buildings

Article

Renewable Energy Use for Buildings Decarbonization Causes Inequity in Consumers? Comparative Analysis of Spain, Mexico, and Colombia

Iván Valencia-Salazar *, Elisa Peñalvo-López, Vicente León-Martínez and Joaquín Montañana-Romeu

Department of Electrical Engineering, Universitat Politècnica de València, 46022 Valencia, Spain; elpealpe@upvnet.upv.es (E.P.-L.); vleon@die.upv.es (V.L.-M.); jmontanana@die.upv.es (J.M.-R.)
* Correspondence: ivalencias@die.upv.es

Abstract: Building decarbonization strategy with Distributed renewable energy sources (DRES) is applied and extended worldwide for its climate change mitigation benefits, however, it generates debate regarding equity in sharing electric system operation costs. To analyze DRES effects on equity, it is conducted a case study, in which same residential consumer is evaluated in three different markets (Spain, Mexico, Colombia). We analyze not only electrical system technical variables, but we also include society's economic, social, technological, and environmental characteristics. Next, energy, economic, and environmental benefits are obtained in each the three case studies, analyzing the impact of using DERS on equity to recover electric system operating costs. We also evaluate whether tariff mechanisms are equitable to motivate all consumers participation, as well as whether all consumers have equal opportunity for using DERS. We conclude that tariff mechanisms in Mexico and Colombia lead to inequity to recover market operating costs, favoring large consumers with high incomes. Furthermore, tariff mechanisms discourage the use of DERS by small and medium consumers due to economic, social, and technological aspects. In Spain, inequity arises due to increased difficulty for some consumers to use DERS, i.e., consumers in apartment buildings.

Keywords: building decarbonization; distributed renewable energy sources; equity; electric tariffs; net metering; net billing; photovoltaic; CO_2 emissions

check for updates

Citation: Valencia-Salazar, I.; Peñalvo-López, E.; León-Martínez, V.; Montañana-Romeu, J. Renewable Energy Use for Buildings Decarbonization Causes Inequity in Consumers? Comparative Analysis of Spain, Mexico, and Colombia. *Buildings* **2024**, *14*, 665. https://doi.org/10.3390/buildings14030665

Academic Editors: Eusébio Z.E. Conceição and Hazim B. Awbi

Received: 2 December 2023
Revised: 12 February 2024
Accepted: 17 February 2024
Published: 1 March 2024

1. Introduction

In 2021 the buildings sector consumed 30% of global final energy and generated 15% of global end-use CO_2 emissions by sector, but, if indirect emissions from electricity and heat production are considered, their share rises to 30% of CO_2. 34% of the final energy consumed in buildings is electricity [1]. To achieve net-zero targets, buildings require the application of digital technologies, energy efficiency actions, renewable generation, and energy storage [2].

Many countries around the world apply policies and programs for consumers to generate part of their electricity consumption; the European Union (EU), the United States of America (USA), and several Asian countries [3] have been applying these for many years. Successful implementation of these strategies require that regulators provide clear signals to market players to encourage the implementation of generation by consumers; the signals can be provided through economic and sustainability incentives based on a clear regulatory structure and efficient regulations.

Successful implementation of Distributed Renewable Energy Sources (DRES) calls for an evaluation of the equity of electricity tariffs [4]. Considering the volume of users, their economic variability, social impact, political considerations and other issues, the residential sector requires special attention.

Each electricity system is unique, all with a technical and an economic part; technical aspect refers to the production and flow of energy, we can consider here mainly the available generation mix, the available transmission/interconnection/distribution networks, and metering/billing systems, as well as the role of the Independent System Operator (ISO) responsible for the efficient and safe operation of the electricity system. The economic part refers to the flow/sharing of the money paid by the consumer, this flow depends mainly on the ownership/management/integration of generation assets and networks, and on the functions and structure of the electricity market operator. Fiscal issues and the regulation of natural monopolies, such as transmission networks, distribution networks and metering systems, are important to highlight.

In a review of studies that analyze tariff mechanisms with DRES, it can be observed that they are based on technical variables related to the operation of the electricity system, they try to achieve equity in the distribution of operating costs based on energy, power and sometimes the location of the consumer. Other studies analyze if tariffs increase DRES implementation in their markets and propose strategies to increase implementation levels. Most of the studies refer to economically developed countries.

The articles' authors consider that analysis and design strategies for DRES implementation should be conducted with a holistic vision that, in addition to the technical and economic aspects of the electricity market, should include social and environmental aspects. The authors of this article consider that analysis and design of a DRES implementation strategy should be carried out with a holistic vision that, in addition to the technical and economic aspects of the electricity market, should include social and environmental aspects. Social aspects include variables such as consumer income, the inequality level in the population, the technology's commercial cost, among others. On the environmental side, the reduction of electricity's CO_2 footprint and the contribution to climate change mitigation should be included. Therefore, equity among consumers transcends technical and economic aspects of the electricity market.

This manuscript presents a holistic analysis about residential consumers in society with specific characteristics in economic, social, technological, and environmental terms, which get energy supply in an electricity market with specific rules. The purpose is visualizing how equitable is electricity market cost sharing considering the factors mentioned above.

