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Article

Public Policies for the Energy Efficiency of Buildings in Mexico

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Abstract: In Latin America, the energy crisis has worsened due to the dependence on energy services and fossil fuel imports from highly industrialized countries at prices established by the international market; this is particularly relevant to the construction industry, which presents a significant deficit in optimal energy consumption. Hence, some governments have established public policies to maximize the efficiency of these services and, at the same time, minimize the carbon footprint. In this research study, we reviewed the public policies, strategies, and incentives for energy efficiency (EE) implementation in the residential sector established by the Mexican government. A scoping review methodology was chosen and implemented in the following steps: 1. Research inquiry identification. 2. Determination of the relevant literature and studies. 3. The literature selection. 4. Data graphing. 5. Results collection, overview, and submission. In this systematic review, we identified five mandatory standards (NOM-008-ENER-2001, NOM-009-ENER-2014, NOM-018-ENER-2011, NOM-020-ENER-2011, and NOM-024-ENER-2012), six optional standards, four strategies (Green Mortgage, Integral Sustainable Improvement in Existing Housing, ECOCASA, and NAMA), and three kinds of incentives (green bonds, credit and interest rates (Green Mortgage, FIDE, and Ecocasa), and taxes (Income Tax Reduction)). As a result of the implementation of the above, as of December 2020, NAMA financed 5106 developers of 38 projects in 15 states; contributed to a reduction of 126,779 tons of CO_2; and aided 19,913 people. From 2013 to December 2023, EcoCasa subsidized 71,440 households for a total of 224 projects in 25 states; contributed to a reduction of 2.6 million tons of CO_2; aided 285,760 Mexicans; and issued EcoCasa certificates for 3,473,556 m^2. The results of the EE indicators in residential buildings showed an increase in the housing unit number as well as an increase in household appliances, with those based on power consumption prevailing. The residential sector ranks third in power consumption in Mexico, consuming an estimated 790 pj, of which 76% corresponds to thermal energy and 24% to electric power. Among countries in Latin America and the Caribbean, Mexico has achieved an Energy Transition Index of 62%.

Keywords: energy efficiency; residential buildings; public policies; strategies; incentives; indicators

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1. Introduction

Human activities worldwide depend on various energy sources, such as coal, oil, and natural gas, as well as renewable sources, such as wind, solar, and hydroelectric power. However, as the population increases, energy demand grows, which has led to an energy crisis that has impacted the environment, the economy, and society [1], in turn affecting households, industries, and entire economies as prices keep increasing. Food insecurity mainly affects the poorest families, who spend most of their income on food [2]. The international organization United Nations, through its 2030 Agenda for

Sustainable Development—specifically objective 7 (universal access to affordable, safe, sustainable, and modern energy without affecting the environment) and objective 13 (climate action)—promotes the incorporation of measures related to climate change in public policies, strategies, and national plans. One of the key actions to mitigate global warming and the use of fossil fuels is implementing EE policies [3].

EE is defined as using less energy to perform a given task, i.e., optimizing energy use [4,5]. Although it focuses on energy saving, its performance has shifted in several sectors, including the construction industry [6].

According to the International Panel on Climate Change (IPCC), in 2019, 21% of the CO_2 emissions generated globally were from the construction sector; of this amount, 57% corresponded to direct emissions from off site electricity and heat generation, 24% to direct emissions produced on site, and 18% to the production of concrete and steel used for the renovation and construction of buildings. In this context, there is a need to implement public policies focused on EE that consider mandatory regulations, economic incentives, and awareness campaigns [7].

Some authors have pointed out that implementing an EE-based sustainable approach to building construction is an emerging topic that needs further study [8].

The authors of [9] presented a systematic review of energy management field investigations of public buildings published from 2010 to 2024 based on the analysis of in-formation from databases such as Web of Science, Scopus, and China National Knowledge Infrastructure; they identified, as the main factors, the investigation standard system's flexibility and the availability of a unified integral evaluation procedure that contributes to addressing the practical problems that energy management faces with this type of buildings. The authors of [10] analyzed the energy-saving potential of integrating innovative phase-changing materials in building wall structures, using the dynamic simulation tool TRNSYS to study heat transference through the modified wall group under typical semi-arid weather conditions in Marrakech, Morocco. Their results showed that this "bioclimatic" design significantly affected the refrigeration consumption, more than the heating demands. Moreover, the authors of [11] performed a comparative analysis of two residential multi-family buildings in Pennsylvania downtown weather zone 5A—where one had been built with conventional methods and the other in accordance with the Passive House certification standards (PHIUS + 2015)—to validate the energy efficiency improvements attributed to the Passive House design; two-year monitoring revealed that the Passive House building consumed approximately 50% less energy than the conventionally built counterpart, which highlights the need for relevant policy-makers and governmental bodies to boost Passive House standard adoption to reach environmental sustainability and reduce energy costs.

In Portugal, research has highlighted the importance of EE public policies for the residential sector as they contribute to sustainable growth, a resource-efficient economy, and reduced greenhouse gas emissions [12]. On the other hand, the authors of [13] analyzed the impact of public policies established by the European Union (EU) for promoting EE improvements in the building sector; in their review, they examined EE in buildings, highlighting both achievements and challenges—in addition to the impact on energy consumption—in the previous 50 years based on an analysis of the literature in the Scopus and Web of Science databases. Likewise, the authors of [14] stressed that EE strategies should provide data on investment needs and corresponding funding sources to governmental institutions, which should, in turn, commit to their implementation. The authors of [15] sought to understand the barriers and contributing fac-tors to EE in the housing stock based on various EU laws; their study included a nationwide survey of construction professionals. Finally, the authors of [8], in a literature review, researched EE in buildings in 43 countries around the world, determining its significant components and finding that China was the leader in the field in several studies, followed by the United States, Italy, and Malaysia.

In Latin America, some countries have implemented several policies and energy pro-grams in an effort to foster energy efficiency and reduce the environmental impacts associated with energy generation and consumption [16]. The authors of [17], in a study in Argentina, Brazil, Chile, and Mexico, consulted the opinion of 30,000 users registered in "Mercado Libre" about their preferences in the acquisition of housing that integrates sustainable criteria and socioeconomic status and found that consumers valued energy efficient housing if it did not oppose economic growth and social protection.

Colombia has implemented policies, such as the Rational and Efficient Power Consumption Program (PROURE) 2022–2030, which aim to promote the implementation of more sustainable practices in the construction sector [18]. El Salvador implemented the National Energy Policy in the period 2010–2024, aiming to establish a new energy scenario in the medium- and long-term, focused on efficiency, optimization, energy saving, sustainable development, and integration with other sectors at the national level [19].

