isolation is expected to save 0.1 %, efficient pumps, compressors and fans are expected to save 3.2 %, efficient lighting is expected to save 1.2 % and cogeneration is expected to save 0.2 %. Estimates made with the official sources of information indicate that total energy demand for the miscellaneous industrial sectors will be 985.1 PJ in 2030. Estimations made here indicate that total energy demand for that sector will be 743.7 PJ in 2030. Fig. 12 presents the comparative results for the estimated electricity savings in 2030. For the measures proposed, the potential electricity savings could result in a nearly 25 % overestimation for the miscellaneous industrial sectors.

These two implications carry a double loss. On one hand, electricity savings potential for NRB can't be assessed correctly and therefore some potential energy savings are not considered. On the other hand, electricity savings potential for the "miscellaneous industrial sector" are overestimated and some of these electricity savings are not going to occur.

[10] From CRE, 2017.

[11] Electricity share for industry and NRB obtained in.

[12] These electricity shares in the energy mix for both sectors were obtained by comparison of the results on electricity consumption estimated in this work and the results of total energy consumption issued from the parametric equations results for 2017.

[13] The energy forecast for other sectors, for example the residential, transport and agricultural sectors, will not be affected, since the discrepancy only lies on the NRB sector and "miscellaneous industrial sectors".

[14] N.C. Not categorized accommodations.

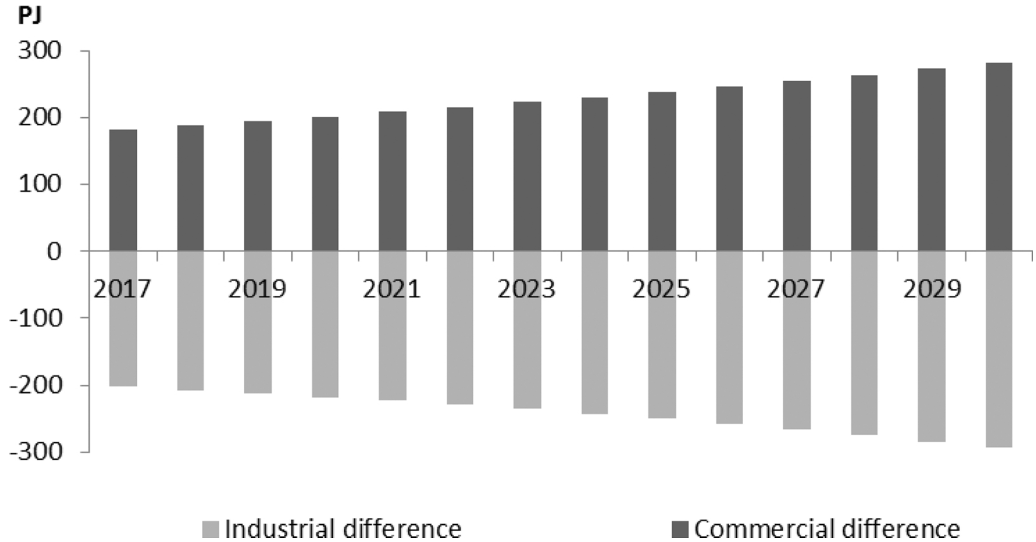

Fig. 11. Comparative forecast results for electricity use in the NRB and industrial sectors for the baseline scenario.

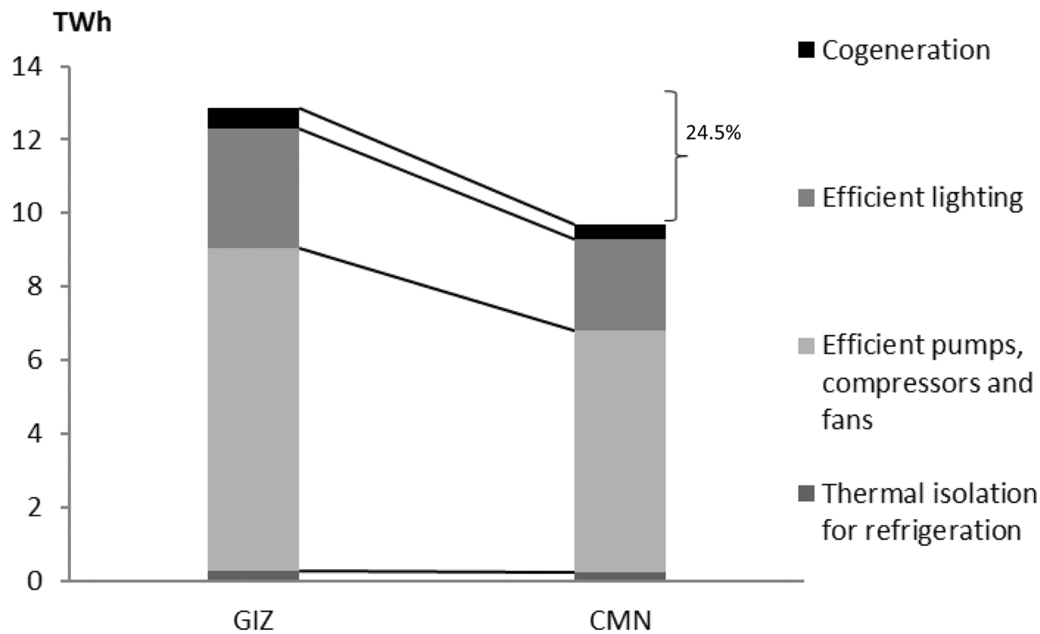

Fig. 12. Comparative results for electricity savings measures for the other industrial branches sector to 2030.

4. Conclusions

The results presented in this analysis significantly alter our understanding of Mexico's energy balance, specifically for electricity showing that NRB are much more relevant than previously thought. It also shows that the buildings sector (residential and non-residential) is the highest electricity consumer in Mexico. This has important policy implications, since major energy savings opportunities exist in the building sector that could be achieved through well-designed and implemented programs such as codes and standards, and market-based incentives. It also has consequences on energy forecasts, since the economic behaviors of the industrial sectors are very different than the NRB sector, and the latter is expected to have a higher growth trend in the future. Another direct consequence is that the end uses for both sectors are not the same, as for the non-residential sector electricity is mainly used for air conditioning and lighting while in the industry is used for electric motors and pumps.

As shown by examples, for future research it would be very useful to incorporate the results presented here in energy forecasts, leading to higher energy savings and emission abatement potentials for the NRB sector. In consequence, the relative and absolute building sector abatement potentials will be larger than previously thought and therefore more attractive to policymakers as a subject of energy efficiency programs.

Author Declaration

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

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