A comparative analysis of DRES tariff mechanisms in Spain, Mexico, and Colombia, three countries with different types of electricity markets and important differences in technical, economic, social, and environmental aspects, is carried out in this article. The purpose is to highlight the differences in electricity trading in the three countries. The differences between them make impossible to establish a universal tariff mechanism, suitable for all markets; and that the effort of citizens to use the same DRES greatly vary from one country to another. In addition, Section 2 provides a state-of-the-art review of electricity tariffs and proposals for improving equity made by other authors. Section 3 describes our procedure for DRES equity analysis in electricity markets. Section 4 presents results obtained in case study developed. Section 5 provides a discussion of equity results obtained within three case study countries. Finally, Section 6 presents conclusions and future research.

2. Literature Review

Initially, this section presents a state-of-the-art review of different tariff structures applied to conventional domestic consumers and those with renewable generation. Afterwards, are presented tariff mechanisms commonly used to incorporate the renewable generation of consumers, indicating some problems detected by researchers in these tariff mechanisms and their proposed solution; additionally, some problems that have occurred in electricity markets worldwide with this type of tariffs are mentioned.

2.1. Domestic Electricity Tariffs

Electricity tariffs applied to consumers attempt pay the operation, maintenance and future development costs associated with the electricity system, some concepts used for this are:

1. Energy. Price paid per kWh consumed. Price can be either fixed or variable depending according to the amount and consumption schedule.
2. Demand: Price paid for maximum power consumed (kW) during a period. It may be applied over one or several hourly, daily, monthly, or seasonal periods.
3. Other. Usually a fixed amount. May include electricity meter rental, operating costs of the electricity system and other taxes.

2.1.1. Energy Term

Cost recovery for transmission, distribution, operation, maintenance, network expansion uses whatever of the three options above, although each electricity system tends to have its own characteristics. For decades, Energy Efficiency and Demand Response programs have been developed to reduce investments in the utility's peak generation capacity [4], and delay investments in the transmission grid by using them to alleviate grid congestion [5–7]. Consequently, because of these programs, different types of energy tariffs are offered to the consumer, most of them are Time of Use type (ToU) with static or dynamic variants, some examples are: [4,8]:

- Flat tariff. All energy has the same price. It is offered in deregulated markets for customers who like price stability [9,10].
- Increasing block prices (IBP). Energy blocks are offered with incremental pricing. [11].
- Real time pricing (RTP). Prices are dynamic, they normally change every hour and are usually indexed to wholesale energy market [12].
- Static ToU pricing. Usually, 2 or 3 blocks of several hours are offered throughout the day, with the possibility of seasonal variation [13].
- Variable peak pricing (VPP). Similar as above, with peak periods added with varying prices depending on the operation of the system [14].
- Critical peak pricing (CPP). Similar to Static ToU pricing, with periods or days with higher prices [15].
- Ramsey pricing, the energy price charged to each consumer is calculated considering their demand elasticity. Mechanism proposed for the Italian electricity market in [16].

2.1.2. Demand Term

Demand Term charge is a mechanism to recover operating costs of electric system mainly in transmission and distribution networks. This method is applied in many electricity markets with multiple combinations of energy charge mechanism, as in Spain and France. However, in other markets, such as in Mexico and Colombia, the residential consumer only pays the energy term.

Electricity markets with demand charges are defined according to different criteria. In some markets, a forecast of the system's annual operating cost is performed, the calculated cost is shared among consumers according either their location, connection voltage, stress contribution to transmission/distribution networks, etc. In other markets, Ramsey prices are applied to assign electricity system costs to consumers; in the case of Spain, consumer elasticity is considered to apportion costs [17].

2.1.3. Fixed Term

This term includes the costs of operating the electricity system, residential consumers pay a constant amount that is usually updated annually [18]. Some markets set a small amount of energy as a minimum consumption that is charged only when energy consumption in billing period is less than the minimum required. Usually, this term is applied in electricity markets where the demand charge does not apply.

2.2. Renewable Energy Integration in Residential Electricity Tariffs

Benefits of renewable energy integration in residential sector in fight against climate change are evident. DRES integration into electricity market requires a tariff mechanism that must meet three conditions: (1) Encourage DRES use by consumers, (2) Recover electricity market operating costs, and (3) Be equity to all consumers. However, achieving all three conditions is complex because sometimes are opposed to each other.

2.2.1. Tariff Mechanisms for DRES Integration to Electricity Market

DRES integration in electricity markets has been developed worldwide through several mechanisms, the most widely used being Net-Metering (see [19–22]), followed by the Net-Billing mechanism; with less implementation, the Feed-in-Tariff mechanism initially used for large renewable installations currently being applied to small renewable installations; and the Virtual net metering mechanism applied to energy communities. General characteristics of the above-mentioned mechanisms are shown below:

- Net-Metering: Energy exported to grid is subtracted from the energy imported from grid at end of billing period. Exported and imported energy have equal values [23]. If the energy balance at end of billing period results in a higher export than import, the consumer's positive balance is stored to be taken into consideration in next energy balance. This positive balance usually has a utilization period, which differs according to market where used [19]. The metering equipment needed for this mechanism is easier in comparison to communication and sampling requirements of other mechanisms.
- Net-Billing: Generation excess is exported to grid and paid at different and lower price than the imported energy price; usually purchase price is either wholesale market price or agreed price with the supplier company. Some markets apply trading charges or other fees related to energy sales.
- Feed-in-Tariff: Energy is sold through long-term contracts at a price defined by the supply company. Several European countries used this mechanism to promote photovoltaic (PV) energy in the first years of this century; however, in some European countries excesses occurred, causing financial problems in their markets [24], in Spain's case, in 2013 and 2014 government changed the incentive regime for renewable energies, leading numerous lawsuits submitted to the International Centre for Settlement of Investment Disputes of the World Bank Group [25,26]. Currently, this mechanism is available to residential consumers in some markets [27].
- Virtual net metering: Many consumers can benefit from a renewable generation facility without having it located on their property. The energy generated is exported to the grid and consumers receive a share of that production, which is deducted from utility bills, like the Net Metering mechanism [28].