Guatemala has implemented the National Energy Plan 2017–2032, which is centered on reducing greenhouse gas emissions, fostering renewable energies, and promoting the sustainable consumption of natural resources [20]. Honduras has compiled the National Energy Balance with the purpose of determining energy flow supply and de-mand in the country and performed an environmental and socioeconomic impact assessment [21]. Further, Panama has enacted the Rational and Energy Efficiency Consumption Law (UREE), with the purpose of regulating energy consumption and promoting the implementation of more efficient practices in the country [22]. Paraguay has established the National Energy Efficiency Plan with the purpose of fostering efficient power consumption and contributing to sustainable development [23]. Peru stands out for its National Energy Policy 2010–2040, which aims to diversify the energy matrix, guaranteeing a competitive energy supply and fostering universal access to energy services [24].

The Dominican Republic is in a process of transitioning to a more sustainable energy system based on institutional strategic plans and laws with the purpose of guaranteeing sector sustainability and fostering economic and social development in the country [25]. Uruguay has implemented the Energy Efficiency National Plan 2015–2024, aiming to reduce power consumption through the promotion of more efficient practices in all economic sectors. Further, Chile, which has been exemplary in adopting public policies for EE in the housing sector, was one of the first Latin American countries to adopt mandatory energy regulations, which positions it as a proactive country in this area [17]; indeed, in 2020, the Ministry of Energy presented various standards, certifications, and incentives for the construction sector, as shown in Figure 1.

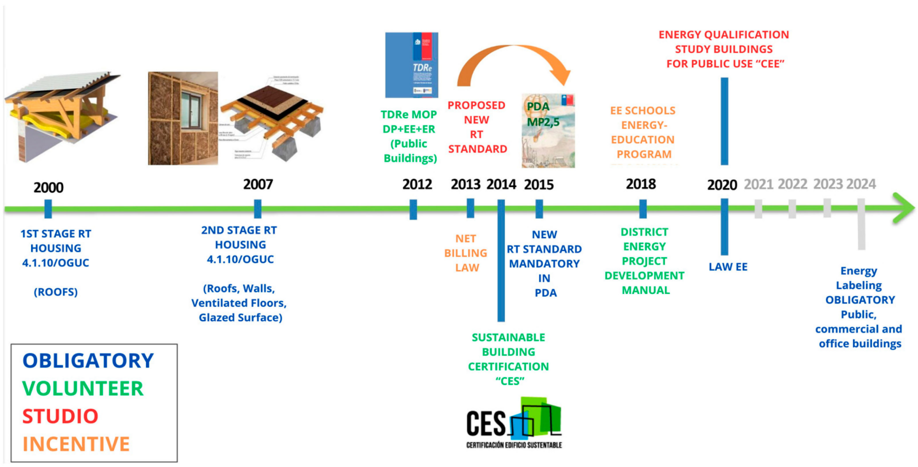


Figure 1. Standards, Certifications, and Incentives [26].

In Mexico, there are 33 official Mexican standards in terms of EE, called "NOM-ENER", only 5 of which are related to construction [27].

The authors of [28] determined air-conditioning demand in Mexico using weather technical indexes and highlighted the greater energy consumption in dwellings; they calculated that over 50% of the country required air conditioning, ranking it first among high-energy-demand countries. The authors recommended focusing on EE strategies to obtain net-zero-energy buildings.

The authors of [29] estimated the maximum energy-saving potential and improvements in thermal comfort that could be obtained when applying an integrated focus to optimization analysis for a typical household in Salamanca, Guanajuato, Mexico, implementing methods to improve household appliance efficiencies, increase the thermal insulation levels of ceilings and walls, and improve water heating systems, reaching an annual energy saving of approximately 52% for new dwellings.

In Western Mexico, in the Purepecha highlands, researchers developed a qua-si-experimental thermal model of heating transference to estimate indoor temperature in rural households with high infiltration by using aerial thermography for measuring temperatures in concrete and asbestos ceilings, obtaining a model with deviations un-der 3 °C [30].

The authors of [31] analyzed the impacts of planned policies on the energy consumption of the population of Mexico, utilizing microdata collected from 97,817 households, considering household size, household appliances, and electricity and LP gas costs, among others. They reported that air-conditioning equipment use in urban households has increased significantly in the northern part of the country, affecting budget electricity consumption in that region.

The authors of [32] similarly evaluated the impact of the Mexican electricity national policy (National Safety Energy) from 1970 to 2020 and observed no significant improvements since the last reform in 2013, indicating that the implemented electric development plans have affected national electric safety directly and significantly. On the other hand, the authors of [33] analyzed and compared a broad range of EE policies on public investment in research and development, as well as related taxes and incentives, and concluded that all the policies fostered EE and that the adoption of a national laboratory of research resulted to be more effective than the implementation of indirect policies involving taxes, incentives, and subsidies.

The authors of [34] evaluated manufacturing household processes in Mexico and identified opportunities for improvements in urban energy efficiency to reduce transport expenses for households. Further, the authors of [35] developed a criterion evaluation tool that regulates social interest households in Durango, Mexico, with minimal guide-lines that promote an improvement in environmental quality and found that the instruments that regulate the development and construction of these types of households are not subject to the minimal guidelines that guarantee environmental quality for the occupants. Likewise, the authors of [36] analyzed the environmental behavior of multifamily buildings in Tampico, Tamaulipas, Mexico, showing the lack of bioclimatic design in that area. Moreover, the authors of [37] reported the usefulness of energy audits and their potential to reveal energy efficiency opportunities in a small public building located in the northwestern part of Mexico. By utilizing the Energy Clean-er-Efficiency Production Handbook published by the United Nations program, they obtained a similar finding, i.e., the main source of energy waste was the occupants' behavior.

It is noteworthy that among the reviewed literature, research in the European Union focused on systematic reviews of EE policies for buildings, and other studies performed in Mexico focused on improving EE features for reducing environmental, economic, and social impacts, among others.

Therefore, this is the first study in which the public policies, strategies, and incentives aimed at implementing energy efficiency (EE) in the residential sector established by the Mexican government are analyzed. We performed a scoping review as follows: 1. Research inquiry identification. 2. Determination of the relevant literature studies. 3. The literature selection. 4. Data graphing. 5. Results collection, overview, and submission. In this systematic review of the public policies adopted in Mexico, the following were identified: five mandatory standards, six optional standards, four strategies (Green Mortgage, Integral Sustainable Improvement in Existing Housing, EcoCasa, and NAMA), and three types of incentives (green bonds, credit and interest rates (Green Mortgage, FIDE, and EcoCasa), and taxes (Income Tax Reduction)). The results of the EE indicators in residential buildings show an increase in the number of house-holds as well as an increase in household appliance demand, where the ones in greatest demand are those based on power consumption, such as television sets and refrigerators. It has been previously found that the power demand in this sector is increasing [16].

