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Review

Residential Refrigeration MEPS in Colombia: A Review and a Comparative Analysis

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Abstract: This paper addresses the energy efficiency issue in household appliances, which has led to the establishment of policies at a global level in favor of setting minimum energy performance standards (MEPS), which guarantee end users are able to select more efficient equipment. The countries of the United States, Brazil, Mexico, Chile, and the Community of the European Union were taken as references to review their policies and implementation strategies, in order to be compared with the Colombian panorama (at the market, technical and political levels). This allows the establishment of common aspects and differences related to the determination of energy consumption, adjusted volume, and formalization of efficiency ranges, and in the specific case of domestic refrigeration. Managing to distinguish the most relevant aspects for the successful adoption of these policies in Colombia. It is evident that the implementation of these guidelines has a positive impact on the market of the countries and communities of reference. Similarly, the MEPS are shown as a mechanism to regulate energy consumption in the residential sector.

Keywords: Colombia; energy efficiency; energy labeling; MEPS; residential refrigeration

Citation: Ramírez Sánchez, A.F.; Solís-Chaves, J.S.; Rodríguez-Muñoz, A.d.P.; Arias Barragán, L.A.; Serna-Pérez, D.X.; Prías Caicedo, O.F. Residential Refrigeration MEPS in Colombia: A Review and a Comparative Analysis. *Energies* **2022**, *15*, 6483. https://doi.org/10.3390/en15176483

Academic Editors: Fabio Polonara and Chiara Martini

Received: 28 July 2022
Accepted: 29 August 2022
Published: 5 September 2022

1. Introduction

In the last three decades (1992–2022), nations have turned to seeking strategies to mitigate the impacts that have resulted from the intensive use of energy. Solutions and measures that range from the social, political, economic and technological, which seek to regulate and optimize energy resources and minimize the impact of the products derived from them without impairing the quality of life. Measures such as those addressed since the Montreal Protocol in 1987 and the control of gases that deteriorate the ozone layer [1]. Kyoto Protocol in 1997 establishes the measures and strategies to minimize the greenhouse effect [2]. By the agreements derived from COP26 and Paris 2015, which seeks to substantially reduce greenhouse gas emissions, in such a way as to control the global temperature rise in this century, with a maximum of 2 °C, or if possible to 1.5 °C. Each signatory country must look for strategies to fulfill the commitments acquired and be reviewed every five years. Likewise, financings are established for developing countries so that they can advance in strategies to mitigate the impact of climate change [3,4].

As of 2018, 3.6 billion pieces of refrigeration and air conditioning-related equipment were in stock (includes equipment from the residential, commercial, and industrial sectors), of which 45% are domestic refrigerators. In this same year, 350 million pieces of equipment were presented for sale, of which 35% correspond to refrigerators for domestic use [5]. According to the report of the International Energy Agency (IEA), electricity consumption in the residential sector has experienced a progressive growth starting from 3.6 EJ (3.61×10^{18} J) in 1971 to reach 21.9 EJ in 2019 worldwide. In this last year, the electricity consumption corresponding to the residential sector was 26.6% [6]. By 2025, the projection of sales volumes of domestic refrigerators is estimated to reach 236 million units worldwide, which presupposes an increase in energy consumption due to the use of these appliances and highlights the need to demand that they be increasingly efficient [6].

The analysis of energy consumption in homes occupies a place of special interest as a result of the growth that has been taking place due to phenomena such as the COVID-19 pandemic and the promotion of teleworking [7,8]. Recent studies show the average times of use of household appliances. For the year 2021, energy consumption in the refrigeration area was close to 235 billion kWh in the United States and constitutes 16% of the total electrical consumption at the residential level and 6% of the total electrical energy consumption of the country. The refrigerators have an average daily operation of 15 h and a half being; devices such as television, modem, PC or multimedia devices that handle operating times of 12 h 42 min; illumination with 7 h 58 min; the water heater with 5 h 46 min; among others [9].

In the European Union, refrigerators and freezers represent an energy consumption close to 86 TWh per year, which corresponds to 11% of residential electricity consumption [10]. Due to all of the above, the implementation of energy efficiency standards MEPS, establish minimum performance conditions, to reduce energy consumption in the home, they have become a state policy for both developed and developing countries [11].

The MEPS are applicable to electrical appliances such as lighting fixtures, refrigerators, air conditioners and electric motors, among others, and these are mandatory for manufacturers and marketers [12]. The application of the MEPS, in addition to having commercial purposes, is also aligned with objectives linked to environmental policies and the normalization of energy consumption under particular operating conditions for household appliances and devices in general, with which the governments of some countries are committed to through international agreements, for example, the SDGs [13] and the Energy Charter treaty [14]. The implementation of MEPS has contributed up to 5% of savings between 2018 and 2019 worldwide [13,15].

The MEPS promotion policy has evolved in the last two decades, establishing specific requirements to reduce the energy consumption of household appliances [16]. Figure 1 shows the projection in the reduction of consumption in kWh by 2030 by 2030 worldwide of some household appliances for residential use, among which is the refrigerator, where the **BAU** consumption corresponds to the energy consumption by household appliances with current technologies by 2030 and the **CoNW** MEPS consumption corresponds to the projected consumption applying the best MEPS technologies and policies [17].

The MEPS guide the user to be able to acquire more efficient equipment. In this way, these policies help to reduce the energy demand of the residential sector mainly, leaving obsolete equipment (not very efficient) out of the market [18]. As a strategy for the application of the MEPS, labeling programs emerge in order to inform the consumer about the specific characteristics of electrical appliances. The implementation of these policies, together with those of labeling, have proven to be effective in reducing GHG, responsible for global warming.

Additionally, by reducing the final consumption of electricity, it is possible to reduce the use of capital investment in the energy supply infrastructure, for instance, the construction of power plants and the reduction of raw materials such as hydrocarbons used for the generation of energy in thermoelectric plants, thus reducing long-term environmental impacts [19].

Currently, more than 80 countries have implemented or are in the process of implementing labeling programs based on the goals set by the different nations on issues related to climate change [20]. The ultimate goal of the label on household appliances is to describe the energy yield of a product so that the consumer can make purchasing decisions and, in turn, encourage the rational use of electrical energy through the acquisition of efficient equipment [21].

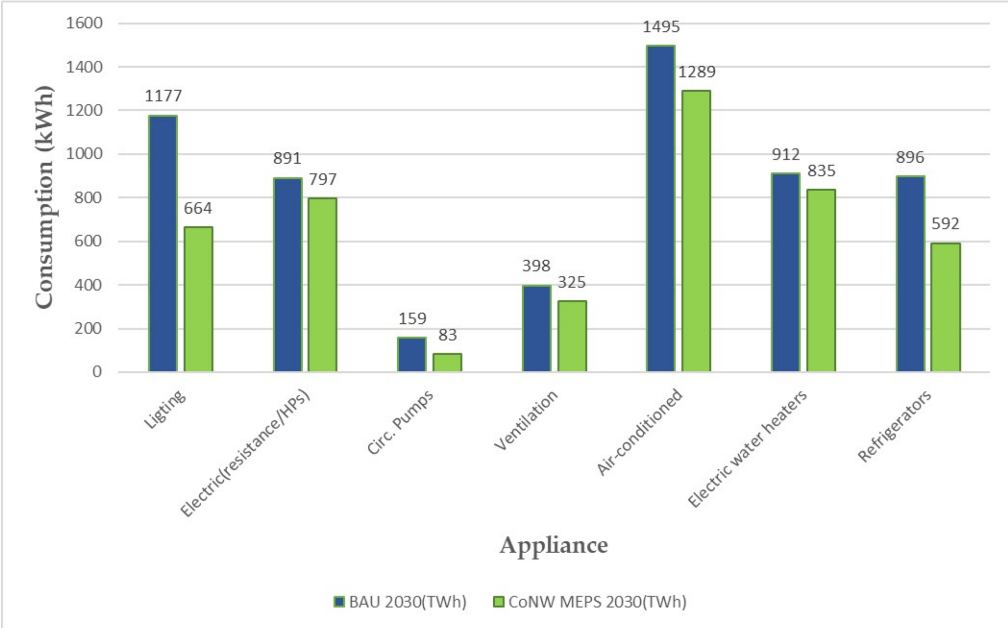


Figure 1. Estimated reduction in refrigeration consumption by applying BAT and MEPS to 2030. Adapted from [17].

In addition, it allows the user to control the economic expense reflected in the billing for the use of electrical energy [22].

The labels proposed in the different programs can be of two types, comparison labels, and recommendation labels [23]. The comparison ones provide information to the user about the performance of a specific product and compare it with the performance of other products of the same family that exist in the market, commonly used in countries of the European Union, Brazil, Chile, Colombia, among others. Recommendation ones are also known as guarantee seals, which are generally associated with energetically efficient products, as in the case of Energy Star. The recommendation label «not to buy products» makes known how energy efficient a device is, in addition to being also known as guarantee seals (for example, the Energy Star seal in the United States) [24].

The informative labels are attached to a manufactured product and include energy consumption characteristics such as the monthly or annual consumption of the equipment and its respective category [25]. Energy consumption and its dynamics of change are subject to ongoing analysis in the international and national context due to its multi-factorial impact on social, economic, and environmental aspects.

In the national context, in 2015, the residential sector represented 16.2% of the total final energy consumption in Colombia thanks to this percentage, it was possible to identify that the principal energy consumption is due to refrigeration, television, lighting, and cooking [26]. According to the National ECV carried out in 2021, more than 80% of Colombian households had at least one refrigerator-freezer in use, which represents between 20% and 50% of electricity consumption of Colombian households [27]. Therefore, improving energy efficiency in the residential sector has been one of the objectives of the rational use of energy policy in Colombia, achieving an increase in the efficiency of the different electrical appliances [28].

Currently, Colombia does not have MEPS policies. However, in 2015 it implemented the RETIQ [29], which establishes measures that promote the Rational and Efficient Use of Energy (URE) in products that use electricity and gas through the establishment and mandatory use of labels that report on their performance in equipment associated with cold production, lighting, driving force, and heat production, particularly focused on the residential and commercial sectors.

This review is a result of the research project «MEPS and labeling for final energy use equipment with the highest consumption in the country» financed with resources from the Colombian Ministry of Science and Technology (Minciencias) and developed jointly between the National University of Colombia at the Bogotá headquarters and the ECCI University. This research has carried out a review and analysis of the MEPS in different countries that are globally and regionally relevant in domestic refrigeration applications, proposing a road-map that allows their implementation in Colombia.

This review is structured in eight sections. First, providing a complete list of abbreviations and acronyms (Nomenclature Part) for an easy read of the paper. That allow the reader to have a clear idea of the concepts on energy efficiency in refrigeration and the analysis methodology implemented (Section 2); policies and strategies of the reference countries for the study, such as Brazil, Mexico, Chile, Colombia, the United States, and the European Union, due to their leadership at the regulatory level and ability to implement strategies in energy efficiency in equipment for the final use of energy in the residential and tertiary sector (Section 3); a look at technological trends from the patent field (Section 4). Subsequently, it is presented a comparative analysis at a technical level around the establishment of energy efficiency indicators for each of the reference countries and Colombia (Section 5). A technical and political discussion on domestic refrigeration in Colombian market is also presented (Section 6). Finally, the conclusions of the research are provided (Section 7).

2. Reviewing & Comparison Methods

The methodology implemented for the collection and processing of information was divided into 5 phases: Phase 1: Search for relevant information; Phase 2: Classification of information according to the type of document; Phase 3: Review of technical parameters, collection of information about energy efficiency, identification of labeling policies and MEPS of the countries under study; Phase 4: Comparative analysis of energy efficiency indicators in refrigerators, and finally Phase 5: Proposal for energy labeling in refrigeration equipment, as shown in Figure 2. The first phase carries out an exploration and collection of information from primary sources, using academic databases (Science Direct, IEEExplore, Google Scholar), technical (Ecollection), and government databases such as SICEX, SUI and DANE, among others. In the second phase, the information is classified according to the type of documents found:

- Research articles from academic databases. The research focused on the energy efficiency issue and technological trends for domestic refrigeration in the period between 2005 and 2022 was consulted.
- Technical standards associated with calculating energy efficiency in domestic refrigerators in the countries considered for comparison, identifying the technical methodologies established by each country to determine energy consumption, and the refrigerator labeling for domestic use, according to Table 1.
- Colombian Government Documents on energy efficiency for refrigeration. The First BEU of 2019, carried out by the UPME and the Ministry of Mines and Energy [30], was used.
- The RETIQ Regulation [29], and the Indicative Action Plan for Energy Efficiency prepared by UPME [26], the Final Report on Cost-Effectiveness Evaluation of Energy Efficiency Programs in the Residential, Tertiary, and Industrial Sectors presented by CORPOEMA [31], and in turn the National Energy Plan: Energy Ideario 2050 carried out by the UPME [32].
- Regulatory Documents of reference countries on energy efficiency in domestic refrigeration using an observation window of 20 years (2001–2021). They consulted the technical standards associated with the energy efficiency calculation in domestic refrigerators in the countries considered for comparison. And thus, managing to identify the technical methodologies established by each country to determine the

energy consumption and the labeling of refrigeration equipment for domestic use according to Table 1.