2.2.2. Challenges to DRES Tariff Mechanisms

Net Metering usually offers greater economic benefits to consumers because prices for energy sold exceed the price obtained through Net-Billing (see Spanish market study [23]). For these reasons, Net Metering was applied at beginning stages of distributed generation programs, i.e., aiming increasing renewable energy deployment in the residential sector as well as needing fewer metering resources.

Successful deployment of distributed generation in electricity markets with volumetric billing and net metering leads toward revenue death spiral [29], which occurs when additional DRES increases the grid cost for consumers without distributed generation and, at the same time, makes self-generation more economically attractive [30], this situation has raised concerns among utilities and regulators [24], as it may negatively affect the stability and flexibility of electric power systems [31]. Furthermore, the increase in tariffs may increase the bills paid by consumers with investments in distributed generation, reducing the expected savings [32].

Designing electricity tariffs is extraordinarily complex and always generates debate, as technical, social, political, economic, and environmental aspects must be combined in order to achieve equity in contributions by different market players through regulations [4]. Whilst cross-subsidies should avoid, in some cases they may be accepted, e.g., transfers by rich to poor agents.

During this century, several studies have been conducted by researchers and regulators to identify the appropriate tariff mechanism to integrate renewable distributed generation. During demand growth periods, utilities prefer volumetric tariffs because increased sales allow them to over-recover fixed costs. Under Net Metering consumers with lower incomes cannot take benefit from the mechanism, while they will most probably have to pay the mechanism's costs [30].

Problems with Net Metering include a potential deficit to cover system operating costs [33,34]. In [35], the authors declare that in New Mexico's electricity market, in USA, residential customers without DRES subsidize residential consumers with DRES and Net Metering, and only 65% of the total cost of residential electricity service is recovered. Furthermore, consumers with export balance at end billing period only pay a small fixed monthly charge to recover cost service and therefore receive a higher subsidy.

The question about what and how to charge those consumers with Net Metering with exports greater than their imports was already raised in 2013 [36], being necessary identify which product or service are more important for consumers. Customers must understand that they must pay to be connected to the grid, to import from the grid when not generating or export to grid their generation surpluses.

For years, regulators have tried to answer the question posed above by trying to improve the tariff mechanisms; one proposed solution has been to increase, or create, a monthly fixed charge, however, this option usually produces strong opposition from several sectors, customers, renewable generation vendors, and others [37]. An example of this, are the changes introduced in the Nevada electricity market in 2015; the Regulator increased the fixed charges and reduced the compensation for exported energy, with the intention of avoiding cross-subsidies [38], however, in 2017, the Regulator reinstated the traditional mechanism [39]. On similar ways, in several US States, Net Metering mechanism changes have been presented in the last few years. In Canada, SaskPower utility suspends the Net Metering mechanism to submit it for review [40], because of the review it was changed to the Net Billing mechanism, in addition credits/bonuses to the Federal Coal Rate were included [41,42].

Electricity markets with tariff mechanisms with Demand term are not exempt from controversy, due mainly to its definition, since usually consider only consumer demand and not its impact on the network's peak demand [31,43]. Analyzes Demand Term used in Australian electricity market, concludes that it produces cross-subsidies, by not taking into consideration the consumer's contribution to network peak demand, therefore, it does not send adequate price signals for network efficiency and reduce cross-subsidies. Further studies consider the convenience of dynamic and real-time access tariffs to charge consumers' demand [44] or use either a variable term based on their contribution to network peak demand and a fixed term to cover system operation residual costs [45].

Experiences and research commented above are referred to liberalized markets in developed countries, most of them located in USA, Canada, and European countries. Analyses refer to markets' technical/economic variables, i.e., consider price mechanisms, energy, and demand variables. In relation to social and environmental variables, only few cases mention tariffs/subsidies for low-income consumers.

For electricity markets in emerging countries, consumers normally buy energy in regulated market with significant subsidies mostly. For example, in Ecuador using increasing price block tariff with Net metering for DRES implementation is only attractive for large residential consumers [46], suggesting tax reduction and administrative simplification for DRES. Similar problems detected in Colombia, financial support lack limits the DRES deployment in residential consumers [47], suggesting selling energy between consumers to reduce the investment recovery period [48].

Residential consumers' socioeconomic aspects are considered in study on Chile's electricity market, considering Net Metering does not guarantee PV profitability. In [49] carried out a sociological analysis of consumers with DRES and potential users in Brazil, Chile, and Mexico. Residential consumers' socioeconomic aspects are considered in study on Chile's electricity market, considering Net Metering does not guarantee PV profitability. In [50] a sociological analysis of consumers with DRES and potential users in Brazil, Chile and Mexico is carried out. An assessment of PV installations concentration levels in cities is performed to identify new PV potential areas; compares tariff mechanisms applied in three countries and concludes that Net metering should be reviewed to avoid inequality to lower-income consumers.