The residential sector, considering urban and rural areas, ranks third in power consumption in Mexico, consuming an estimated 790 pj, of which 76% corresponds to thermal energy and 24% to electric power [38]. Mexico has achieved an Energy Transi-tion Index (ETI) of 62%, while Uruguay, Costa Rica, Colombia, Brazil, and Chile, more advanced countries in Latin America and the Caribbean, have an Energy Transition Index greatly exceeding 63% [39].

2. Materials and Methods

Methodology

The scoping review [40–42] method was used to examine Mexican EE normativity and strategies for buildings and was developed in five stages: Stage 1 included research inquiry identification, which consisted of an exploration protocol based on the Population–Concept–Context (PCC) method and the question "What are the energy efficiency policies or strategies applied in residential buildings in Mexico?", where Concept = energy efficiency policies or strategies; Context = buildings; and Population = Mexico. Stage 2 included the determination of the relevant literature studies, where the investigation evidence search strategy aimed to find—in Scopus, Web of Science, ScienceDirect, Google Scholar, and y gob.mx—building or construction terms and the applied normativity in the country; the keywords used were energy efficiency, energy efficiency in buildings, sustainable housing, sustainable buildings, energy efficiency in Mexico, energy efficiency policies, and energy efficiency and strategies in buildings. The search period included the last 20 years, with a view to identifying satisfactory or poor results of the proposed programs and their evolution. Stage 3 included the literature selection, which resulted in 33 mandatory official Mexican EE standards named "NOM-ENER", 25 scientific articles, and 21 public policies. The inclusion criteria considered for document selection were the following: a. English and Spanish articles; b. reference to plans or strategies for energy efficiency in buildings; c. location in the study area; d. government programs. Those not presenting data concerning buildings or data sources were excluded. Moreover, for the benefit study, as a result of the incentives and strategies applied in both situations, a qualitative methodology was used. Stage 4 included data graphing, and Minitab 18 statistical software was used for the graphic representation of the obtained information. Stage 5 included results collection, overview, and submission; in this stage, a qualitative descriptive study was performed, and the results were organized in tables and graphs.

3. Results

3.1. Energy Efficiency Policies or Strategies Applied in Residential Buildings of Mexico

Over the past twenty years, Mexico has developed regulations that seek to enhance energy performance in terms of climate, materials, equipment, and the design of the building itself and involve the use of indicators for EE evaluation.

3.1.1. Mandatory and Optional Standards for Buildings in Mexico

In Mexico, limiting consumption in equipment, commercialized systems, and buildings is standardized, with the latter focusing on proper design and thermal envelopes.

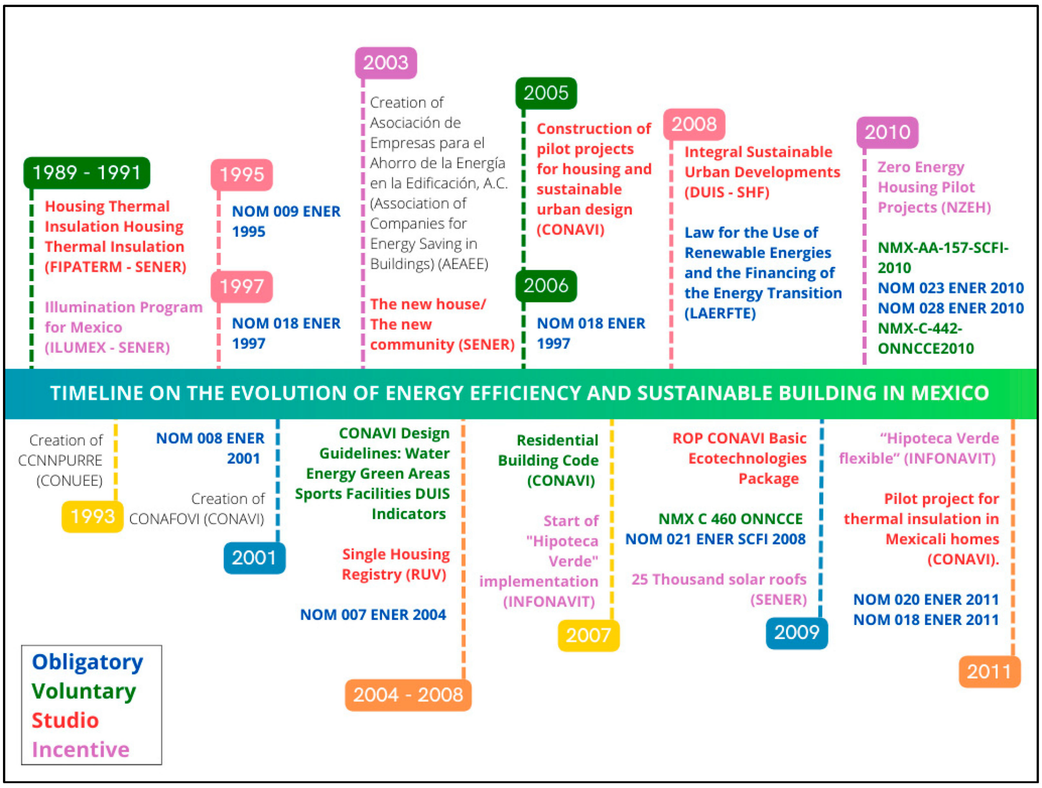
The official Mexican standards for energy efficiency (NOM-ENER) issued and implemented by the National Commission for the Efficient Use of Energy (CONUEE), avail-able on the official website of the Mexican government, are based on the Federal Law on Metrology and Standardization (see Tables 1 and 2 and Figure 2a,b) [43,44].

Table 1. Mandatory Official Mexican Energy Efficiency Standards [43].