In phase 3, the review of technical parameters was carried out, such as the capacity of the compartments (in liters), the defrosting technology (Frost and no Frost), the type of compressor (Conventional or Inverter), the average energy consumption in $kWh/month$ among others. In parallel, information was collected on energy efficiency, technological trends in refrigerators, and patents granted for developments in the refrigeration area using the database of patent documents from Latin America and Spain [33]. Additionally, it was possible to identify the labeling and MEPS policies of the countries under study.

After compiling and reviewing information, regulations, and technical characteristics, MEPS both in Colombia and in the reference countries, a comparative analysis was carried out in phase 4 between the different methods of calculation and definition of categories and efficiency indicators. Finally, in phase 5, activities, time, and resources are proposed to establish a road-map aimed at the implementation of MEPS in Colombia with the inclusion of a proposal for a modification of the current energy label in Colombia. Next, phase 3 of the proposed methodology is contextualized.

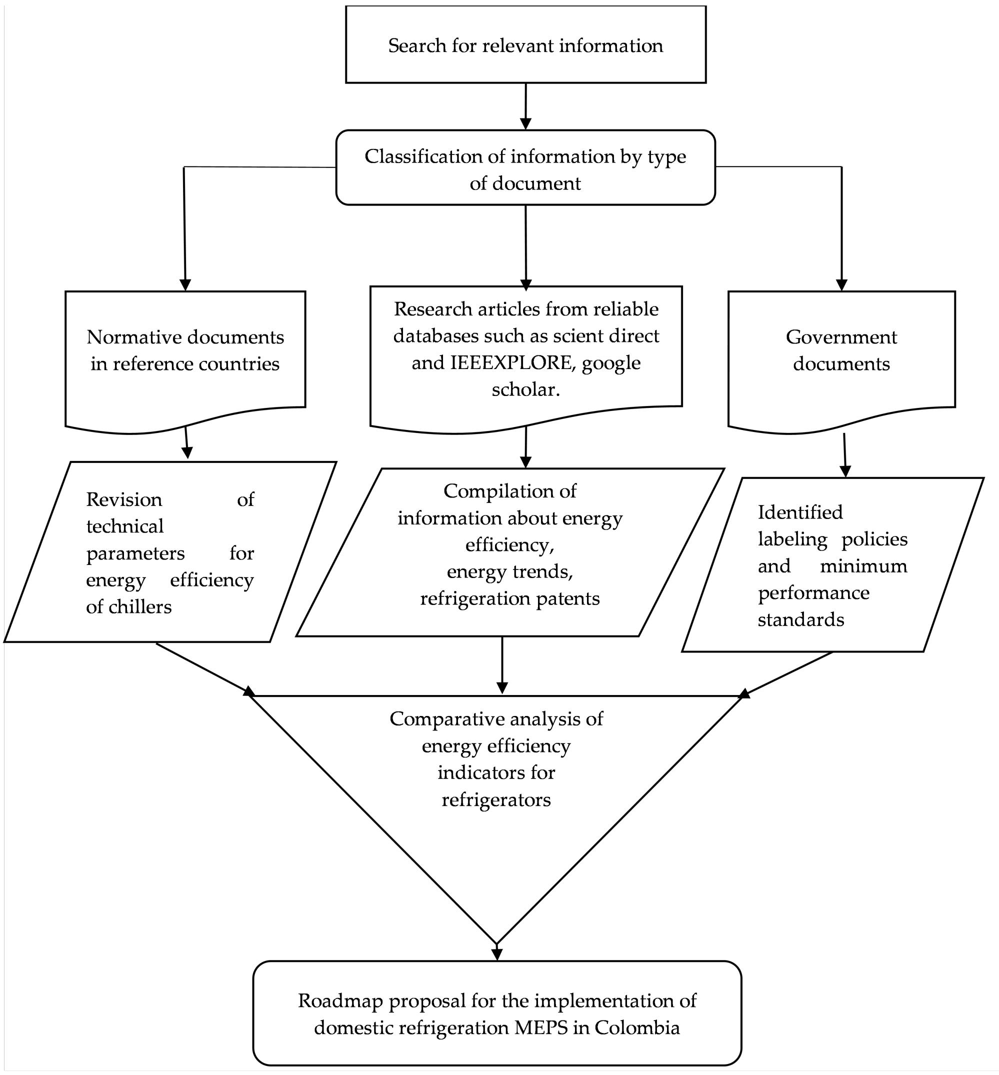


Figure 2. Methodology used.

Table 1. List of labeling regulations by country.

Country	Labeling Regulation or MEPS	Technical Rules
Colombia	RETIQ	NTC-IEC 62552
Brazil	RTAC 002813	IEC 62552
Chile	NCh 3000:2006	IEC 62552
Mexico	Mexican Official Standard Nom-015-Ener-2018	The same labeling regulation
European Union	Delegated Regulation (UE) 2016/2019 from the commission of march 2019	The same labeling regulation
USA	Part 305- Energy and Water Use Labeling for Consumer Products Under the Energy Policy and Conservation Act («Energy Labeling Rule»). Appendix A to Subpart B of Part 430	The same labeling regulation

3. MEPS & Labeling Policies

The MEPS have become a mandatory government document to evaluate the energy efficiency of different equipment and thus limit the minimum energy consumption in domestic, commercial, and industrial applications [20,34,35]. Figure 3 hows consumption by sector in Latin America and the Caribbean for the year 2020, in which the transport sector participates with 34.8% of the total, followed by the industrial sector (30.2%) and the residential sector (18.2%). In addition to other sectors such as commercial and services, agriculture and mining, construction and others, which together cover the remaining 16.8%.

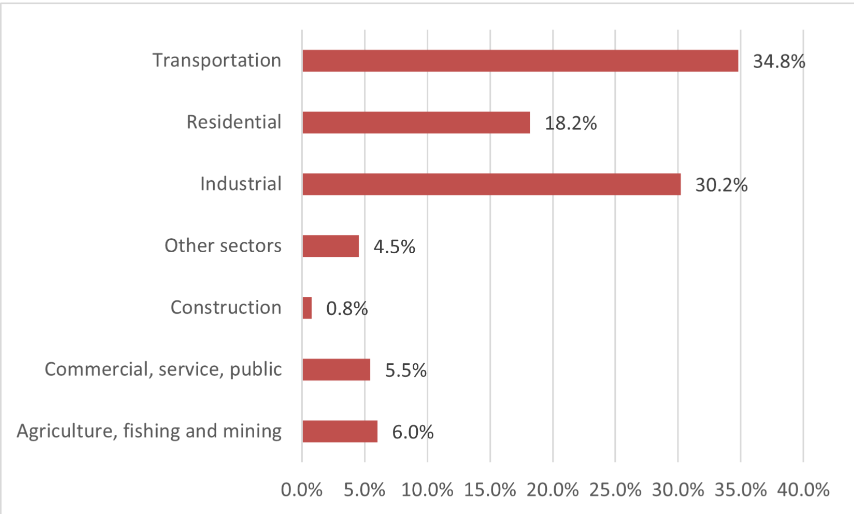
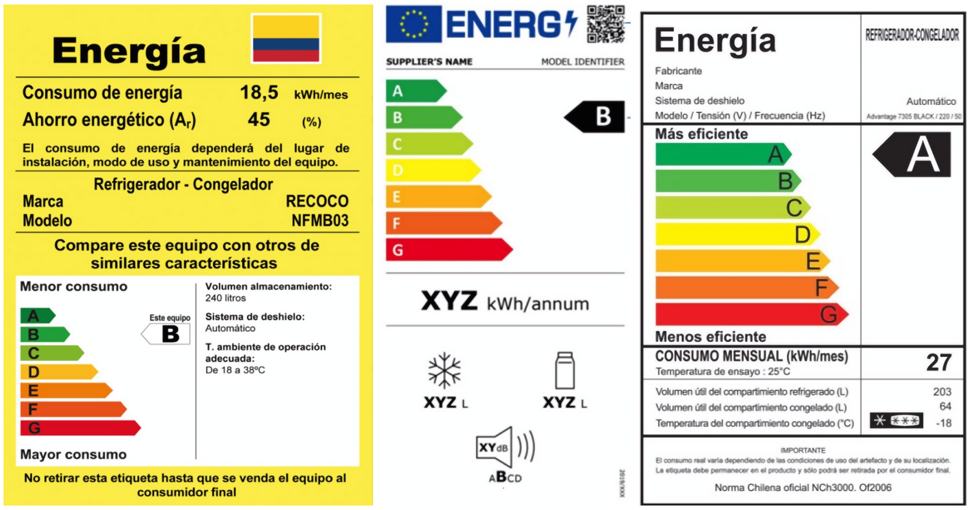


Figure 3. Share by sector of final energy consumption in Latin America and the Caribbean for the year 2020. Adapted from [36].

The refrigerator is one of the appliances with the greatest presence in homes and it is estimated that annually consumes 6% of the total energy in the world [37], hence the importance of MEPS implementation as a method of controlling energy consumption and expenditure that allows controlling the distribution of inefficient products in the market and thus encourage users to acquire equipment taking efficiency over cost as a decision criterion. The MEPS implements labeling as a mechanism to inform the user about the energy consumption and the efficiency index of the equipment they are purchasing. In this way, it is possible to make a general projection of the energy consumption of the equipment and how it will impact it economically. Similarly, the label commits the manufacturer to provide relevant technical information that allows evaluation of the energy efficiency of the equipment acquired under previously established technical regulations [38]. Figures 4 and 5 illustrate the energy labels used by Colombia and the reference countries, where some similarities can be observed, such as the label of the European Union and Chile, where it is observed that their categorization of energy efficiency is from A++ to G.

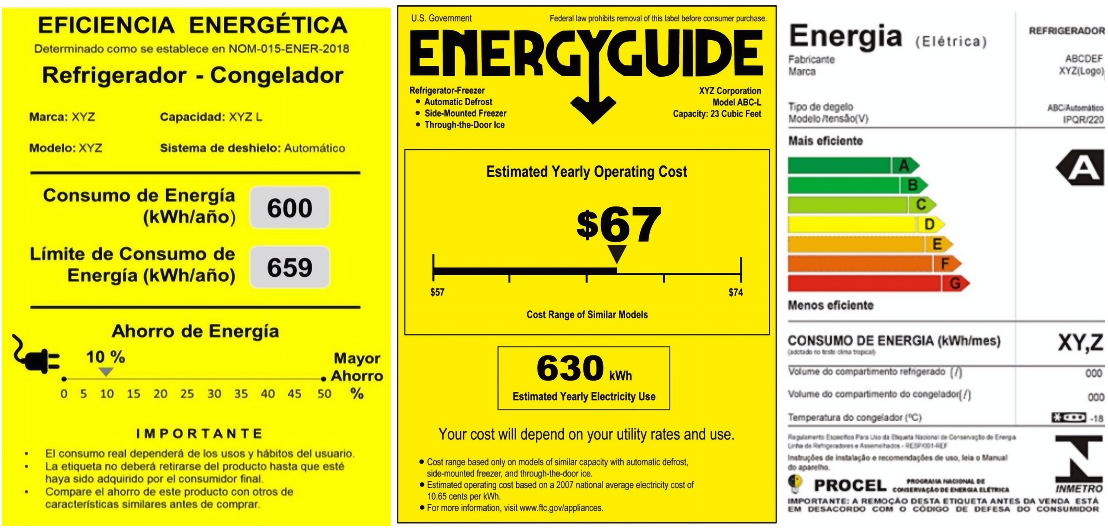
In the case of Mexico, the energy guide label of the United States is adopted, it can also be noted that the European Union label incorporates the refrigerator noise index.

A review of the labeling and MEPS policies in the following reference countries is presented below: European Union, Chile, United States, Brazil, Mexico and Colombia. In the review process, particular emphasis has been placed on historical milestones such as the promulgation of the first efficiency regulations, the different modifications in energy and regulatory policies, and the design of label structures.



(**a**) Colombian Label (**b**) European Label (**c**) Chilean Label

Figure 4. Energy Labels for Domestic Refrigeration in Colombia, EU and Chile.



(**a**) Mexican Label (**b**) US Label (**c**) Brazilian Label

Figure 5. Energy labels for domestic refrigeration in Mexico, US and Brazil.