For Mexico, [51] propose setting up installation programs for 1 kW PV at least for high energy consumption customers, considering that system savings are greater than subsidies granted [52]. Proposes application of non-uniform fixed term based on consumer income. Considers feasible to install PV in 12% residential consumers and Evaluates energy and CO_2 emissions savings.

Our literature review has found that inequity occurs in sharing market operating costs before and after residential consumers' DRES installation. Equity in sharing operating costs in liberalized electricity markets has been extensively studied, always focusing on system technical variables. There is unanimity that Net metering mechanism is ideal to encourage DRES implementation due to providing more benefits to consumer, at same time that Net metering is very inequitable to consumers without DRES if only volumetric energy variable is applied. On the other hand, Net billing mechanism reduces benefits/incentives for DRES consumers but improves market economic efficiency. We also note that broad consensus exists to include a demand-based term in tariff mechanisms; however, how to calculate its quantity is subject to discussion. Subsidies are provided to low-income consumers outside tariff mechanisms in some markets. Economic, social, and environmental variables are not included in the analyses developed. Society's economic and environmental variables are not included in analyses developed.

Social, regulatory, economic, and technological conditions in emerging countries are different among themselves and very different in comparison to developed countries. Electricity is often subsidized, and DRES costs are generally higher than in developed countries. Energy uses differ due to environmental and economic conditions, and residential consumers are less electrified in their daily activities. In emerging countries DRES implementation is scarce; in some cases, DRES development programs are recent; in others, due mainly to high costs, only large residential consumers use DRES. Studies reviewed often include in addition to technical variables, economic and environmental variables.

3. Methodology

The technical and economic variables discussed in previous section are insufficient to determine if building decarbonization strategy using DRES is equity and at the same time to understand its energy/social impact into applied market, therefore, authors consider necessary to include into analysis social and environmental variables. Variables considered in this study are shown in Table 1:

Table 1. Variables and indicators used to assess building decarbonization strategy equity using DRES.

	Operational Definition	Indicator
1	Energy term	$/kWh
2	Demand term	$/kW
3	DRES Tariff Mechanism	$/kWh
4	Population	Inhabitants
5	Electricity consumption per capita	kWh
6	CO_2 emissions per MWh electric	T
7	Adjusted net national income per capita	$
8	Minimum salary	$
9	PV kit power to install	kW
10	PV kit price to install	$
11	Gini index	Dimensionless
12	Subsidies	$

In Table 1, variables 1 and 2 refer to technical variables used to evaluate consumers' energy behavior, and variable 3 regulates consumer's DRES operation in electricity market. On the other hand, variables 4 and 5 show society's electrification level, and give us an idea about future energy requirements, either due to population growth, greater industrial development, higher per capita consumption, or climatic change effects due for example to higher temperatures. Variables 6 and 7 enable us visualizing and comparing effect of saving 1 kWh and its impact globally. When an electricity market presents high CO_2 emission factors, DRES use provides a higher global benefit. Variables 8–11 can be used to estimate consumer's economic effort to implement DRES in their buildings. Variable 12 indicates whether consumers receive subsidies for the implementation of DRES in their buildings or receive subsidies in energy prices.

In order to analyze equity of DRES use in residential buildings, consumer performance is studied in two scenarios, first a conventional scenario pre-DRES use, followed by DRES scenario. Results obtained in evaluation process stages enable to visualize consumer equity in DRES use. Stages and variables considered in evaluation process are shown in Figure 1:

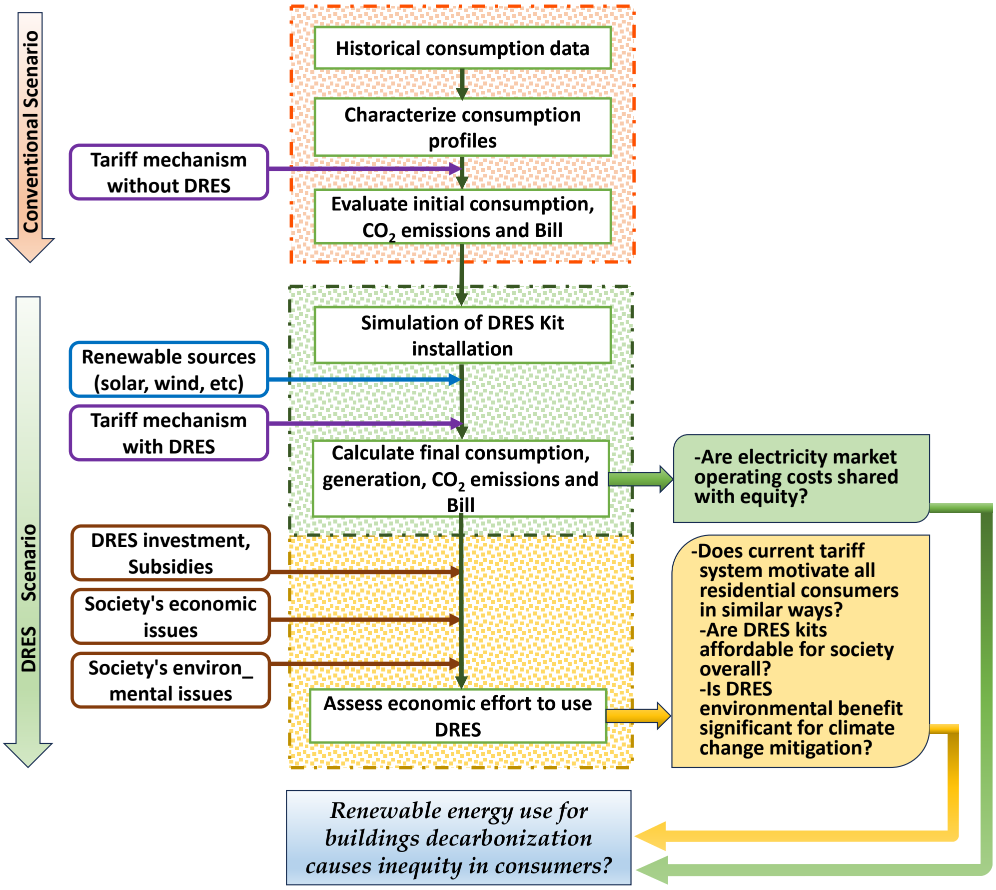

Figure 1. Process to assess equity of DRES use in residential buildings.

In Figure 1 it is observed that, in the first stage, consumer's energy behavior without DRES and its energetic, economic, and environmental impact are analyzed using conventional tariff mechanism. Second stage assumes that DRES is installed by consumer, then renewable generation is simulated based on renewable sources at consumer's location, energetic, economic, and environmental profits are assessed considering tariff mechanism with DRES. At the end of this stage, we should answer the question: *Are electricity market operation costs equity distributed between users with DRES and those without DRES?* At third stage, society's economic and environmental variables are considered to evaluate economic effort required by consumer to install DRES in building, giving rise to questions Is current tariff system equity motivating all residential consumers? Are DRES kits affordable for society overall? Is DRES environmental benefit significant for climate change mitigation? After answering these previous questions, we can answer our final question: Is the use of renewable energies for the decarbonization of buildings equitable?

A case study is carried out as example of application of methodology proposed, in which electricity markets of three countries are compared to highlight importance to include society's economic and environmental variables. Spain, Mexico, and Colombia are the three countries included in case study. Selection of countries is based on many reasons, first, Spain a developed country, ranked 16th in the world ranking of GDP 2022, has liberalized electricity market where residential users can buy energy through regulated tariffs or commercial companies, Net billing tariff mechanism is used for DRES.; Mexico, emerging country, ranked 15th in world GDP, 10th for population and 11th in CO_2 emissions, has a regulated market with large energy subsidies, Net metering tariff mechanism is used for DRES; Colombia, emerging country, ranked 45th in world GDP, has liberalized electric market with public and private companies, residential consumers purchase their energy through regulated tariffs in which economic transfers are established from rich consumers to poor consumers, i.e., rich consumers subsidize poor consumers paying a surcharge on energy prices, Hybrid tariff mechanism is used for DRES.

Additional reasons for selection are, Spain is a developed country with high DRES implementation in residential buildings, while Colombia and Mexico have programs for DRES use, but they are in early development stages. Concerning tariff mechanisms, Spanish and Mexican mechanisms are very different from each other, but both have some similarities with Colombian mechanisms. The rest variables presented in Table 1, sometimes similarities appear between Spain and Colombia, in others between Mexico and Colombia, this variance increases interest in comparative analysis among these electricity markets. Comparison is carried out using one-year hourly energy records from a residential consumer. The consumer's energy profile is identical in all three countries, so we can see how market mechanism and other variables influence economic, energetic, and environmental profit and equity in DRES use.

4. Results

This section develops the case study. Before starting the consumer assessment process described in Figure 1, we must describe both electricity markets and society's economic and environmental aspects in Spain, Mexico, and Colombia.

4.1. The Spanish, Mexican and Colombian Markets

This section describes regulatory structure and participation mechanisms for residential distributed generation in the Spanish, Mexican, and Colombian markets. Before doing so, Table 2 shows some interesting indicators about these three countries.

Table 2. Energy, economic and environmental indicators for electricity use by country.

Variable	Spain	Mexico	Colombia
Population 2022 (millions) [53]	47.615	127.504	51.874
CO_2 emissions per capita tCO_2eq/capita [54]	4.6	3.1	1.5
Electricity consumption per capita 2022 MWh/capita [54]	6.0	3.1	1.7
CO_2 emissions per MWh tCO_2eq/MWh-year	0.16 [55] *	0.435 [56] *	0.1263 [57] **
Adjusted net national income per capita USD 2022 [58]	46,332	22,298	20,269
Minimum salary 2023 EUR/month	1080 [59]	311 [60]	259 [61]
PV kit kW-EUR	2.5 kW EUR 1662 [62]	2.7 kW EUR 2263 [63]	2.5 kW EUR 2367 [64]
Gini index 2020 [58]	0.349	0.454	0.535

* Year 2022, ** Year 2021.