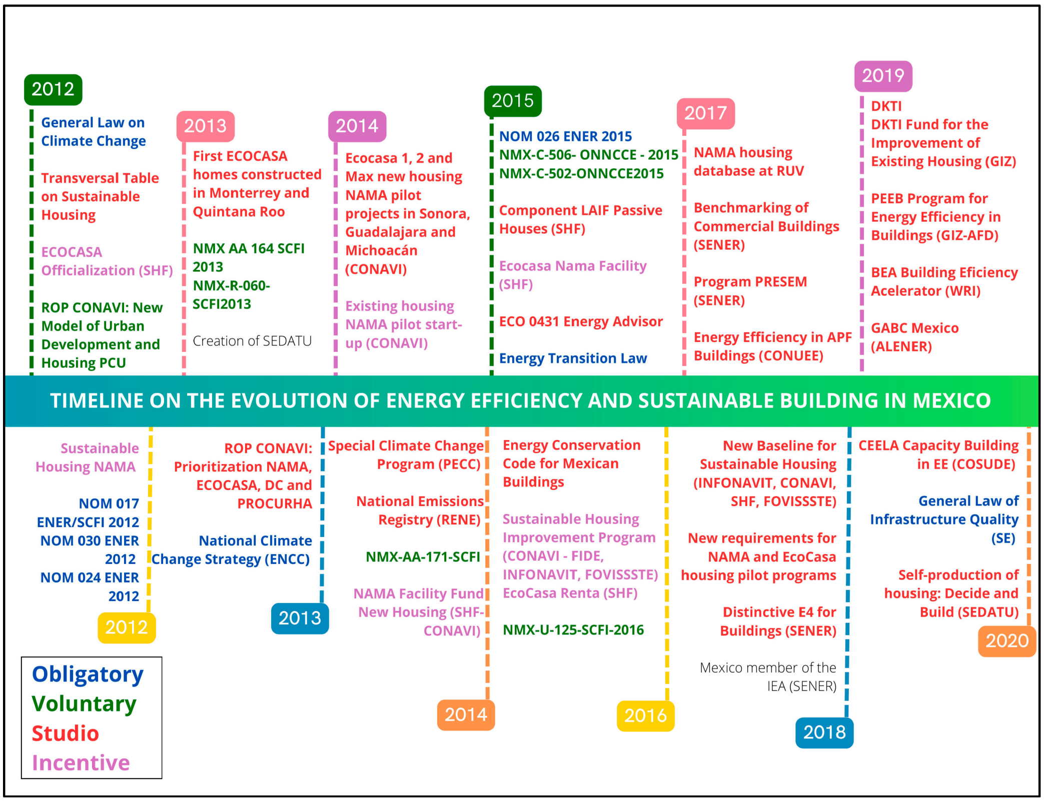
Standard	Authority	Application	Type of Building	Objective
NOM-008-ENER-2001 **Energy efficiency in buildings, non-residential building envelope** [45].	Secretary of Energy (SENER).	All the new no residential buildings and the existing extension buildings to optimize the thermal insulation behavior design obtaining benefits like, the energy saving due to the diminishing on the capability of the cooling equipment and better comfort.	New no residential buildings and existing building extensions.	Limits the heating profit of the buildingd through their insulation with the purpose of rationalize the energy use in the cooling systems.
NOM-009-ENER-2014 **Energy Efficiency in Industrial Thermal Insulation Systems** [46].	Secretary of Energy, through the National Commission for the Energy Efficient Use	New industrial thermal insulation systems, extensions and/or modifications, that operate at hight temperature (298 K (25 °C) and up to 923 K (650 °C) and below under 298 K (25 °C) and up to 73 K (−200 °C).	Industrial	Establish the energy efficiency industrial thermal insulation systems, through the maximum density of independent thermal flow of the thermal insulation system utilized in the pipe or industrial equipment.
NOM-018-ENER-2011 **Thermal insulation for buildings. Characteristics, limits and test methods,** (NORMA Oficial Mexicana NOM-018-ENER-2011, Aislantes térmicos para edificaciones. Características ymétodos de prueba., 2011) [47]	Secretary of Energy, through the National Commission for the Energy Efficient Use and the Federal Consumer Procurement.	Products, components and elements that are domestic manufactured or import with thermal insulation properties for ceilings, plafonds and walls of the buildings, produced and commercialized with that purpose, without prejudice of other purposes, Thermal insulation for foundation are excluded.	Industrial, commercial and residential buildings.	Establish the features and trial methods that the products, components and elements have to accomplish for ceilings, plafonds and the walls of the buildings.
NOM-020-ENER-2011 **Energy efficiency in buildings, building envelopes for residential use** [48].	Secretary of Energy, through the National Commission for the Energy Efficient Use	All the new buildings for housing purposes and extensions of the buildings for existing housing purposes	Buildings for housing purposes.	Limit the heating profit of buildings for housing purposes through its insulation, with the purpose of rationalize the energy use in the cooling systems.
NOM-024-ENER-2012 **Thermal and optical characteristics of glass and glazing systems for buildings. Labeling and test methods** [49].	Secretary of Energy, through the National Commission for the Energy Efficient Use and the Federal Consumer Procurement.	Glass and glazing systems homogeneus transparent and translucents, domestic manufactures or import, to be utilize in the building that will be built in national terrotory.	Industrial, commercial and residential buildings.	Establish the obligation to certify the optical and thermal features of the glass and glazing systems, just like the verification trial methods, for its verification, with the purpose of ensuring the thermal insulation in buildings.

Table 2. Non-mandatory Mexican standards for sustainable construction [44].

Standard	Authority	Application	Type of Building	Objective
NMX-C-460-ONNCCE-2009 **Thermal insulation—"R" value for housing envelopes by thermal zone for the Mexican Republic. Specifications and verification** [50].	Secretary of Economy	Insulation dwellings to improve the conditions of habitability and to diminish the energy demand used to thermal refurbish indoors, according to the thermal zonerdo where located.	Dwellings and extensions of them.	Establish the specifications of total thermal resistance (R Valor).
NMX-U-125-SCFI-2016 **Roof coatings with high solar reflectance index. Specifications and test methods** [51].	Secretary of Economy	Dull fluid products of placement on site and premanufactures products ir imported, to use or to commercialize, they could be commercialized as "High Index Solar Reflectance coatings".	Industrial, commercial and residential buildings.	Establish the specifications and essay methods that coatings for building ceilings have to accomplish and to be named "High index sola reflectance coatings".
NMX-AA-164-SCFI-2013 **Sustainable building. Minimum environmental criteria and requirements** [52]	Secretary of environment and Natural Resources (SEMARNAT)	All the public and private bu ildings destined in a whole or a mixed use to different activities of same nature, for housing, commercial, services or industrial.	Residential commercial, services or industrial buildings.	Especifies the criteria and environmental minimal requirements in a building and the sustainable benefit of natural resources, without overlooking socioeconomic aspects that ensure your viability, habitability and integration of the las topic.
NMX-AA-171-SCFI-2014 **Environmental and specifications of performance requirements for lodging establishments** [53].	Secretary of Economy	Establishments of hospitality interested in demonstrate the accomplishment of touristic environmental performance requirements.	Hospitality establishment.	Establishes the requirements and specifications of environmental performancefor the operation of hospitality establishments.
NMX-C-7730-ONNCCE-2018 **Construction Industry-Ergonomics of the thermal environment-Analytical determination and interpretation of thermal comfort by calculating the VME and PEI indices and local thermal comfort criteria** [54].	Secretary of Economy	To determine and to interpret the thermal comfort of people outdoors.	Any type of building, either residentia, office or public space.	Presen methods for prognosis of the general thermal sensation general and the discomfort degree (thermal dissatisfaction) of exposed people to moderate thermal environments.
NMX-R-060-SCFI-2013 **Windows and architectural products for the exterior enclosure of facades. Classifications and specifications** [55]	Secretary of Economy	Doors, windows and enclosure in general, including: Rooftop windows, balcony, emergency pedestrian doors, fixed mosquito screen, foldable or rolling.	Industrial, commercial and residential buildings.	Establish the doors, windows and enclosures properties to guarantee the safety and qualityof these products in Mexico.