3.1. European Union

In the European Union, the implementation of the appliance labeling program for the first time was in 1992 with the EU Directive 92/75/EC on the «Indication Through Labeling and Standard Information of the Consumption of Energy and Other Resources by the Appliances» [39] establishing an initial classification of categories from A to G, in which category A represents the most efficient equipment and G would be the least efficient category, It is noteworthy that the label does not provide the IEE given by the manufacturer, but rather the category where the IEE is found. Later the European Union would migrate to an update of its labeling policies by changing the categorization of the label categories [40]. In the year 2000, new, more efficient equipment emerged, for which the EU Delegated Regulation 1060/2010 was updated, incorporating categories A+, A++ and A+++ [41]. In 2016, this Delegated Regulation of 2010 is updated again, eliminating the categories from E to G and adding the noise level categorization on the label [42]. this update hardened the distribution of less efficient equipment in the European Union countries.

The preliminary review of the MEPS process in Europe shows that the implementation in the different EU countries is not the same, revealing marked differences due to the promotion that governments make about efficient equipment and the subsequent removal of equipment with higher consumption from the market. The reason for these differences is given, according to the criteria of some authors and the heterogeneity in the composition of the stocktaking of electrical appliances between countries that directly influence the effectiveness in the MEPS application and energy labels [10,43]. From 1 September 2021, categories A +, A++ and A+++ were included again, recategorizing [44], which generated confusion in the population. In addition to the MEPS and the labeling regulation, the EU adopted the Climate Change Plan determined by the European Directive 20/20/20 [45], the main objective of this Plan is to reduce GHG emissions by 20%, and improve the energy efficiency of buildings by 20% [46].

An important indicator on the implementation of MEPS in Europe is an improvement of around 27% in the efficiency of domestic refrigeration appliances, compared to prelabeling efficiency levels. According to EU reports, the average energy consumption of refrigerators fell from approximately 450 kWh/year in the period from 1990 to 1992 to an estimated 364 kWh/year immediately after MEPS was adopted [47].

Emissions derived from the use of electrical appliances represented 25% of total emissions in 2010, increasing equally to the emissions produced by the industrial sector [48]. The growing increase in the purchase of household appliances leads to the creation of new control policies that help mitigate the effects produced by the use of residential appliances, among which are domestic refrigerators [49], for example, the comparative label, which has a high impact on home appliance buyers and provides better decisions in the acquisition of new and more efficient products [50–52]. See Figure 4b, in which the current label is shown.

The review of energy efficiency policies and MEPS labeling shows a more comprehensive trend on the part of the EU when assessing the energy performance of the equipment, including regulations related to ecodesign, thus seeking to integrate environmental aspects in the design, production, distribution, use and final disposal of the product throughout its life cycle [53,54]. Among the novelties proposed in the energy label, there is a QR link that expands the information and provides more details about the product, such as its materials and manufacturing processes in general. Additionally, it has been proposed to include standards on repairability and availability of spare parts. Finally, it promotes the use of recycled materials in the manufacture of new models [55].

An additional element that stands out in the EU energy label is the inclusion of the noise parameter, which links to the application of compartment design strategies and the control of refrigerant fluids, thus achieving a reduction in noise emissions and an improvement in sound quality in non-Frost type refrigerators, which are the most commercialized [56,57].The noise regulation extends to other devices such as air conditioners and is undoubtedly an important criterion at the time of purchase, not only due to aspects of comfort during the operation of appliances but also due to the close correlation that exists between the decreased noise and energy efficiency [58,59].

3.2. United States

One of the main barriers to improving the energy efficiency of US household appliances for residential use is the high cost of acquiring new technologies by manufacturers to produce more efficient equipment. One of the strategies to address this barrier is by implementing incentives for both manufacturers and consumers, lowering the production cost and equipment acquisition [60]. Mechanisms such as electrical appliance labeling programs (MEPS) have influenced the purchase by users of more efficient refrigerators. Mechanisms such as electrical appliance labeling programs (MEPS) have influenced the purchase by users of more efficient refrigerators. Studies such as the one by Zainudina et al. show that there are close relationships between knowledge, attitude, social norms, and the energy efficiency label of users with the purchase intention [61].

In the United States, the first MEPS standards were applied in 1974 for refrigerators at the state level. However, until 1978 through the NECPA, it established the obligation of minimum standards at the national level. Between 1974 and 2004 there was a reduction in energy consumption of 74% associated with the implementation of measures such as MEPS [62]. This country implemented the EnergyStar seal in 1992 as a complementary measure to the MEPS, which represented the most significant government effort in the country, and which would represent a saving of 164 million dollars annually in electricity costs in homes, with a reduction in carbon emissions of approximately 1.1 million metric tons per year [63,64].

In the development of labeling programs comes the Energy Guide label (a comparison label), administered by the FTC. Later, in 2001, the DOE, together with the EPA, were in charge of exercising control over the EnergyStar label [65]. At the end of the same year, the NAEWG group was created, with the aim to improve the commercialization, development, and interconnections of North America [66]. The participating countries (Mexico, Canada and the United States), created this working group specifically to study and improve the policies, energy efficiency, renewable energy, clean energy and nuclear energy of these countries. For 2020, EnergyStar established updates in terms of trial and test methodologies [67], an example of US Energy Label is shown in Figure 5b.

3.3. Mexico

Over the last few years, energy consumption in the residential sector in Mexico has had a considerable increase. Studies reveal that the kitchen is the main factor in final energy use and that water heaters and other appliances are the ones that show the higher growth [68]. Strategies have been seeking to meet the demand of the different country regions through energy generation from renewable sources and developing new energy efficiency standards that can be applied in government policies to control energy use [69].

In 1992, the Mexican Energy Efficiency Standardization System began with the Federal Metrology and Standardization Law, coordinated by the National Consultative Committee for Official Mexican Energy Efficiency Standards (NOM-ENER), which are mandatory [20]. These standards establish the testing procedures, the MEPS, as well as the labeling requirements [34]. In 2002, the Nom-015-Ener-2002 standard was proposed, which establishes the parameters for evaluating the energy efficiency of refrigerators and freezers, the limits, test methods, and labeling [70]. The energy label used in Mexico, its testing procedures and MEPS are adapted from the United States energy guide model, including a continuous scale that indicates the relative savings of the product concerning the threshold defined by the standard [71].

In 2012, the CONUEE enacted the update of the NOM-ENER-2002, updating the maximum limits of energy consumption of refrigerators and freezers for domestic use, operated by a hermetic compressor motor, according to the type of refrigerator and its defrost system [72]. As of 2018, 29 standards are current, including specifications for refrigeration appliances, as well as standards that control CO_2 emissions and fuel efficiency of automobiles. In addition, the standards and mandatory labeling program of the CONUEE and the Fiduciary FIDE [73] offer manufacturers the possibility of acquiring a FIDE endorsement-seal label for equipment that exceeds the minimum level of energy efficiency defined by the NOM [74]. A Mexican energy label is presented in Figure 5a. In that same year, the Nom-015-Ener-2018 was published, and the program to replace old and inefficient refrigerators with modern and high-efficiency models was proposed.

In this way, Mexico would save 4.7 TWh/year [34,75,76], projecting a decrease in total residential electricity consumption of 9.9%, and the associated expense decreases by 11.3%. Additionally, the electricity subsidy decreases by 7500 million Mexican pesos per year (that is, 403 million dollars at the average exchange rate registered in 2017), and there is an annual decrease of 3.9 million tons of CO_2 equivalent emissions [77].

3.4. Chile

In early 2005, the Chilean government established the Energy Efficiency Standards and Labeling Program (PPEE), to be implemented in 2006. This was one of the most visible and comprehensive energy efficiency programs in the region. In 2007, the energy efficiency labeling came about and with it the first rational energy use program «Use Energy Well—Follow the Current», creating regional energy efficiency tables and diagnosing several productive sectors in the country [78]. In 2008, the implementation of energy labeling for refrigerators-freezers was carried out, according to efficiency standards ISO 15502 [79], IEC60335-2-24 [80], and according to the NCh3000 [81].

Subsequently, the Ministry of Energy received technical assistance from the Division of Environmental Energy Technologies of the LBNL and issued in 2012 the regulation that defines the criteria and procedures that will be applied to establish MEPS. The regulation requires, among other things, the preparation of a regulatory impact assessment, consultation procedures and coordination between government entities and the public [82]. In 2014, Decree No. 64 was established, which approves the regulations that establish the procedure for the elaboration of technical specifications for energy consumption labels and the necessary standards for their application [83].

In the 2016 follow-up report, the Chilean government reaffirms its commitment that 100% of commercialized appliances are energy-efficient equipment, as promoted in one of the goals for the year 2050 [84]. For 2018, the total consumption of refrigerants in the domestic refrigeration and air conditioning sector reached 70% of the substance benchmarking in Chile [83].

More recent studies show how the Chilean government has proposed campaigns to diagnose the current situation in the refrigeration sector, based on the quantification of equipment. Thus, in 2019 it was estimated that the installed fleet of refrigerators in Chile of around 6.8 million units as part of the Baseline Report for the project entitled «Accelerating the Transition to a Market of Efficient Refrigerators in Chile» which 43% belonged to energy efficiency category B or lower. The predominant EE categories in Chile are category A+ and category A with 28% and 25% participation, respectively. A Chilean domestic refrigerator energy label appears in Figure 4c.

Additionally, this report considers the refrigerants used in this equipment, which cause a high environmental impact, so they must be regulated by applying mitigation policies [85]. Currently, these standards are mandatory and introduced through protocols and resolutions issued by the Superintendence of Electricity and Fuels (SEC). This one is in charge of adapting to the test conditions related to the labeling apply to products such as motorized vehicles and boilers in the industrial mining sector, among others [86].

3.5. Brazil

As antecedents of energy expenditure produced in the residential sector, since 1980, the Brazilian government has worked on policies that reduce energy losses and on programs that encourage energy efficiency in end-use equipment [87]. In 1993, the National Energy Conservation Program (PROCEL) voluntarily introduces the labeling program, adopting a classification ranging from category A to E, with A being the most efficient category and E the least efficient [87]. A decade later, the PEB emerged, incorporating mandatory labels (please see Figure 5c), with as main objective of informing the consumer about specific characteristics of consumption, temperature, and additional information, such as: brand, model, defrost type, refrigerator size (usually in liters), freezer size and temperature, to end users. It is noteworthy that the form of the labels implemented in Brazil based on the US model, adapting the Energy Guide label [88].

Brazil is considered one of the pioneering countries in programs related to climate change, which acquired the commitment to reduce its carbon footprint between 36% and 39% by 2020. This carbon footprint receives a considerable contribution from part of the residential sector. In 2013, household energy consumption represented around 9% of total energy consumption in Brazil and accounted for about 994 PJ due to an increase in energy consumption in this sector since 2005 [89].

Due to the significant energy consumption by refrigerators for residential use in 2007 corresponding MEPS were established, taking as a starting point the «Energy Efficiency Law» enacted in 2001 [90]. This year they were achieved energy savings of approximately 1379 GWh and a reduction of 197 MW in Brazilian demand, as a result of efficiency labeling in refrigerators and freezers [91]. As a consequence of the labeling and MEPS policies introduced in Brazil in 2009, complementary policies to labeling emerge, such as the national refrigerator exchange program, which encourages the replacement of inefficient refrigerators [92]. The annual energy consumption of domestic refrigerators in 2010 was 182.8 GWh, and according to the projections made, the future impacts of the Energy Efficiency Law. It is estimated that the energy savings for the year 2030 would be close to 14,325 GWh, which represents 9% of the installed capacity for the electricity generation in 2010 [87]. According to the Energy Efficiency Indicators Management Committee (CGIEE), these standards must be undergoing a review process every two years, being updated for the last time in 2011 [93].

Since 2013, Brazil has had an electrical energy conservation program (PROCEL), distinguishing the most efficient products in the market, industry, buildings, government and public lighting. This seal was successfully applied to more than 36 appliances from more than 150 manufacturers [62]. Since the enactment of Law 13 280/2016, PROCEL has been able to count on energy providers to dedicate 20% of their resources to energy efficiency through the PROCEL resource application plan [94]. By 2018, 7.3% of final energy use was covered by mandatory energy efficiency policies [95]. With the implementation of PROCEL actions, it was possible to save a total of 23 TWh, which in Brazil's energy consumption was equivalent to 4.87% of consumption for 2018 [94].

3.6. Colombia

In Colombia, the residential sector represented 40% of electricity consumption in 2015, of this percentage refrigerators represent 43.25% [28,32]. In 2015, the RETIQ was launched, establishing the energy label (as is shown in Figure 4a) for household appliances for residential use and an information label for equipment for commercial use [29]. Seven energy efficiency categories are stipulated, from A to G, with A being the most efficient and G the least efficient. As of 1 September 2021, the last three categories will disappear and along with them, the domestic refrigerators thus categorized. In Table 2, you can see the ranges of energy efficiency and the relative savings levels with which household refrigeration equipment is categorized for the year 2021 and the perspective towards the year 2023, where category D is expected to be eliminated.