Table 2 shows similar populations in Spain and Colombia, while Mexico exceeds both countries combined; however, Spain has more CO_2 emissions per capita, Colombia has approximately one third of Spain's emissions, and Mexico approximately double that Colombia, which could be explained due Spain's more industrial and economic development.

Spanish society's greater electrification results in very high per capita electricity consumption in Spain versus Mexico and Colombia; however, Colombia's consumption is slightly over half Mexico's consumption. In CO_2 emissions electricity factor Colombia and Spain are similar, Colombia's being lower due mainly use of hydraulic generation, while Mexico's factor is higher than others because it uses mainly natural gas and other fossil fuels. Relating these two variables, annual electricity consumption of each inhabitant in Colombia generates 0.2 tCO_2, compared to 0.74 t in Spain and 1.12 t in Mexico.

Colombia and Mexico's Adjusted net national income per capita is similar, while Spain's double that of both countries. Minimum salary in Mexico and Colombia are similar between them, but they are approximately 25% of Spanish minimum salaries. A PV kit price is very similar in Colombia and Mexico, however, in Spain it is 30% lower. Relating both variables, it is observed for Spain under two minimum monthly salaries are required to purchase a PV kit; however, for Colombia, with lowest minimum salary and highest PV kit price, purchase implies more than 9 salaries; in Mexico, 7 salaries are necessary to purchase PV kit.

Gini index, last variable in Table 1, indicates equity in income distribution, showing that Spanish society is more equity in income distribution in all three countries, while Colombia is the country with lowest equity in redistributing wealth. Equity in Mexico is intermediate between Colombia and Spain.

4.1.1. Market Regulatory Structure

Spain

The public company Spanish Electricity Network (REE, Red Eléctrica de España) [65] performs two functions, Independent System Operator and Transmission Company. Generation, distribution, and commercialization activities are carried out by private companies. The commercialization activity is carried out by 744 regional and national companies [66]. In the liberalization process, it was forbidden any company to participate in different market activities, i.e., the company cannot have simultaneous generation and commercialization; however, the separation of their accounting and operational activities is allowed.

The residential electricity tariff is mainly composed of three elements:

1. Demand Term. Determines the maximum power that can be consumed in each period of the day, either peak or off-peak. An annual cost per period, EUR/kW/year, is paid monthly for each kW contracted. The electrical installation is equipped with a power breaker to disconnect the installation in case contracted power is exceeded.
2. Energy term. Refers the energy cost consumed during the billing period, EUR/kWh.
3. Taxes and others. The rental of the energy meter and other taxes are charged.

Generally, the Energy Term represents the bill's major part, Demand Term oscillates between 10 and 20% of bill depending on total consumption and contracted power; in special cases with low energy consumption, the Demand Term can be a major part of the bill. Third component does not usually have a significant amount.

There are several free contracting options with commercial companies, but there is also a government-regulated tariff, PVPC (Voluntary Price for Small Consumers), with energy prices varying hour by hour according to the price of the Wholesale Electricity Market. This study takes as reference price for contracted power EUR 40/kW/year and energy price EUR 0.15/kWh.

Mexico

Market activities are mostly carried out by state-owned Federal Electricity Commission (CFE, Comisión Federal de Electricidad) [67]; participation of private companies in this market is limited to generation.

Electric tariff applied to a residential consumer depends on:

1. The region where it is located, there are seven regional tariffs depending on the ambient temperature.
2. The energy consumption, the basic supply tariff is applied to small and medium consumers, and the high consumption tariff for large consumers (DAC).

Therefore, there are seven basic supply tariffs applied for small and medium consumers (1, 1A, 1B, 1C, 1D, 1E and 1F) and the DAC tariff, which is subdivided into 6 regions [68].

The basic supply tariff provides the consumer with three or four blocks of energy at different prices, the number of blocks and the energy contained in each of them depends on the season of the year, summer, or winter, as well as the region where the consumer is located. For example, Table 3 [61] shows the 1C tariff configuration applied in Veracruz city during 2023.

Table 3. Energy blocks and prices of CFE's 1C rate.

Energy Block	Basic	Intermediate Low	Intermediate High	Extra
Winter kWh	75	100	-	-
Summer kWh	150	150	150	-
Annual average price EUR/kWh *.	0.0465	0.0550	0.0655	0.1745

* Conversion of EUR 1 = MXN 20 (Mexican pesos) has been used.

As shown in Table 3, a small consumer has a block of energy of 75 kWh at EUR 0.0465/kWh in winter, in case he requires more energy, he has at his disposal another block of energy of 100 kWh at EUR 0.0550/kWh and, finally, if his consumption grows, the energy that exceeds the previous blocks is paid at EUR/kWh.

For the DAC tariff, consumers pay a Fixed Term for EUR 6.5 monthly. For the DAC tariff, the consumer pays a Fixed Term of EUR 6.5 per month; in the Energy Term all kWh have same price, for Veracruz region the energy average price in 2023 is around EUR 0.3125/kWh [69].

Colombia

Colombian market structure is similar to Spanish market, with competition in generation and commercialization areas. A state-owned company performs Market Operator and Independent System Operator functions, while transport and distribution services operate in monopolies provided by several companies with public and private participation [70]. More than 30 public and private companies compete in commercialization [71].