(**a**)



(**b**)

Figure 2. (**a**). Timeline of sustainable construction and energy efficiency in building in Mexico from 1989 to 2011 [56]. (**b**). Timeline of sustainable construction and building energy efficiency in Mexico from 2012 to 2020 [56].

3.1.2. Strategies Implemented for Energy Efficiency in Buildings

In the last 15 years, the Mexican government has promoted the implementation of ecotechnologies and systems that promote energy saving and efficient energy use in Mexican low-income housing, such as the following:

1. The Green Mortgage program, a low-cost credit scheme, grants an additional amount to National Workers' Housing Fund Institut (INFONAVIT) beneficiaries to finance the purchase of ecotechnologies in their households. This program began as a pilot test in 2007; as it was successful, it was institutionalized nationwide in 2009. Since then, the program has functioned as an optional credit scheme that provides an additional amount to beneficiaries to finance fixed packages of ecotechnologies to be chosen among several options, depending on the climate zone in which the households are located. In 2011, a new scheme called "Flexible Green Mortgage" was approved; it allows beneficiaries to select the ecotechnologies that best meet their needs, obtained from a list approved by INFONAVIT. All housing loans granted by INFONAVIT must include an additional amount for using ecotechnologies. This becomes mandatory for all eligible borrowers who acquire a loan, whether for used or new housing, expansion, remodeling, or self-construction. The granting criteria comply with minimum savings generated by ecotechnologies based on their salary segment (without considering the consumption habits of the beneficiaries).
2. The ecotechnologies contemplated in this program depend on the bioclimatic zone where the house is located and include energy-saving light bulbs, high-efficiency or low-consumption air-conditioning equipment, thermal insulation for roofs or walls, gas water heaters, ecological-grade toilets, showers, faucets, or valves with energy-saving devices, and double-glazed windows with PVC frames. This list is updated with equipment that complies with certifications or efficiency reports and is authorized by INFONAVIT. The program has granted financing to approximately 3 million workers' housing units with INFONAVIT credit, of which more than 500 thousand have been evaluated with the Green Housing Evaluation System (SISEVIVE) [45].
3. Another program, the Integral Sustainable Improvement in Existing Housing program, promoted by the National Housing Commission (CONAVI), supports the residential sector in acquiring sustainable and efficient technologies to re-duce household electricity consumption. Participating technologies include efficient gas heaters, solar heaters, photovoltaic systems, air conditioners (omit-ting heating systems), and thermal insulation [57].
4. The EcoCasa program was created in 2014 by SHF in conjunction with the Inter-American Development Bank and the German Development Bank in the framework of National Appropriate Mitigation Action for Sustainable Housing (NAMA); with three schemes, EcoCasa I, II, and III, it offers preferential rates based on the level of energy efficiency, location, and water savings according to the operating rules of the program and the bioclimatic zone of the project [58].
5. EcoCasa seeks to reduce at least 20% of carbon dioxide emissions through sustainable criteria based on the integral performance of housing. DEEVi is an evaluation of the energy efficiency of housing aimed to guide users towards more sustainable designs, creating awareness of the critical measures that can be applied in residential buildings. SAAVi, i.e., a household water-saving simulator, is used to estimate the water savings in a dwelling based on the comparison of the efficiency of its de-vices and the consumption level of a reference dwelling (the baseline) (see Figure 3).

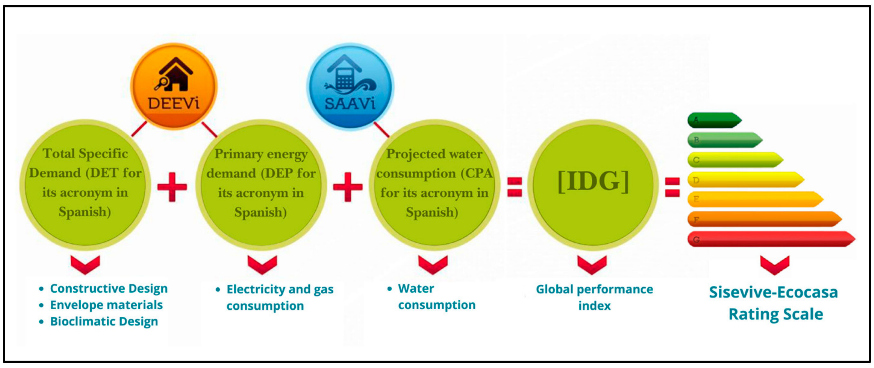


Figure 3. Global Performance Index [59].

6. NAMA Facility is an SHF program that provides financial incentives and technical assistance to SMEs (Small and Medium Enterprises). Its objective is to facilitate the incorporation of Small and Medium Developers (DPyMEs) into the low-carbon housing market by eliminating investment barriers and providing better access to financing sources for the construction of 8000 to 11,000 households that achieve at least 20% CO_2 reductions compared with a baseline home [60].

The benefits of this program include a subsidy of up to 100% of the amount in-vested in ecotechnologies and energy efficiency measures proposed for the optimization of the project and comprehensive technical assistance at no cost to the participating developers, such as training workshops (project personnel), energy assessments through the preparation of DEEVi sheets for each prototype, comprehensive advice available to the developer, marketing strategy support for sales personnel, the training of construction personnel, and the supervision of the correct installation of efficiency measures through on site visits.