Historical references in Colombia show that there have been some programs that directly offer incentives to replace and dispose of old refrigerators, such as «Deliver it and Save», which encouraged the replacement of about one million refrigerators that were an average of 10 or more years of use. This initiative was enacted through Decree 2143 of 2017 [96], establishing, among other guidelines, a VAT of 5% to replace 19% for the purchase of efficient and environmentally friendly equipment [97]. This same year, the MME defined the strategic and sectoral actions to meet the goals established in terms of energy efficiency within the action framework of the PAI PROURE, in the period between the years 2017 to 2022, presenting the consumption characteristics of sectors such as: transportation, industrial, commercial, government, public services and residential [26].

Table 2. Energy efficiency ranges for domestic refrigeration equipment for Colombia from 2021 to 2023.

Energy Efficiency Range	Relative Saving A_r (%)	Relative Saving A_r (%)	Relative Saving A_r (%)
Validity	**Until 31 August 2021**	**From 1 September 2021**	**From 1 September 2023**
A	$A_r \geq 56$	$A_r \geq 67$	$A_r \geq 67$
B	$56 > A_r \geq 45$	$67 > A_r \geq 56$	$67 > A_r \geq 56$
C	$45 > A_r \geq 35$	$56 > A_r \geq 42$	$56 > A_r \geq 42$
D	$35 > A_r \geq 25$	$42 > A_r \geq 25$	REMOVED
E	$25 > A_r \geq 15$	REMOVED	REMOVED
F	$15 > A_r \geq 5$	REMOVED	REMOVED
G	$5 > A_r \geq -20$	REMOVED	REMOVED

Labeling for domestic refrigeration equipment, reference monthly consumption data in kWh/month, Relative Savings (Ar) in percentage, storage volume in liters, defrost system (manual, semi-automatic or automatic), ambient temperature and the minimum operating temperature in °C is shown in Figure 4. Within the framework of international agreements such as the 2030 Agenda and the SDG, it establishes as one of the priorities the promotion of use of efficient appliances and lighting, in addition to affordable and nonpolluting energy, as formulated in goal seven of the SDGs [13]. To be in accordance with these international initiatives, RETIQ is in the process of being updated in accordance with technical regulations, such as IEC 62552, with the aim of improving energy consumption [98–100]. The IEC 62552 standard deals with about 11 types of tests and trials, among which there are some such as tightness of doors and drawer seals, storage temperatures (according to the climatic class to which they correspond), in addition, to tests of water vapor condensation and evaluation of energy consumption by a loading plan in the freezer and food compartments with test packs of different weights and alternation in freezing and recovery times.

4. State of the Art of Residential Refrigeration Efficiency

Regarding technological trends present in refrigerators, the industry has sought to improve efficiency, thus obtaining lower energy consumption. When developing a new refrigerator or proposing a more efficient model, it is sought that the device cools more quickly and with less energy consumption, in a quieter way, with the ability to maintain the temperature of the product more stable, which has been manufactured with recyclable materials or materials with low environmental impact, that have an accessible cost [57,101].

The main refrigerator's role is to keep food fresh, that depends on factors such as the ambient temperature, the insulation capacity and the thermal load of the food. The food compartments must maintain an average temperature of 4 °C, and the freezer compartments a temperature of between −6 to −24 °C [102]. However, maintaining these temperature ranges depends a lot on the behavior of the users. This is how the habits related to the frequency of opening the doors of the refrigerator compartments directly influence its energy efficiency. With respect to this factor linked to the frequency of opening and closing the doors, there are investigations that studied the habits of use of refrigerators by users and conclude that, thanks to the implementation of automatic learning controllers, according to the user habits, regulate compartment temperatures, generating a 3% reduction in energy consumption depending on the frequency of door opening [103].

On the other hand, manufacturers seek to provide consumers with the reliability of acquiring efficient refrigeration devices, innovating in their manufacturing processes and resource optimization, with which they have managed to improve the refrigeration circuit, its components, materials, manufacturing processes, etc. These innovations allow refrigerators to be available that consume up to 60% compared to standard consumption refrigerators [51,104]. Recent research in domestic refrigeration has focused on several factors, such as: thermal insulation, the efficiency of the refrigeration cycle depending on its refrigerant, and equipment control systems. Some of these are detailed in the following subsections.

4.1. Thermal Insulation Efficiency

In terms of thermal insulation, it is evident that inefficient refrigerators use polyurethane resin (PU) as thermal insulation that over time lose their capacity as an insulator in addition to the great environmental impact that is generated, therefore the proper selection of the insulator of the refrigerator implies a better thermal efficiency and a significant contribution in the reduction of environmental pollution and its impact on the environment [105]. In experimental works such as Kurma et al., the use of an alternative insulating material such as nitrile rubber is proposed, obtaining results that show that the cooling effect of the system increases with nitrile rubber (190 kJ/kg) as insulating material compared to PU (177 kJ/kg) and glass wool (175 kJ/kg) [106]. Additionally, the work of the compressor is reduced when using nitrile rubber due to its high insulating capacity compared to PU and glass wool [106].

4.2. Refrigerant Efficiency

Technological advances in refrigerants have sought to replace elements that deplete the ozone layer and increase GHGs. Examples of domestic refrigerator refrigerants include CFCs, HCFCs, and HFCs. Among R134a and R600 are the most commonly used in domestic refrigerators [107], while R22 and R12 are subject to phase-out under the Montreal Protocol [1].

Linked to this substitution process, the implementation of hydrocarbon-based refrigerants (HC) is observed, such the case of the work of Isaza and Jara in 2015 [108], which proposes changing the HFC-type R134a refrigerant for the R600a refrigerant, which is hydrocarbon-type isobutane. In this investigation, both refrigerants were subjected to similar operating characteristics, and the performance coefficients for each type of refrigerant were calculated. As a result, it was obtained that HC refrigerants are the best option to replace HFC-type refrigerants, due to their short time in the atmosphere (<12 months) and their low global warming potential (<8 months). In this sense, research shows that the application of HC R600a and HC R290 refrigerants are seen as the best alternative concerning to the operation and performance of R134a refrigerant [109], based on the fact that the use of these types of refrigerants represents a savings of 20% of electrical consumption compared to R134a [110]. In the work of Sánchez et al., six low-GWP alternatives of R134a were experimentally analyzed and compared, demonstrating that fluid R290 reduces the energy of the R134a in 27.5% [111].

4.3. Compressor's Efficiency

Considering that the world trend is the efficient use of electrical energy used for refrigeration, studies such as that of Corte et al. [112] presented the main advances in energy efficiency achieved in domestic refrigeration that have been developed between the years 2006 to 2011, focused on four important factors: environmental impacts, costs, performance and reliability. From the point of view of the performance of the compressor, it was found that its performance can be improved with the use of linear compressors that allow the speed of the compressor to vary depending on the refrigeration demand either with use of electronic controllers or by means of piston displacement control (dead volume) analyzing the possibility of recovering energy in the gas re-expansion process with this, significant energy savings can be achieved and could reduce environmental pollution.

Through the use of electronically controlled compressors that include VFD type devices, the energy and exergetic performance in refrigerators increases ostensibly. Binneberg et al. [113] studied the form of control through numerical simulation and found that this This type of operation can generate energy savings of up to 30% due to factors such as lower friction losses in the compressor, higher evaporation temperature, lower condensation temperature and reduction of losses associated with pressure equalization at compressor stops.

Compressor's Noise Level

Based on the fact that the area of a home has now been considerably reduced, the installation of refrigerators in places such as the living room it is a relatively common thing now; therefore, measuring the noise generated by a refrigeration system (specifically the compressor and the engine) is something that some manufacturers have begun to consider to improve performance and reduce the noise level generated by the movement of components such as the shaft, piston, rotor, suction and discharge valves to of maintaining comfortable conditions at home [114].

The research conducted by Cingiz et al. [115] indicates that the source of noise in refrigerators is generally from the operation of the compressor and the flow of the refrigerant in the pipes. Park et al. [116] identified that one of the causes of the noise generated in the compressor is due to the structural vibration of the discharge cover attached to the linear compressor in the mechanical compartment to mitigate this problem, they proposed the design of a dynamic absorber, which will be combined with the discharge cover, reducing the noise level from 2.5 to 1.7 dB.

Han et al. [117] studied the noise from the refrigerant at the evaporator inlet and capillary tube outlet and found that due to the transition from expansion to evaporation, bubble formation and interaction caused some degree of flow-induced noise. Therefore, novel studies regarding the noise mitigation of refrigerators produced by compressors are vitally important in reducing energy consumption and increasing energy efficiency [118].

These investigations have been directed, sometimes, to comply with laws and regulations, in others, to meet the needs of large specifiers and, in still others, at the request of end users. Research relates the noise produced by the components of the compressors as factors that affect its energy efficiency because the noise disturbances of energy losses [16].

4.4. SPV Refrigerators Efficiency

As a consequence of the health emergency presented throughout the world, technological progress in refrigeration is a significant factor to be considered in preserving process cold chains for vaccines against Covid-19. There are regions that are not connected to an electrical network, creating the need to look for alternative energy sources for these refrigerators in the most remote regions [119]. Refrigeration systems have the opportunity to be powered by green technologies such as solar energy, which is used in absorption refrigeration systems or vapor compression refrigeration systems [120].

The adaptation of household appliances that use alternating current (AC) and are powered through the interconnection system to a direct current (DC) microgrid, it was studied by Sabry et al. [121], finding that recent advances in home appliances are moving toward DC compatibility as home appliances include electronics in their power stage to drive and control their components. Therefore, all the appliances can work with a DC power supply with a suitable voltage level also conclude that the efficiency of recent appliances available with DC is higher than the old AC equivalents. For products such as refrigerators, efficiency improvements can be around 20–30%.

Rajkumar and Rathinam proposed the use of photovoltaic energy as a power source and in this way guarantee that populations that do not have access to the interconnected energy system can use household appliances such as refrigerators called SPV-powered offline refrigerators [122]. The production of energy by solar panels and the implementation of this form of energy in refrigerators influence the behavior in such a way that the current of the system would cease to be alternating current AC and would become direct current DC, guaranteeing the operation of the refrigeration systems of regions outside the interconnection network [123,124]. According to the authors Su et al. [125], they indicate that the use of photovoltaic energy applied directly to the compressor increases the average efficiency of photovoltaic use increases by 45.69%, and the cooling capacity of the variable speed mode increases by 32.76% thus, that by using the radiation intensity increases, the refrigeration capacity increases significantly. However, the study carried out by Modi et al. [126] related to the performance of a domestic refrigerator operated by solar photovoltaic energy indicates that the system can only be economically viable in terms of costs if an initial investment or a reduction in component costs, mainly the SPV panels and the battery bank.

4.5. New Patents on Refrigeration Efficiency Outlook

Regarding the manufacture of new products based on technological developments, the LATIPAT database was explored, which allows the search for technical information in Latin America and Spain. A search focused on domestic refrigerators was carried out, for this, the investigation was limited to records of international IPC patent classification and cooperative classification of CPC patents of F25D11/02 that corresponds to the family F25D 11/00 Autonomous mobile devices associated with refrigeration machinery, for example, domestic refrigerators with compartments at different temperatures [40].

As a result, 346 patents registered under these codes were identified. Subsequently, the search was limited to records from the last 20 years, this means that from 2001 to 2021, finding a total of 209 patents. In Figure 6, 2005 and 2017 were the years with the most patents granted a total of 20 and 21 patents, respectively [127]. In contrast, 2020 was the year with the lowest number of patents granted, 3 in total (excluding the current year).

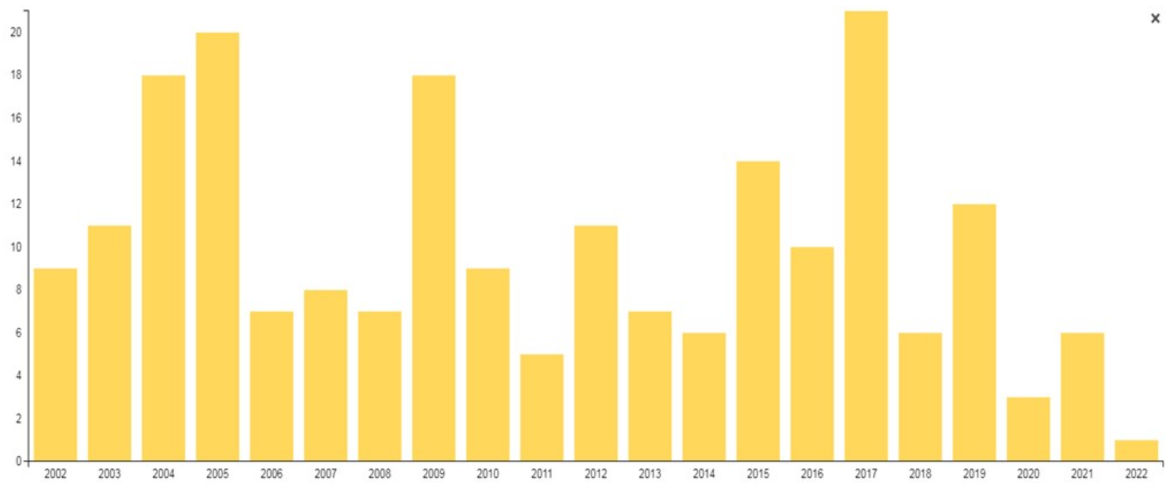


Figure 6. Number of patents between 2002 and 2022 registered with IPC and/or CPC F25D11/02 numbers [33].