Consumers were grouped on the basis by demand:

1. Demand over 2 MW. Consumers negotiate their energy directly with market agents; industrial and large commercial consumers are in this group. This is a free market.
2. Demand lower 2 MW. The consumer purchases its energy using any of tariffs available in the market. It is a regulated market.

The Energy and Gas Regulatory Commission (CREG. Comisión de Regulación de Energía y Gas) is the entity responsible to establish tariffs used by regulated users. CREG defines monthly energy prices (EUR/kWh) based on Unit Cost of Service Provision (CU), which is updated monthly according to Consumer Price Index. CU consist in the aggregation of following costs: [72].

- Energy purchase cost in the market, G (EUR/kWh).
- Transportation cost, T(EUR/kWh).
- Distribution cost, D(EUR/kWh).
- Commercialization cost, Cv (EUR/kWh).
- Losses cost, PR (EUR/kWh).
- Restrictions and adjustment services cost, R (EUR/kWh).

Residential consumers are stratified according to their economic level, those with the lowest income level are assigned to level 1, while those with the best economic level are placed in level 6 [73]. Electric tariff design establishes economic transfers from rich consumers to poor consumers, therefore, rich consumers make a social contribution paying an extra cost for consumed energy, while poor users receive a subsidy on their consumed energy. Contributions and subsidy's structure is shown in Table 4.

Table 4. Subsidies and contributions structure in Colombia's residential tariffs.

Level	Subsidies	Contributions
1	−60%	-
2	−50%	-
3	−15%	-
4	-	-
5	-	+20%
6	-	+20%

As shown in Table 4, level 5 and 6 consumers pay an extra cost that seeks compensate the subsidy made to consumers in levels 1, 2 and 3. Only consumers in level 4 pay an energy price equal to CU. The CREG authorizes commercial companies can apply a lower value as long as it is economically justified [74].

The subsidy applied to levels 1, 2 and 3 only applies to an energy block defined as "subsistence consumption" CS. All energy consumed above CS limit is paid at CU. CS is defined according to consumer's location, such as [75]:

- 173 kWh for localities below 1000 masl.
- 130 kWh for locations above 1000 masl.

For July 2023, energy prices in different levels are shown in Table 5.

Table 5. Monthly energy prices by consumption range in July 2023.

Level	Monthly Consumption Range kWh	Price EUR */kWh
1	0-CS	0.0718
	>CS	0.1794
2	0-CS	0.0897
	>CS	0.1794
3	0-CS	0.1525
	>CS	0.1794
4	All	0.1794
5	All	0.2152
6	All	0.2152

* Conversion rate used is 1 EUR = COP 4474.12 (Colombian pesos).

Table 5 shows consumers in levels 5 and 6 pay higher prices than Spain and Mexico, while energy purchased at CU prices in levels 1 to 4 is more expensive than Mexico and Spain.

4.1.2. Participation Mechanisms for Residential Consumer's Distributed Generation

Considering that different types of electricity markets operate, Net-Metering and Net-Billing tariffs are used and applied with variations to improve market adaptation and increase customer acceptance. Descriptions of distributed generation participation mechanisms in the three countries are described below.

Spain

After braking implementation of distributed generation for self-consumption caused by the well-known "sun tax" in 2015 [76], regulatory changes introduced in 2019 [77] have incentivized self-consumption installation, mainly PV, in the residential, commercial, and industrial sectors.

In 2022, 2507 MW of PV were installed in self-consumption (47% industrial, 32% residential, 20% commercial and 1% isolated) [78], Before 2022 there were only 2742 MW of PV installed. The increase can be explained due three factors: first, high electricity prices in 2022, partly due Ukraine's war; second, the administrative simplification for the distributed generation approval and, third, important financial aid by Government at different administrative levels.

A residential self-consumption installation must be less than 100 kW and be 100% renewable. The installation can be for individual or collective use (Energy Communities) [79,80].

Net Billing is the billing mechanism used; the consumer has three different options for economic management of their energy produced [77]:

- Self-consumption without surplus: It is necessary to install equipment that avoids excess energy injection to grid. Excess generations are lost because they cannot either be used or exported to the grid.
- With surpluses receiving compensation: Generation surpluses are exported to grid and are compensated in following bill at a price previously established with commercial company that sells electric energy imported from the grid. The export price, called compensation price, is always lower than import price.
- With surpluses without compensation: Surpluses are sold directly to electricity market. Registration in electricity market is required.

In order to select the most appropriate modality of self-consumption, it is essential to know how energy is consumed every hour throughout the year. It is important to remember that the savings obtained in self-consumption only affect the variable part of the bill, i.e., demand term, energy meter rental, and taxes are not decreased.

Mexico

Three types of Interconnection Contract are offered by the CFE for DRES under 500 kW [81]:

- Net Energy Metering: Supply contract where generated is subtracted from consumed. If the subtraction is negative, the difference is considered a credit in favor of the consumer, "..which will be automatically applied to energy metering billed in each subsequent billing period, up to a maximum of 12 months." [82].
- Net Billing: Energy consumed is paid according to supply tariff and energy generated is paid using a Local Marginal Hourly Price at consumer's connection node.
- Total Energy Sale: The client only sells energy to CFE, not consuming energy from CFE. Payment procedure for energy generated is same as the previous point.

Installations operating in low voltage may install up to 50 kW, if the supply is high voltage the installation must be less than 500 kW.