The criteria for choosing a developer include their status of being a small- or medium-sized company with an annual housing production between 5 and 3000 dwellings registered per year in the Single Housing Registry. To be eligible to participate, the project must meet the following criteria: 1. Have a bridge loan with a financial intermediary registered with the SHF. 2. Be a home valued at up to MXN 2,250,000. 3. Have a minimum construction value of 38 m^2 plus a positive HEEVi report. 4. Be located within the urban containment perimeter (with at least U3, that is, in metropolitan areas with the most significant source of employment, with U3 referring explicitly to growing areas adjacent to consolidated urban areas). 5. Comply with the current base-line of the industry (in terms of construction elements and ecotechnologies).

As of December 2020, this program has financed 5106 dwellings for 25 developers in 38 projects in 15 states of the Mexican Republic, contributed to a re-duction of 126,779 tons of CO_2 (over the housing lifetime), and aided 19,913 people [60].

3.2. Evaluation Systems

At the end of 2012, INFONAVIT established the Green Housing Evaluation System (Sisevive-EcoCasa), which has three stages: 1. Comprehensive evaluation of housing EE and water consumption, based on the premise that design is key to efficiency. 2. The incorporation of EE and environmental measures in common areas of housing complexes, such as the grounds, the public lighting system (adopting or not renewable energies), rain-water harvesting, water management, the construction materials, the types of pavements, solid waste collection, and the emissions as a result of transfers. 3. The measurement of developments in municipalities that encourage environmentally friendly measures [61].

Sisevive-Ecocasa is a platform where other programs implemented in the last 15 years coexist, such as EcoCasa, executed by Sociedad Hipotecaria Federal (SHF). Nationally Appropriate Mitigation Action (NAMA), a framework strategy for the scaling up of the construction and energy efficiency standards of housing in Mexico, incorporates more evaluation elements, such as the quality of the urban environment and the environmental footprint based on location and the analysis of the life cycle of some building materials [56].

Sisevive-Ecocasa uses two calculation tools, DEEVi and SAAVi, which are used together to determine the environmental and energy impact of housing (see Equation (1)) based on Mexican Official Standard NOM-020-ENER-2011; the evaluation of the energy balance of Mexican housing for the Sisevive program; and the register on the Unified Housing Registry platform [62].

$$IDG = A \cdot DET + B \cdot DEP + C \cdot CPA \quad (1)$$

where

- IDG is a Global Performance Index
- DET is a Total Specific Demand (sensible and latent cooling plus heating), in kWh/m^2·year
- DEP is a Primary Energy Demand (heating, cooling, domestic hot water (DHW), dehumidification, auxiliary electricity, household electricity), in kWh/m^2·year
- CPA is a Projected Water Consumption

A, B, C is a Weighting parameters. Values from 0 to 1 depending on climate zone and type of dwelling. Note: DEEVi software is used to obtain DET and DEP, see Figure 4.

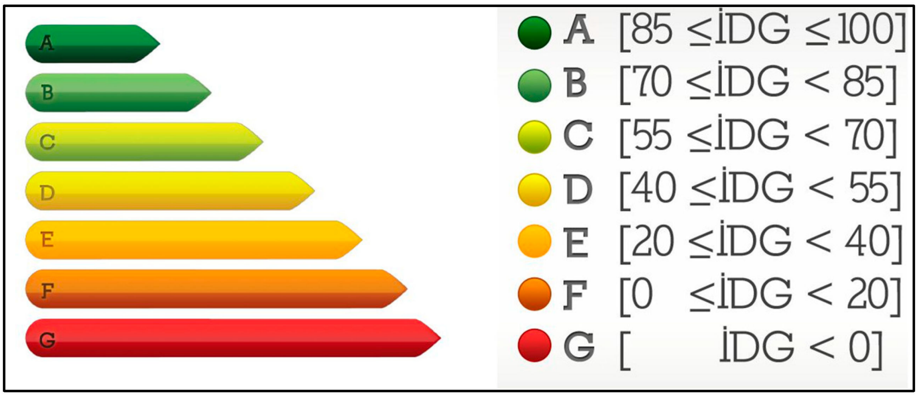


Figure 4. Rating scale according to the type of IDG [59].

HEEVi, the Housing Environment Evaluation Tool, is used to perform the analysis of the characteristics of the urban context of a housing unit to assess whether it is located somewhere that allows for an adequate quality of life for its inhabitants. The evaluation is based on 32 criteria (proximity to public transportation, employment density, and essential equipment, among others), resulting in a score from 0 to 100. ACV, i.e., the Carbon Footprint Analysis of Construction Materials, is a tool developed by the Institute of Engineering of the National Autonomous University of Mexico and SHF to quantify the carbon footprint based on the analysis of the extraction of the raw mate-rials necessary for the manufacture of building materials and systems, including distribution and production and all incoming and outgoing flows; it also determines the environmental impact in kilograms of CO_2 [60].

From 2013 to December 2023, EcoCasa included 71,440 homes in 224 projects in 25 states of the Mexican Republic, contributed to a reduction of 2.6 million tons of carbon dioxide, aided 285,760 Mexicans, and issued EcoCasa certificates for 3,473,556 m^2 [58].

3.2.1. EE Key Indicators in Residential Type Buildings

To evaluate the EE programs impact in the residential sector (urban and rural areas) the following indicators are considered: food preparation, water heating, thermal conditioning for enclosed spaces, lightning, food refrigeration, hygiene and entertaining devices, communication systems, computers, and an endless number of household appliances, inter alia. Thus, the activity level for some EE indicators is presented as terms per inhabitant, per inhabited dwelling, depending on the variable that directly shows the energy performance, Figures 5 and 6 [63].