Regarding the companies that were granted patents, the following appear in the first five places: Whirlpool CO with 50 patents; BSH Bosch Siemens Hausgeraete with 37; LG Electronics Inc. with 16; BSH Electrical Appliances Spain 7 patents and Multibras Electrical Appliances S.A with six patents. Finally, the countries where the headquarters of these companies are located concentrate 80% of the patents, being led by the United States with 33.49% (70); Germany with 20.57% (43); Brazil with 8.61% (18); Spain with 8.13%; Italy with 4.3%; Mexico and Argentina with 1.91% (4) and Colombia with 0.95% (2).

It is important to note that domestic refrigerator manufacturers, with a presence in Colombia, are between the leading companies in patents, from which it is inferred that they are working on improving the equipment and that this may affect the next 15 years in the Colombian market, possessing refrigerators with better designs and technology that can impact its energy performance and therefore its Relative Savings Index. In the development of phase 4, activities have been carried out focused on comparative analyzes between the different methodologies for calculating energy efficiency, as well as the definitions of categories associated with efficiency indicators. Section 5 below illustrates the methodologies for calculating energy consumption, equivalent volume, efficiency index and comparison of energy efficiency categories.

5. Methodologies for the Estimation of Energy Efficiency in Residential Refrigeration

Based on the control that countries exercise over energy consumption, regulations were identified that establish a methodology to evaluate the energy consumption of refrigerators for household use that each country has. The reference parameters consulted in the different methodologies evaluate parameters such as energy consumption, the equivalent volume, the energy efficiency index and their respective categorization both for Colombia, as well as the referents. For the Chilean case, the current technical regulations are not publicly accessible and free; therefore, in this section the calculation expressions are not related, but the ranges established for the different refrigerators categories are.

5.1. Energy Consumption Calculation

Next, a review of the different formulations that exist in the regulations of the reference countries for the calculation of energy consumption is carried out.

5.1.1. Energy Consumption Calculation in Colombia

In Colombia, energy consumption is taken according to the RETIQ, emphasizing the results obtained in a 24-h test period under controlled conditions under the IEC 62552 standard. Equation (1) shows the calculation method for power consumption:

$$AC = 30 * \frac{day}{month} * E_{comp}. \tag{1}$$

where:

AC: Annual energy consumption of the device, determined as Energy Consumption (E_{comp}) in accordance to numeral 9.1.3 of the RETIQ [29].

E_{comp}: Energy consumption test result for 24 h (kWh/day).

5.1.2. Energy Consumption Calculation in European Union

In the EU, the energy consumption is based on the annual energy consumption takes into account several factors, such as the energy consumed by the antifreeze resistances and load factors, among others. Equation (2) shows how the annual energy consumption for domestic refrigerators is calculated:

$$AE = 365 * \frac{E_{daily}}{L} + E_{aux.} \tag{2}$$

where:

L, Thermal load factor of the foods used in the test. E_{daily}, daily estimated energy in kWh/24 h.

E_{aux}, the energy used by an anticondensation heater controlled by the environment (kWh/year).

5.1.3. Energy Consumption Calculation in Brasil

In Brazil, energy consumption is defined as the declared monthly energy consumption, Equation (3) shows how to calculate this consumption:

$$CE_M = CE_D * \frac{30}{1000}. \tag{3}$$

The CE_D is the energy consumption in Wh per 24 h, based on the ambient temperature determined at 32 °C.

5.1.4. Energy Consumption Calculation in the United States

Regarding energy consumption, the regulations of the United States make a difference depending on the type of refrigerator, which presents several alternatives for calculating energy consumption, the refrigerator types equipment are:

- Refrigerators.
- Refrigerators-Freezers.
- Miscellaneous refrigeration products.

Refrigerators and refrigerator-freezers can be classified according to their defrost mechanism: manual, semiautomatic or automatic. Additionally, in the case of refrigerator-freezers, it is specified concerning the location of the freezer: top and side. In accordance with the above, Table 3 shows ways to calculate the monthly energy consumption for residential refrigerators depending on their defrosting type.

Table 3. Formulation of energy consumption by type of refrigerator in the USA.

Refrigerator Type	Energy Consumption Calculation	Definitions
Equipment with manual and automatic defrosting	$ET = \frac{EP*1440*K}{T}$	ET test cycle energy expended in kilowatt-hours per day. EP energy expended in kilowatt-hours during the test period. T duration of the trial period in minutes. 1440 conversion factor to adjust to a 24-h period in minutes per day. K dimensionless correction factor of 1.0 for chillers and chiller-freezers; and 0.55 for chillers and combined refrigeration products for chillers to adjust for average household use.
Equipment with automatic long time defrosting	$ET = \left(1440 * K * \frac{EP_1}{T_1}\right) + \left(EP_2 - (EP_1 * \frac{T_2}{T_1})\right) * K * \frac{12}{CT}$	EP_1 energy expended in kilowatt-hours during the first part of the test. EP_2 energy expended in kilowatt-hours during the second part of the test. T_1 and T_2 time in minutes of the first and second test parts respectively CT defrost timer run time or compressor run time between defrosts in hours required to cycle the compressor through a complete cycle, rounded to the nearest tenth of an hour. 12 factor to adjust for 50% compressor running time in hours per day.
Equipment with variable defrost control	$ET = \left(1440 * K * \frac{EP_1}{T_1}\right) + \left(EP_2 - (EP_1 * \frac{T_2}{T_1})\right) * K * \frac{12}{CT}$ $CT = \frac{CT^L * CT^M}{F*(CT^M - CT^L) + CT^L}$	CT^L shortest compressor run time between defrost used in the variable defrost control algorithm (greater than or equal to 6 but less than or equal to 12 h). CT^M maximum compressor run time between defrosts in hours rounded to the nearest tenth of an hour (greater than CT^L but not more than 96 h. F ratio of energy consumption per day in excess of the least amount of energy and the maximum difference in energy consumption per day y is equal to 0.20. For the variable defrost models with no values for CT^L and CT^M in the algorithm, the default values of 6 and 96, respectively, will be used.

5.1.5. Energy Consumption Calculation in Mexico

The Mexican Standard NOM-015-ENER-2018 [75] establishes that the yearly maximum energy consumption (E_{max}) in kWh/year and classifies it according to the type of refrigerator as shown in Table 4. Equation (4) shows this relationship:

$$E_{max} = \alpha * VA + \beta. \quad (4)$$

where: E_{max} is the maximum energy consumption by year, α and β correlation coefficients dependent on the type of cooler and VA (also in Table 4) is the adjusted volume of all of the refrigerator compartments.

Table 4. Energy Consumption Estimation for Different Refrigeration Devices in Mexico, adapted from [72].

Mexico	
Maximum Energy Consumption for Household Refrigerators, Refrigerator-Freezers and Freezers	
Description of the Device	**Maximum Energy Consumption per Year (Emax)**
1. Refrigerator-freezers and refrigerators refrigerators other than refrigerators appliances with manual defrost only	$0.282 * VA + 224.0$
1A. Only refrigerators with manual defrost.	$0.240 * VA + 193.6$
2. Refrigerator-freezer with partially automatic defrost.	$0.282 * VA + 225.0$
3. Refrigerator-freezer with automatic defrost, with top-mounted freezer, without automatic icemaker.	$0.285 * VA + 233.7$
3-BI. Built-in refrigerator-freezer with automatic defrost, with top-mounted freezer without automatic icemaker.	$0.323 * VA + 317.7$
3I. Refrigerator-freezer with automatic defrost, with top-mounted freezer with automatic ice maker without ice inlet through outside door.	$0.285 * VA + 317.7$
3I-BI. Built-in refrigerator-freezer, with automatic defrost with top-mounted freezer with automatic icemaker without outside door ice delivery.	$0.323 * VA + 248.9$

Finally, Table 5 summarizes all the calculation formulas and highlights their differences and similarities.

Table 5. Formulation for calculating energy consumption Colombia and reference countries.

Colombia	$AC = 30\left[\frac{day}{month}\right] * E_{Comp}$	AC Annual energy consumption of the device, determined as E_{Comp} is the Energy Consumption in a test period of 24 h * 365 days
European Union	$AE = 365 * \frac{E_{daily}}{L} + E_{aux}$	AE is the annual energy consumption given in kWh/year. L Heat load factor of the food used in the test E_{daily} Daily energy in kWh/ 24 h E_{aux} Energy used by an environmentally controlled anti-condensation heater (kWh/year)
United States	$ET = \frac{EP*K*1440}{T}$ $ET = (1440 * K * \frac{EP_1}{T_1}) + (EP_2(EP_1 * \frac{T_2}{T_1})) * K * \frac{12}{CT}$	ET test cycle energy expended in kilowatt-hours per day. EP energy expended in kilowatt-hours during the test period. T test period duration in minutes1440 conversion factor to adjust to a 24-h period in minutes per day. K dimensionless correction factor of 1.0 for chillers and chiller-freezers; and 0.55 for chillers and refrigeration products combined for chillers to adjust for average household usage
Brazil	$CE_M = CE_D * \frac{30}{1000}$	CE_M declared monthly energy consumption CE_D is the energy consumption in Wh per 24 h, based on the ambient temperature determined at 32°C.
Mexico	$E_{max} = \alpha * VA + \beta$	E_{max} Maximum power consumption VA adjusted volume α and β correlation coefficients dependent on the type of cooler

A differentiating factor in the calculation of energy consumption handled by the European regulations includes the L factor, corresponding to the thermal load of the food used during the test and reflects the climatic diversity of the seasons, in addition to the L factor, the European regulations have taking into account the energy used by the anti-defrost resistance, a factor that is not taken into account in any of the reference countries. Another notorious fact is that in the formulation of energy consumption for Mexico, the adjusted volume is included, a factor that is not taken into account in any of the formulations. The US formulation includes a dimensionless factor depending on the type of refrigerator that is also not included in the formulations of the reference countries.

5.2. Equivalent Volume Calculation

The Equivalent Volume (V_{eq}), or the Adjusted Volume (AV), for most countries refers to the space occupied by the different compartments of the refrigerator.

5.2.1. Equivalent Volume Estimation in Colombia

The criteria considered in the RETIQ [29] for the calculation of the equivalent volume are illustrated in Equation (5):

$$V_{eq} = \left[\sum_{c=1}^{c=n} V_{cn} * \frac{T_{amb} - T_c}{T_{amb} - 5} * FF_C \right] * CC * BI. \tag{5}$$

where:

n is the total number of the refrigerator's compartments.
V_{cn} is the useful volume of the compartment or compartments, in liters.
T_c is the nominal compartment temperature in °C. FF_C, CC and BI are correction factors.

5.2.2. Equivalent Volume Estimation in the European Union

The energy consumption is expressed in terms of the Adjusted Volume (AV) where Equation (6) is the sum of all compartments:

$$AV = \sum V_c * W_c * F_c. \tag{6}$$

where: V_c is the net volume of a given type of compartment in the apparatus. W_c is the weighting coefficient for different types of compartments (equal to 1 for the fresh food compartment (at 5 °C) and equal to 2 for the non-fresh food compartment). F_c is a factor equal to 1.2 for the frost-free compartments and 1 for the other compartments.

5.2.3. Equivalent Volume Estimation in Brazil

The AV in Brazil is defined as the internal volume of the product in relation to the nominal classification temperatures of each compartment and section as shown in the Table 6. This is calculated using (7):

$$VA = V_r + \sum f * V_c. \tag{7}$$

where: V_r, volume of the refrigerator compartment (liters). V_c, volume of the freezer compartment (litres) and f is an equivalent value of the classification of each compartment.

Table 6. Nominal rated temperature for Brazilian Refrigerators.

Maximum Temperature Obtained in the Freezer Compartment or in Its Section (T_C)	Nominal Temperature Rating (°C)	Number of Stars
$T_C > -6°$	0	0
$-12° < T_C < -6°$	−6	1 (*)
$-18° < T_C < -12°$	−12	2 (**)
$T_C \leq -18°$	−18	3 (***)

(*), (**) and (***) are the maximum temperatures obtained in the Freezer Compartment.

5.2.4. Equivalent Volume Estimation in United States

The United States defines the adjusted volume in cubic feet and is defined by Equation (8):

$$VA = (VF * CRF) + VFF + VC \tag{8}$$

where: VF, is the refrigerator's compartment volume (in liters). VFF, is the fresh food compartment volume (in liters). VC is the freezer's compartment volume (in liters) and CR y CRF are adjust factors.

5.2.5. Equivalent Volume Estimation in Mexico

Mexico, by adopting the United States regulations, calculates its adjusted volume in the same way. Equation (8) could be also used.

As shown in Table 7 the f factor used in the Brazilian formulation for the equivalent volume calculation can be similar to the factor Fc used in the European formulation, which depends on the type of refrigerator compartment. Concerning compartment volumes, the US regulations use the VF and VFF factors similar to the Vc and Vr coefficients of the Brazilian and Mexican standards.

Table 7. Calculation of Adjusted Volume in Colombia, EU, US, Brazil and Mexico.

Colombia	$V_{eq} = [\sum_{c=1}^{c=n} V_{cn} * \frac{T_{amb}-T_c}{T_{amb}-5} * FF_c] * CC * BI$	n is the total number of compartments of the equipment. V_{cn} is the useful volume of the compartment(s), in liters. T_c is the nominal compartment temperature in °C. FF_c, CC and BI are correction factors
European Union	$AV = \sum V_c * W_c * F_c$	V_c is the net volume of a given type of compartment in the apparatus. W_c is the weighting coefficient for different compartment types (equal to 1 for the fresh food compartment (5 °C) and equal to 2. for the nonfresh food compartment. F_c is a factor equal to 1.2 for frost-free compartments and 1 for other compartments.
United States	$VA = (VF * CRF) + VFF + VC$	VF freezer compartment volume in liters. VFF volume of the fresh food compartment in liters VC cooler compartment volume in liters. CRF adjustment factor
Brazil	$VA = V_r + \sum f * V_c$	V_r Refrigerator compartment volume (liters). V_c Freezer compartment volume (liters). f Equivalent value of the classification of each compartment.
Mexico	$VA = (VF * CRF) + VFF + VC$ $VA = (VF * CR) + VFF + VC$	VF freezer compartment volume in liters. VFF volume of the fresh food compartment in liters VC cooler compartment volume in liters. CR and CRF adjustment factor

5.3. Efficiency Energy Index Calculation

The energy efficiency index is an indicator pointing the level of energy consumption of a device, for its performance. In other words, this indicator tells us how many resources will be necessary to generate a specific amount of energy. The different methods used by the countries considered in this review to calculate the energy efficiency index are shown below.

5.3.1. Efficiency Energy Index Calculation in Colombia

Colombia uses the concept of relative saving Ar to classify how efficient a refrigerator is. Equation (9) illustrates how to calculate relative savings:

$$Ar = \frac{SC_\alpha - AC}{SC_\alpha}. \tag{9}$$

AC in Equation (1) is the annual energy consumption of the appliance and is denoted as the energy consumption in a 24-h test period, multiplied by 365 days, by RETIQ numeral

9.1.3, and SC_α is the reference normalized annual energy consumption, which must be determined according to the RETIQ numeral 9.1.2.2 [29].

5.3.2. Efficiency Energy Index Calculation in the European Union

For its part, the European Union defines the Energy Efficiency Index (IEE) to categorize the energy performance of refrigerators. Equation (10) shows how IEE is calculated:

$$IEE = \frac{AE}{SAE}. \tag{10}$$

where AE is the Yearly Energy Consumption in kWh/year and SAE is the Normalized Energy Consumption.

5.3.3. Efficiency Energy Index Calculation in Brasil

Brazil does not define categories but a maximum energy consumption index in percentage with which it categorizes the energy performance of refrigerators in its national market. Equation (11) shows how this index is calculated.

$$I_e = \frac{CE_M}{CP}. \tag{11}$$

where C_p is the standard consumption, defined as the energy consumption equivalent to the adjusted volume, and CE_M is the declared monthly energy consumption.

5.3.4. Efficiency Energy Index Calculation in the United States

The United States does not establish the emission of an energy label, but the EnergyStar Program Requirements Product Specification for Residential Refrigerators and Freezers is accepted, where the Maximum Annual Energy Consumption requirement is calculated in (12):

$$AEC_{Max} = AEC_{Base} + \sum_{i=1}^{n} AEC_{ADD_i}. \tag{12}$$

where, AEC_{Base} is associated to the base energy consumption and classifies this consumption depending on the type of refrigerator as shown in Table 8, and according to the general formulation presented in (13):

$$E_{Max} = \alpha * VA + \beta. \tag{13}$$

where, AV is the Adjust Volume and α and β are correlation coefficients dependent on the type of refrigerator.

Table 8. Energy consumption in the United States by type of refrigerator, adapted from [128].

USA		
Product Class	**Annual Energy Consumption Base Allowance, AECBASE (kWh/year)**	**% Less Energy Than Measured Energy Use**
Full-Size Refrigerators and Refrigerator-Freezers		
1. Refrigerator-freezers and refrigerators other than all refrigerators with manual defrost.	$7.19 * AV + 225.0$	10%
1A. All Refrigerators refrigerators with manual defrost	$6.11 * AV + 174.2$	10%
2. Refrigerator-freezers partial automatic defrosts.	$7.19 * AV + 202.5$	10%
3. Refrigerator-freezers automatic defrost with top-mounted freezer without an automatic icemaker	$7.26 * AV + 210.3$	10%
3-BI. Built-in refrigerator-freezer automatic defrost with top mounted freezer without an automatic icemaker.	$8.24 * AV + 238.4$	10%
3I. Refrigerator-freezers-autmatic defrost with top mounted freeser with an automatic icemaker without through-the-door ice service	$7.26 * AV + 294.3$	10%

5.3.5. Efficiency Energy Index Calculation in Mexico

Mexico adopts the same methodology for calculating the maximum consumption of the United States. Equation (14) illustrates how to calculate this consumption:

$$E_{Max} = a * VA + b. \quad (14)$$

where a and b are factors that depending of the appliance description, and VA is the Adjust Volume in liters.

Colombia is the only country that uses the concept of relative savings to define the efficiency of refrigerators, EU uses the concept of the energy efficiency index, Brazil uses the indicator of maximum energy consumption and the USA, like Mexico, uses the maximum consumption to define the efficiency indicator in this equipment. It is also observed that there is a conceptual equivalence between the terms AE of the Colombian regulation [29], with AEC of the US standard [128] and CE_M of the Brazilian regulation [91] which are defined as energy consumption in a given period.

US and Mexican regulations define energy consumption through mathematical formulations corresponding to linear regressions. In the case of the Mexican formulation, given by Equation (14), the adjusted volume is taken as the basis and the correlation factors α and β are included, which according to the NOM-015-ENER-2018 standard take values according to 18 types of different refrigerators including their type, their defrost system and their total adjusted volume [75].

5.4. Efficiency Energy Categories Comparison

Each reference country uses its own categories to indicate how efficient are the refrigerators that are marketed. It is evident as a common factor the categories adoption that go from A to G in descending order of efficiency, as shown in Table 9. The ranges differ depending on the efficiency parameter used. Therefore, it is not possible to establish a face-to-face comparison of the efficiency of the same refrigerator model in light of current regulations in these countries.

Table 9. Energy efficiency ranges for domestic refrigerators in Colombia, EU, Chile and Brazil.

Energy Efficiency Range	Colombia			EU	Chile	Brazil	
	Relative Saving A_r (%)	Relative Saving A_r (%)	Relative Saving A_r (%)	Energy Efficiency Index IEE	Energy Efficiency Index Refrigerator IEE	Maximun Efficiency Rates (% in relation to Cp) (Valid until 29 June 2022	
Validity	**Until 31 August 2021**	**From 1 September 2021**	**From 1 September 2023**			**Refrigerator Freezer (RC)**	**Refrigerator-Freezer Frost-Free (RC FF)**
$A++$	–	–	–	–	$IEE < 30$	–	–
$A+$	–	–	–	–	$30 < IEE < 42$	–	–
A	$A_r \geq 56$	$A_r \geq 67$	$A_r \geq 67$	$IEE \leq 41$	$42 < IEE < 55$	85.50%	84.60%
B	$56 > A_r \geq 45$	$67 > A_r \geq 56$	$67 > A_r \geq 56$	$41 < IEE \leq 51$	$55 < IEE < 75$	93.10%	92.10%
C	$45 > A_r \geq 35$	$56 > A_r \geq 42$	$56 > A_r \geq 42$	$51 < IEE \leq 64$	$75 < IEE < 90$	97.20%	97.20%
D	$35 > A_r \geq 25$	$42 > A_r \geq 25$	REMOVED	$64 < IEE \leq 80$	$90 < IEE < 100$	–	–
E	$25 > A_r \geq 15$	REMOVED	REMOVED	$80 < IEE \leq 100$	$100 < IEE < 110$	–	–
F	$15 > A_r \geq 5$	REMOVED	REMOVED	$100 < IEE \leq 125$	$110 < IEE < 125$	–	–
G	$5 > A_r \geq -20$	REMOVED	REMOVED	$125 < IEE$	$125 < IEE$	–	–

In Mexico, Brazil, and the EU, the tests are carried out at an ambient temperature of °C. Colombia adopted this same condition as of 1 September 2021. Previously, the tests were established at both 25 °C and 32 °C. While Brazil, as of the second half of 2022, establishes that the daily energy consumption in refrigerators is calculated with equal weighting for both a temperature of 16 °C and 32 °C [91].

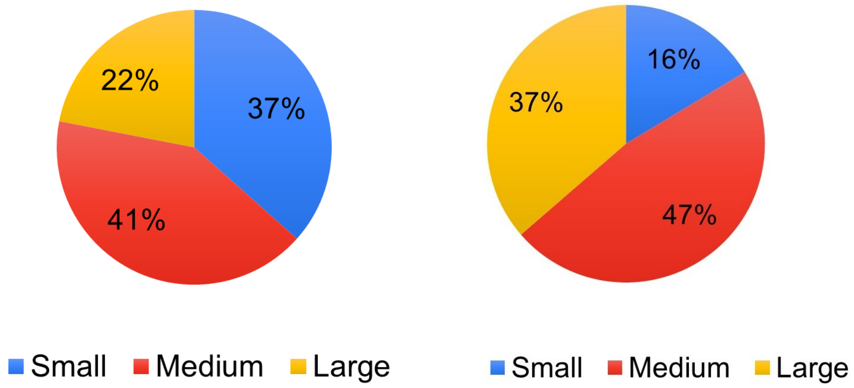
6. Discussion

Taking into account the technical regulations with which each country is governed, it is observed in the energy efficiency indicators used by the reference regions, that only Colombia uses the Relative Savings indicator Ar, while Chile and the European Union establish an IEE, in turn, Brazil establishes energy efficiency percentages for refrigerator-freezers and refrigerator-freezers-Frost Free, and finally, Mexico and the United States establish maximum consumption allowed according to the characteristics of the refrigerator. It was evidenced that Colombia, Brazil and Chile are based on the international standard IEC 62552 [98,129], while Mexico establishes the test methodology within the Official Mexican Standard NOM-0.15-ENER-18 [75], the European Union manages the EU Delegated Regulation 2019/2016 of the Commission of 11 March 2019, associated with the energy labeling of domestic refrigeration appliances [130]. The United States is governed by the Code of Federal Regulations, where in the chapter called «Business Practice», Section 305 decrees the labeling of energy and water consumption for consumer products. Section 305.3 of the policy defines the concepts of refrigerators and refrigerator-freezers [128]. Mexico adopted the United States standard that does not establish categories but instead establishes maximum consumption limits, and its form of certification is through EnergyStar. Regardless of the indicator established by each of the countries or regions (case of the EU), it is identified that they are all based on similar parameters such as monthly or daily energy consumption and the adjusted volume, although with different ways of calculating them.