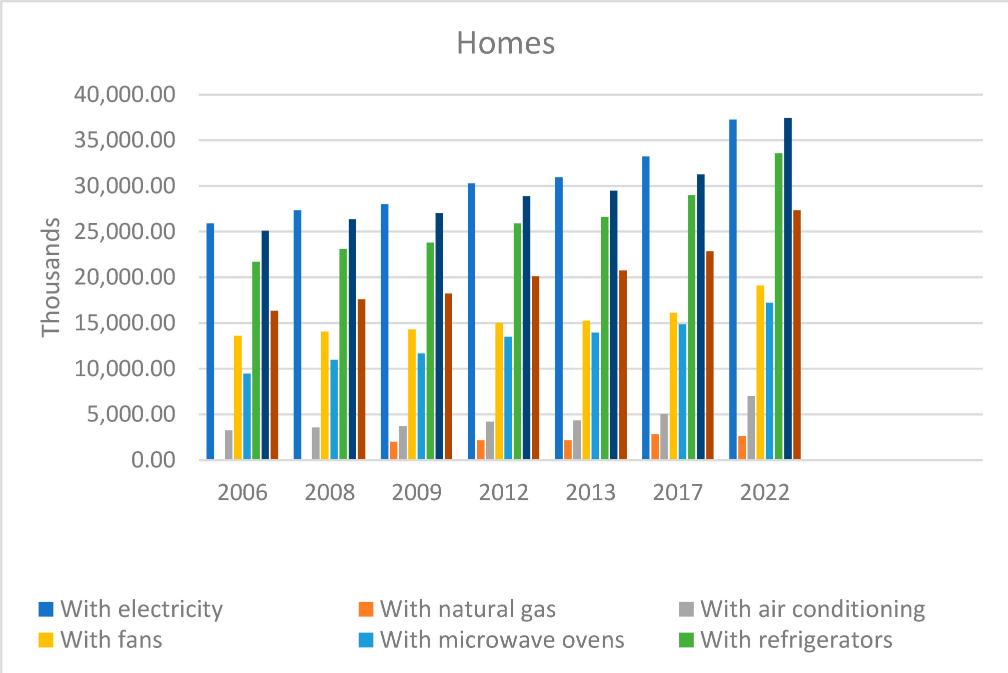


Figure 5. Dwellings per type of household appliances. Data obtained from BíEE-CONUEE for free consultation [16].

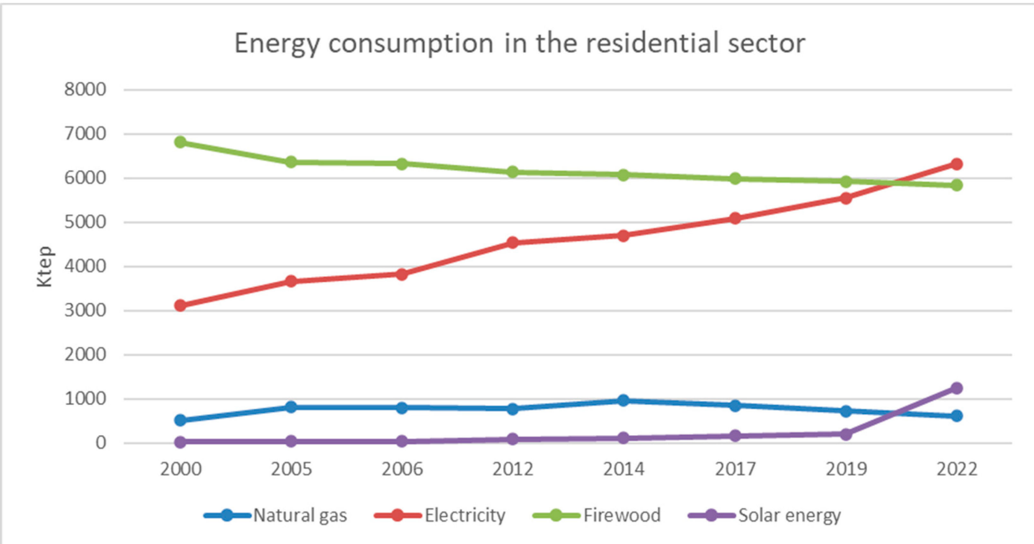


Figure 6. Energy consumption in the residential sector. Data obtained from BíEE-CONUEE for free consultation [16].

3.2.2. Analysis of Benefits Resulting from Incentives and Strategies Applied in Both Cases

In Mexico, a series of financial incentives have been implemented that integrate the systemic vision of sustainable building, seeking benefits in their implementation, see Tables 3 and 4 [56].

Table 3. Current financial incentives for private investment in energy-efficient buildings in Mexico [56].

Incentive	Strategy and/or Program	Features
Green Bonds	Any entity with eligible green assets can issue green bonds and/or obtain green loans.	Sustainable financial market actors can incorporate metrics and emissions targets compatible with the goals set in their credit products or green bonds, to be incorporated directly into the construction of urban infrastructure and highly efficient buildings [64].
Credit and Interest Rates	INFONAVIT Green Mortgage	It grants an additional amount in the mortgage loan to end users, under the premise of incorporating eco-technologies in the home, which means economic savings for the user and increases their debt capacity [65].
	Trust Fund for Electric Energy Saving (FIDE)	It is granted to industry and MyPIMEs to incorporate energy efficiency measures in their operation, to increase their profitability and thus the ability to pay and economic growth [66].
	EcoCasa of Federal Mortgage Company	It grants the bridge loan rate for the construction of sustainable housing and its variants depending on the products in its portfolio and in which case, the granting of resources allows obtaining better levels in rates, which is key for the implementation and sustainability of the Program [67].
Taxes	Decrease in Income Tax (ISR), contained in the Income Tax Law, establishes support for the use of natural resources, protection of the environment, flora and fauna, preservation and restoration of the ecological balance, as well as the promotion of sustainable development at regional and community level in urban and rural areas.	Tax benefits for companies that use renewable energy, establishing the maximum percentages used, in the case of fixed assets by type of asset, for example 100% in machinery and equipment for the generation of energy from renewable sources.Currently, the government of Mexico City grants a tax benefit of 10% in the reduction of property tax, to individuals who prove to be owners of residential properties that voluntarily install a rooftop naturalization system or green roof [68].

Table 4. Non-financial incentives for promoting EE in buildings in Mexico [56].

Type	Name	Country	City	Initiative/Program	Promotion of EE	Regulatory Compliance Management	Degree of Replication		
							High	Medium	Low
Technical Advisory	Training of public servants	Mexico	Mexico	Mexican sustainable housing NAMA	x	x		x	
	Technical assistance to industry	Mexico	Mexico	Green Mortgage	x	x	x		
	Open technical training	Mexico	Mexico	CONUEE Webinars for Energy Efficiency in Buildings and Industry	x	x		x	

Table 4. *Cont.*

Type	Name	Country	City	Initiative/Program	Promotion of EE	Regulatory Compliance Management	Degree of Replication		
							High	Medium	Low
Awards and recognitions	Awards for high energy efficiency buildings	Mexico	Mexico City	Excellence in Energy Efficiency in Buildings	x	x	x	x	
Public coordination	Management of federal/state initiatives (new and existing)	Mexico	Merida, Yucatan	Compliance mandate for public buildings	x	x	x		
Market tools	Energy performance labeling	Mexico	Mexico	Sisevive-Ecocasa	x	x		x	

3.3. EE Study in the Residential Sector

In Mexico, EE in the residential sector has undergone significant restructuring since 1995 through the implementation of a high number of official Mexican energy effi-ciency standards (NOM-ENER) to regulate equipment income and marketing as well as energy consumption systems on the national market. As a result, there has been a continuous improvement in the energy efficiency levels of standardized equipment, laying the technical basis for the development of programs for the substitution of household appliances and lighting technologies promoted by the federal government in recent years.