It was also shown that Colombia, EU, Chile and Brazil established alphabetic categories in descending order; the categories A++, A+ and A are the most efficient, and categories F and G are the least efficient. In the case of Brazil, categories A, B and C are handled, Colombia in the current regulation has seven categories A, B, C, D, E, F and G, but it is contemplated that as of 1 September 2023, this last category is discarded and domestic refrigerators in this denomination may not be marketed. Although Chile and the EU use the same indicator, their ranges, and categories present discrepancies, about Chile, nine categories are contemplated, being A++ the most efficient for refrigerators with an IEE of less than 30 and a category G for the least efficient or with an IEE greater than 125. As observed in the comparison of the calculation of the different efficiency indicators used in the reference countries and as discussed in the previous sections, even though Colombia, Brazil and Chile are based on the international standard IEC 62552 [98,129], there are differences in the establishment of efficiency ranges; this is because each country, through its policies and socioeconomic conditions, establishes regulations for the determination of energy efficiency categories in domestic refrigerators. For example, Colombia includes evaluation factors according to its climatic classes (Tropical and Subtropical) that European regulations do not contemplate due to their conditions. On the other hand, the EU is the only region that takes into account the energy loss in the resistors used in the refrigerator defrost process (E_{aux}), that is presented in Equation (2).

Concerning requirements for certification of efficiency among the different countries, it can be seen that the EU is the region that contemplates a greater number of factors that are taken into account in the different calculations of the methodology. Among the factors that the EU takes into account, the noise level produced by the compressors and the recyclability index of the components used in the manufacture of each refrigerator stand out. With the noise factor, it is guaranteed that the useful energy used by the system is under real working conditions because the different losses of the system are being taken into account, a condition that was not observed in the evaluation of the indices by the other countries. A search was carried out in the SICEX database and an analysis of the Colombian market was carried out through the inventory of the main chain stores in Colombia, also taking into account that the country is a producer of refrigeration equipment. The categorization of residential refrigerators was divided into «Small», «Medium» and «Large», these classification criteria were used in concordance with the BEU [30]. The climatic classes are based on the international standard IEC 62552 [98,129] and adopted by RETIQ [29]. These classes are Tropical (T - from 16 °C to 43 °C) and Subtropical (ST - from 16 °C to 38 °C).

Ninety-six models for domestic refrigerators were characterized, identifying technical parameters such as the capacity of the compartments (in liters), the defrost technology (Frost and no Frost), the type of compressor (Conventional or Inverter), the average energy consumption in kWh/month; the price in Colombian pesos (COP) and the energy efficiency category according to the label reported by the manufacturer (and/or seller). A consumption of refrigerators was evidenced according to the Medium size, with 41% for the T category and 47% for the ST category. This is observed in Figure 7a and 7b, respectively.

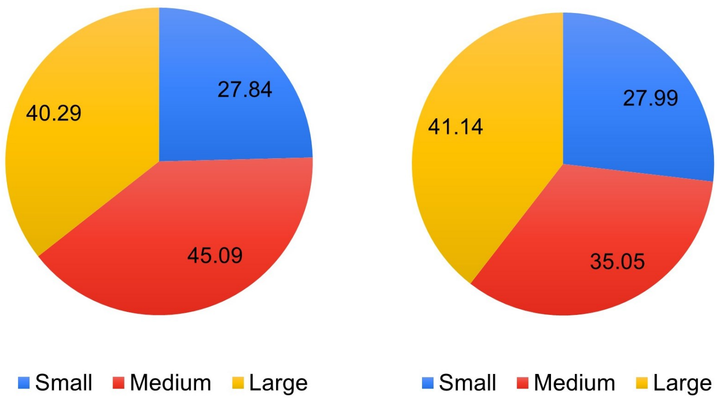


(**a**) (**b**)

Figure 7. Distribution of refrigerators inventoried at the national level according to climatic class: (**a**) Tropical [T] and (**b**) Subtropical [ST].

The next preferred size of consumers is a small refrigerator categorized with climate class T at 37% and 36% for large refrigerators categorized as ST.

In Figure 8, the average consumption is shown according to climate class and size. It is evident that the medium refrigerators with climatic class T are the ones with the highest consumption with 46.09 kWh/month and in the ST category the ones with the highest consumption are the large refrigerators with 41.14 kWh/month.



(**a**) (**b**)

Figure 8. Monthly average consumption of domestic refrigerators inventoried in the SICEX database according to climate class: (**a**) Tropical [T] and (**b**) Sub Tropical [ST], in kWh/month.

It can be seen in Figures 9 and 10 that all of the 96 inventoried models of refrigerators were classified under the BEU [30] and the RETIQ [29] established parameters. These fridges were categories A and B and the rest were in category C. In the inventory carried out, no D or E categories in class T refrigerators were found. Something similar happens with class ST refrigerators, which are mostly classified in categories A and B.

As a result of this comparative analysis, the following set of activities is suggested, aimed at structuring a possible road map for the implementation of MEPS in Colombia.

Understanding the road map as a planning strategy to provide a solution to critical development needs, through the necessary steps to achieve the main objectives in a specific area and therefore, constitutes a valuable tool for decision-making [131].

Figure 11 details the phases involved in the road-map for the implementation of MEPS for residential refrigeration in Colombia. It must be considered that each phase considers time and resources that will be arranged between the regulatory entities, the executing promoters and the target population, understanding this, manufacturers, marketers, associations and users.

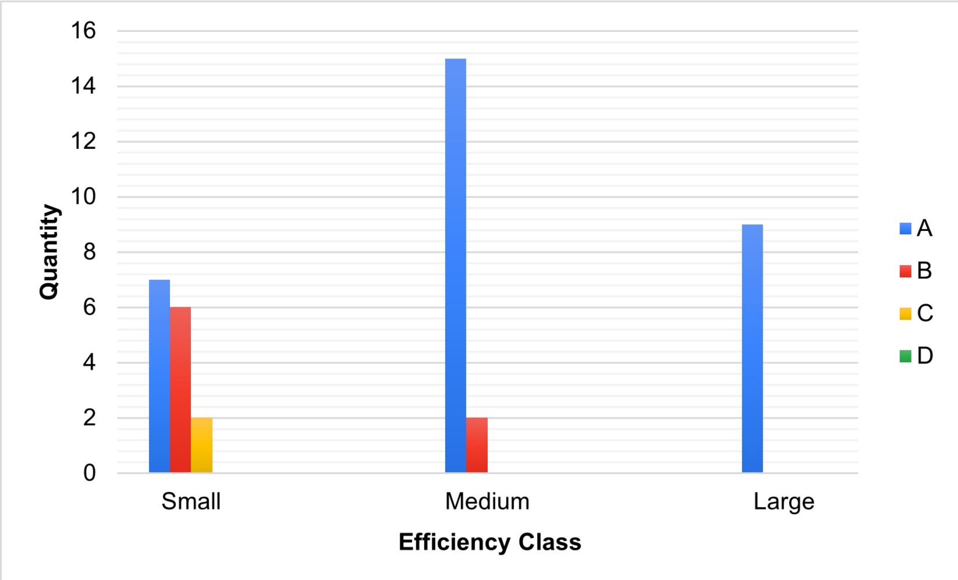


Figure 9. Efficiency Ranges for Residential Refrigerators Categorized as Tropical [T].

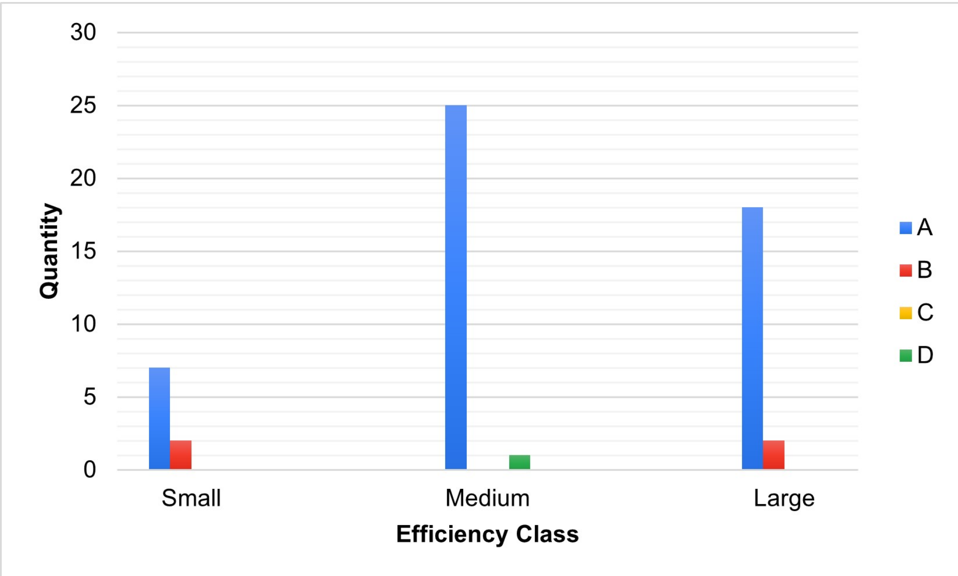


Figure 10. Efficiency Ranges of Residential Refrigerators categorized as Subtropical [ST].

In Figure 12 an outline of the labeling proposal is shown.

As a product of the process carried out within the framework of the MEPS project, the authors of this article have proposed a new label format where data such as the noise level, the recyclability index, the date of issue of the label and the date of validity of the label along with details such as a QR code with relevant information on the product's life cycle. This proposed label is presented to UPME and, if adopted, will be implemented for the final user to make the right decision when purchasing a domestic refrigerator.

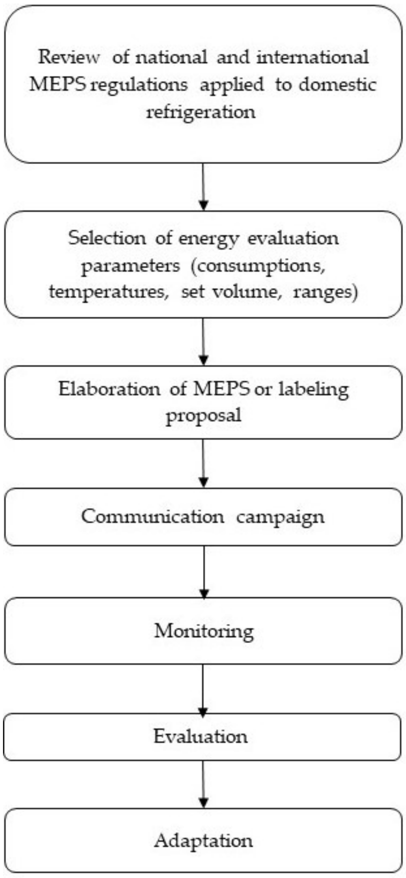


Figure 11. Proposed Road-map for the implementation of MEPS in residential refrigeration in Colombia.

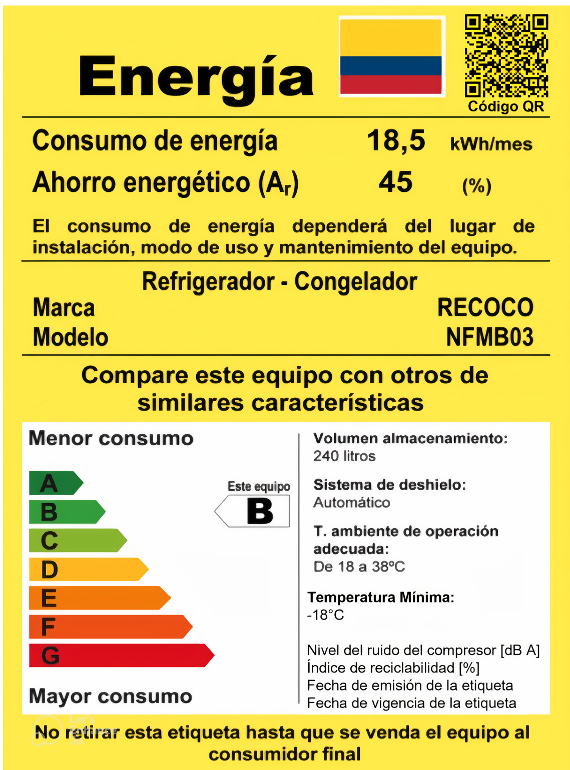


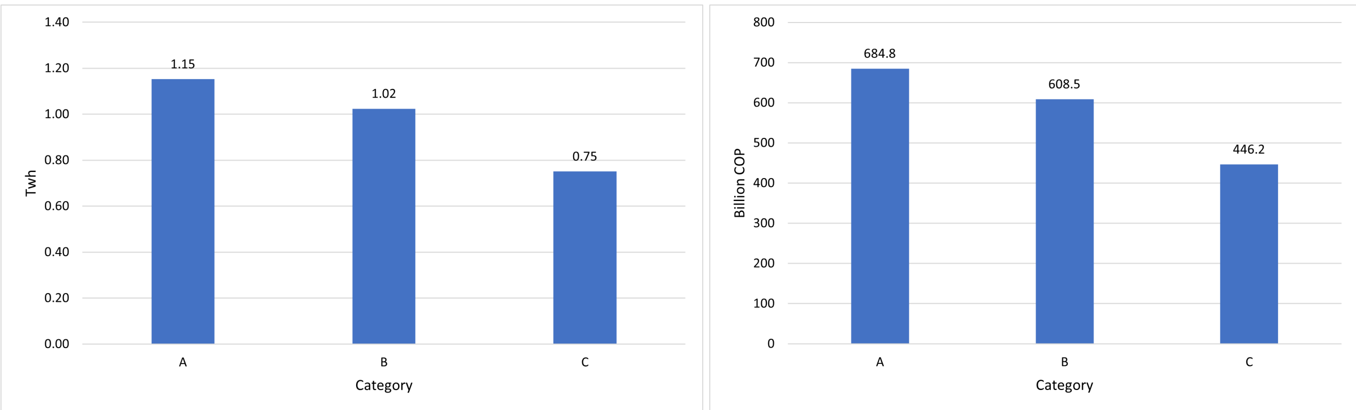
Figure 12. Proposed Energy Label for Domestic Refrigerators in Colombia.