The residential sector, considering both urban and rural areas, ranks third in power consumption in Mexico after the transportation and industrial sectors, consuming an estimated 790 pj, of which 76% corresponds to thermal energy and 24% to electric power. In terms of public policies, Mexico has made significant progress; however, it is essential that governmental actions give priority to boosting EE and the substitution of fuel for thermal energy utilization (which, as outlined above, represents 76% of total consumption) [39].

Water heating is responsible for 31.4% of GLP consumption, which represents the currently complex relationship between price and supply due to 70% of GLP being imported. Research results indicate the need to implement an aggressive nationwide pol-icy to substitute gas boilers with solar water heaters, which would reduce the pressure on the energy demand, provide environmental benefits (such as decreasing the social and greenhouse gas emissions), and address the issue of high GLP imports [39].

As the residential energy consumption associated with air conditioning is very high in Northern Mexico (representing 53% of the total regional energy consumption), an integral policy to address the thermal comfort problem is required, not only to boost the utilization of efficient equipment but also to promote the thermal insulation of dwellings through bioclimatic construction.

As reported in previous studies, it is also important to accomplish electrification with renewable energy integrated systems in 100% of Mexican towns at the small scale, as well as ensuring access to affordable and efficient household appliances so that a greater number of households may overcome energy poverty. Finally, it is essential to conduct studies on energy utilization in households; it is particularly urgent to include direct measures of consumption per final use along with registering access to energy services in such research endeavors [39].

Comparative Studies of EE Policies or Strategies in Latin America Countries

Even though all the countries in Latin America and the Caribbean promote renewable energy utilization in some way, abandoning the use of fossil sources has not yet been accomplished, with fossil fuels still dominating the regional energy matrix.

This is also the case for Uruguay, Costa Rica, Colombia, Brazil, and Chile, the five countries that have made the most progress in the energy transition and whose Energy Transition Indexes (ETIs) greatly exceed 63% (Figure 7).

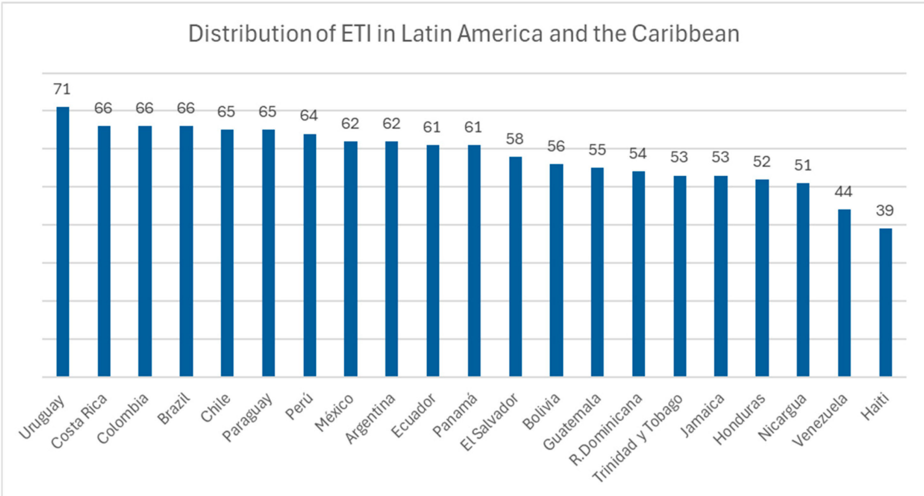


Figure 7. ETI distribution in Latin America and the Caribbean. Data from World Economic Forum, "Fostering Effective Energy Transition", April 2021 [16].

4. Discussion

The main results show that EE policies or strategies implemented since 2001 have played a significant role in energy efficiency promotion in Mexican residential buildings. Through the implementation of only five mandatory standards, of which three apply to households (NOM-018-ENER-2011, construction industry—ergonomics of the thermal environment; NOM-020-ENER-2011, energy efficiency in buildings and immersive buildings for residential use; NOM-024-ENER-2012, thermal and optical features of glass and glazing systems for buildings—labeling and test methods) as well as programs, some significant results have been obtained as of December 2020: the financing of 5106 households for 25 developers of 38 projects in 15 states of the Mexican Republic and a reduction of 126,779 tons of CO_2. Public policy evaluation is important to determine the impact of the above, as also noted by various authors, such as [5,31,34–36,69,70] who expressed the significance of evaluating such EE measures in terms of manufacturing and optimization processes in buildings, the maximization of energy savings, and the implementation of more efficient lighting technology as the most cost-effective solution.

This study shows that the number of programs implemented has allowed for significant progress in the energy transition. In terms of public policies, Mexico has achieved significant advancement; however, it is essential that governmental actions prioritize boosting EE and the substitution of fuel for thermal energy utilization, which alone represents 76% of the total consumption [39].

An EE impact evaluation in the residential sector was further performed with the following indicators: food preparation (62.8%), water heating (27.2%), thermal conditioning for enclosed spaces (21.2%), lighting (8.6%), food refrigeration (21.2%), hygiene and entertainment devices (18.3%), microwaves (1.8%), and others (17.2%) [63]. It is noteworthy that food preparation has the greatest energy consumption, followed by water heating and thermal conditioning for enclosed spaces [39]. Another important aspect is the increasing demand for electricity in the residential sector over the last 20 years (Figure 7). Currently, Mexico has reached an ETI of 62%, while Uruguay, Costa Rica, Colombia, Brazil, and Chile (in Latin America and the Caribbean) are more advanced in the energy transition, as shown by their indexes exceeding 63% (Figure 7).

5. Conclusions

In this study, we focused on EE public policies and strategies, identifying which of them promote EE in residential buildings in Mexico. Over the last 20 years, limited mandatory standards and strategies have been implemented in this sector. Extensive evaluations have been conducted that have highlighted increases in energy consumption; thus, an increased number of mandatory EE standards and strategies should be implemented to foster responsible energy utilization in society. The residential sector has the third highest energy consumption (27.1%), following the transportation and industrial sectors, which depends on several factors, such as construction quality, insulation level, and the types of household appliances. In Mexico, the residential sec-tor's energy consumption represents a significant part of the carbon footprint and is responsible for yearly greenhouse gas emissions equivalent to 34 million tons of CO_2, a gas that contributes to global warming. One way to reduce these emissions could be to increase alternative energy sources in this sector. The findings from this investigation suggest that decision-makers should take the necessary steps to speed up the EE transition in residential buildings, covering all relevant aspects, from construction to installation. Further, future research should include cost–benefit analyses of public policies for EE in residential buildings.

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