For this research project, refrigerators forecast sold annually until the year 2032 were made. Three possible scenarios were analyzed, with the appliances available in the market. These scenarios are:

- **Reference scenario:** All available fridges are D category.
- **Scenario 1:** All available fridges are A category.
- **Scenario 2:** All available fridges are B category.
- **Scenario 3:** All available fridges are C category.

It is possible to estimate the total energy saved (TWh) and its representation in money (billions of pesos), and the CO_2 emissions avoided (thousands of tons of CO_{2eq}), with respect to the reference scenario. The total saving in pesos was estimated based on the average value of the kWh of stratum 4 that the electricity service providers charge in each of the seven regions (Centro, Caldas-Quindío-Risaralda (CQR), Northwest, Northeast, Coast, Tolima Grande and South West).

In the first scenario, a total of 1.15 TWh (equivalent to $685 billion Colombian pesos COP) can be saved by 2032. On the other hand, third scenario would generate national energy savings of 0.75 TWh (equivalent to $446 billion COP), which represents a 34.78% less energy savings (see Figure 13a,b). The avoided emissions will be higher in scenario 1, with 482,000 tons of CO_2, while scenario 3 avoids emitting 314,000 tons of CO_2, as shown in Figure 14. These three parameters are directly proportional to the efficiency of the equipment.



(**a**) (**b**)

Figure 13. (**a**) Energy Savings and (**b**) Total Savings in Billions of COP.

Currently, Colombia has strategies for domestic refrigerators replacement through national programs supported by manufacturing companies and national and foreign government entities. These two strategies are:

- Buy your fridge and pay only 5% VAT: Campaign led by Red Verde, the first post-consumer appliance program in Colombia. It is in charge of the administration, operation and financing of the selective collection system and environmental management of household refrigerators when they have completed their life cycle and are discarded by consumers. To access this benefit, the user of strata 1, 2, 3, and 4, must request through the network digital channels the fridge collection so that a certificate is issued with which they can later access the discount when buying a more efficient refrigerator.
- Efficient Caribbean: The PEECES was created in 2017 as a proposal for the Green Climate Fund—GCF, with technical support from the UPME and the collaboration of the DNP, foreseeing an estimated investment of 200 million dollars by the GCF and the Colombian State through FENOGE. To access this benefit, the user of strata 1 and 2 (with a consumption of less than 210 kWh/month) of the departments of

Atlántico, Bolívar and Córdoba, must fill out the form where the refrigerator is delivered, complying with some characteristics like state, age and size of the fridge and a commitment to purchase a more efficient refrigerator is possible, being part of the program (for follow-up), and a training in energy efficiency. The benefit is granted through a discount bond of $400,000 COP pesos ($100 USD) by the Ministry of Mines and Energy and with the possibility of additional support of $200,000 COP, this is called «Air-e», and will be redeemed in stores allied to the program.

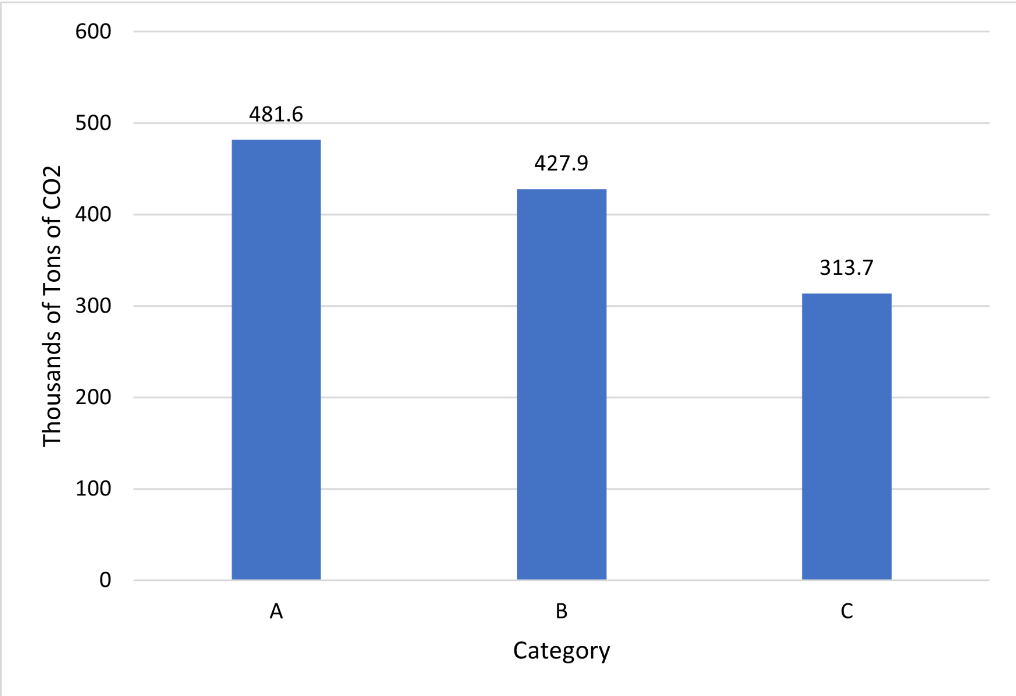


Figure 14. Avoided CO_2 emissions at country level.

7. Conclusions

According to the research carried out on the state of the labeling policies and the MEPS, the positive impact that these guidelines have had on the market of the countries analyzed and Colombia can be evidenced. Similarly, it is inferred that one of the most effective alternatives to regulate energy expenditure in the residential sector is through the implementation of these policies. Although energy consumption at the level of Latin America and the Caribbean in all sectors (transport, industry and construction, among others) showed a decrease between 8% and 12% as a result of the COVID-19 health emergency, the residential sector, was the only one that had an increase in energy consumption of 1% in 2020 compared to the immediately previous year, to supply the dynamics of the pandemic and the new modalities of working at home [36]. The confinement created new habits of use and consumption in household appliances, producing an increase in the working time of the equipment and its daily electrical load. Hence, the importance of controlling the market for inefficient refrigerators, guaranteeing through MEPS and energy labels, that end users acquire more efficient equipment and implement assertive strategies that allow adequate final disposal of the replaced equipment, thus minimizing the impact environment that they generate.

In most of the reference countries, new technologies are being implemented in order to take advantage of energy from renewable sources such as photovoltaics, covering not only the use of refrigerators but also different residential equipment in remote regions without access to the interconnected energy system. The vast majority of refrigerators supplied with alternative and renewable sources are characterized by high levels of efficiency because they do not produce firm energy and the maximum available energy must be used in periods of low energy generation, as is the case of SPV refrigerators [121].

Concerning energy labeling, not only technical aspects such as technical standards (national and/or international) must be considered, guaranteeing that tests of energy consumption, temperatures and volumes are standardized, but also social (promotion campaigns, pedagogy), economic (tax benefits) and environmental benefits. Regarding the recyclability factor that is proposed for the Colombian label, which is consistent with European labeling trends, it should be noted that this factor is related to the final disposal of old or obsolete refrigerators, allowing the use of components of the equipment, Colombia must review the European scenario, specifically about the calculation of energy consumption since the latter contemplates the calculation of the consumption of auxiliary equipment (defrost resistors), which is not currently contemplated in the RETIQ. On the other hand, there are differences in the environmental temperatures used for the tests associated with consumption; in Colombia, the latest update of the RETIQ indicates the test temperature of 32 °C, which allows establishing the consumption in more demanding operating conditions. Additionally, it was not possible to establish equivalence in the energy efficiencies of the reference countries, mainly since there are differences in their calculation methodology, so, for example, in the Colombian case, energy consumption is evaluated annually as well as that the EU, whereas Brazil does it per day just like the United States, and Mexico does not clarify the test time since it only determines the maximum consumption.

Regarding the efficiency indices, Colombia is the only country that determines the energy efficiency of refrigerators through the concept of relative savings. The EU and Chile define it through the IEE; although these two countries use the same indicator, they do not have a direct equivalence. The same happens with Brazil and the United States, who define the maximum consumption depending on the type of refrigerators. The efficiency index determined by Mexico and the United States corresponds to a linear function that is directly proportional to the adjusted volume, including an additional correlation factor depending on the type of refrigerator. In the Colombian case, Ar is not dependent on the equivalent volume of the refrigerator, while Brazil determines its efficiency index according to the adjusted volume. Colombia could choose to follow the strategies that Brazil has implemented in updating the efficiency indices, strategies that have been based on the study of the refrigerator market and, following this study, have updated the performance ranges.

Author Contributions: Conceptualization, A.d.P.R.-M. and J.S.S.-C.; methodology, A.F.R.S. and L.A.A.B.; formal analysis, A.d.P.R.-M., J.S.S.-C., A.F.R.S., D.X.S.-P., L.A.A.B. and O.F.P.C.; investigation, A.d.P.R.-M., J.S.S.-C., A.F.R.S., D.X.S.-P. and L.A.A.B.; resources, A.d.P.R.-M. and O.F.P.C.; writing—original draft preparation, A.d.P.R.-M., J.S.S.-C., A.F.R.S., D.X.S.-P. and L.A.A.B.; writing—review and editing, A.d.P.R.-M., J.S.S.-C. and A.F.R.S.; supervision, A.d.P.R.-M.; project administration, O.F.P.C.; funding acquisition, A.d.P.R.-M. and O.F.P.C. All authors have read and agreed to the published version of the manuscript.

Funding: This work is funded through project number 50627 of the Ministry of Sciences and Technology (Minciencias), call 879 of 2020 «Estándares mínimos de desempeño energético, MEPS y de etiquetado para los equipos de uso final de energía con mayores consumos en el país. Línea temática 3 convocatoria energía sostenible y su aporte a la planeación minero-energética».

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would thank the Colombian Ministry of Sciences and Technology (Minciencias), the Energy Mining Planning Unit (UPME), Universidad ECCI, and Universidad Nacional de Colombia for their financial support.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

A_r	Relative Savings
AV	Adjusted Volume
EJ	Exajoule
E_{Max}	Maximum power consumption
GWh	Gigawatt-hours
I_e	Maximum energy consumption index
IEE	Energy Efficiency Index
kWh	Kilowatt-hour
PJ	Picojoule
TWh/year	Terawatt-hours per year
V_{eq}	Equivalent Volume
Acronyms & Abbreviations	
AC	Alternating Current
BAU	Business as Usual
BEU	Useful Energy Balance
CFC	Chlorofluorocarbon
CGIEE	Energy Efficiency Indicators Management Committee
CONUEE	National Commission for the Efficient Use of Energy
CoNW	Cost of Non World
COP26	Conference of parties 26th edition
CORPOEMA	Corporation for Energy and the Environment
DANE	National Statistics Administrative Department
DC	Direct Current
DOE	Department of Energy
EPA	Environmental Protection Agency
ECV	Survey on Quality of Life
EU	European Union
FENOGE	Fund for Non-Conventional Energies and Efficient Energy Management
FIDE	Fund for Electric Energy Savings
FTC	Federal Trade Commission
GHG	Greenhouse Gases
HC	Hydrocarbons
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
IEC	International Electrotechnical Commission
LATIPAT	Latin America and Spain
LBNL	Lawrence Berkeley National Laboratory
MEPS	Minimum Energy Performance Standards
MME	Ministry of Mines and Energy
NAEWG	North American Energy Working Group
NCh	Chilean Standard
NECPA	National Energy Conservation Policy Act
NOM-ENER	National Consultative Committee for Official Mexican Energy Efficiency Standards
PAI PROURE	Indicative Action Plan for Energy Efficiency
PEB	Brazilian Labeling Program
PEECES	Sustainable Energy Caribbean Energy Efficiency Program
PROCEL	National Energy Conservation Program
RETIQ	Technical Labeling Regulation
SICEX	Colombian market research company owned by the Quintero Bros.
SPV	Solar Photovoltaic
SUI	Unique System of Information

SDG	Sustainable Development Goals
UPME	Energy Mining Planning Unit
URE	Efficient Use of Energy
VAT	Value Added Tax
VFD	Variable Frequency Driver

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