Colombia

Residential consumers as having installed power under 100 kW is eligible to become a Small-scale Self-Generator with Renewable Generation (AGPE) by simplified procedure [83]. It is only required two grid availability conditions to be reviewed, first, power to be installed must be less than 15% of transformer capacity, and second, the energy generated must be less than 50% of the average annual minimum demand during production period. Also, consumers must have a bi-directional meter with hourly metering.

When billing, if generation surpluses are less than energy imports from grid, the surpluses will be deducted from consumption, but commercial company charges Cv commercialization cost for each kWh exported. In the case that surplus exceeds imported energy, the difference is purchased by commercial company at market price, G, and paid within next monthly bill.

4.2. Case Study

For comparative analysis of mechanisms available to residential consumers in Spain, Mexico, and Colombia, we use hourly consumption profiles from residential consumers located in Valencia, Spain. House annual consumption is 2873 kWh with a contracted maximum power of 4.4 kW. Figure 2 shows the house's annual consumption profile. In Figure 3 the house's monthly consumptions are shown.

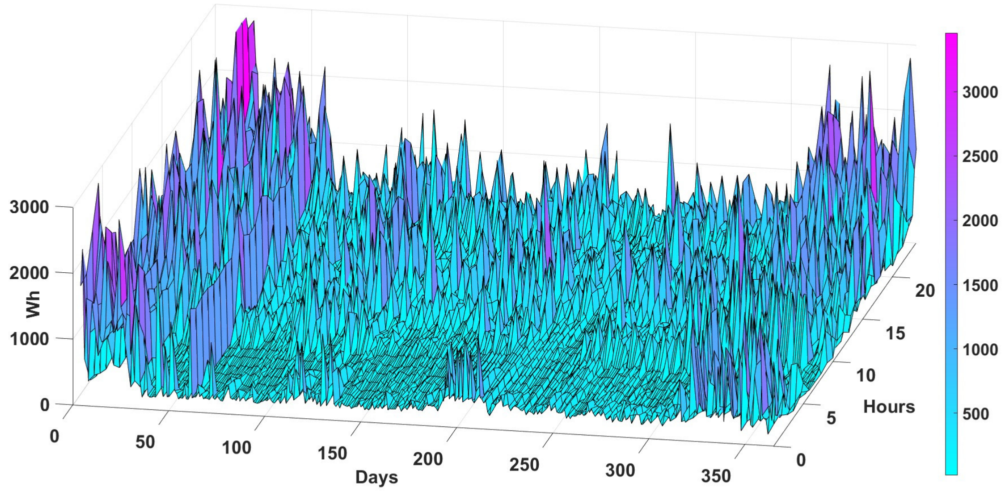

Figure 2. Household annual consumption in the Case Study.

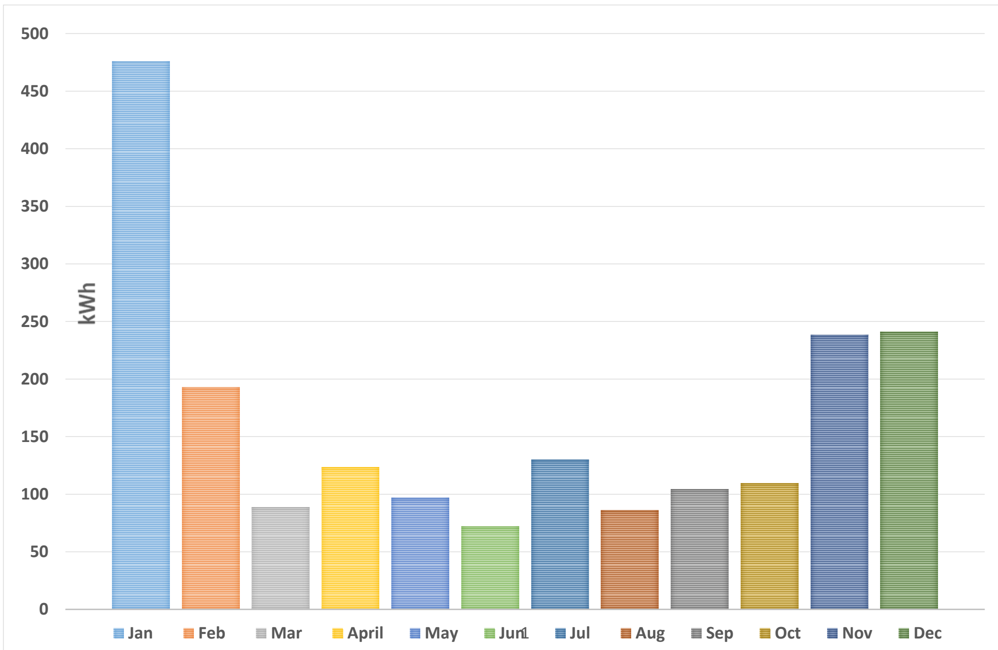

Figure 3. Monthly consumption in the Case Study.

The CO_2 emissions associated with household consumption, using the data in Table 2, show that in Spain 460 kg of CO_2 are produced, while in Mexico 1250 kg of CO_2 are emitted, and in Colombia the associated emissions are 362 kg of CO_2.

Using available data, profiles are obtained for work and weekend/holiday consumption during winter and summer, which are shown in Figure 4.

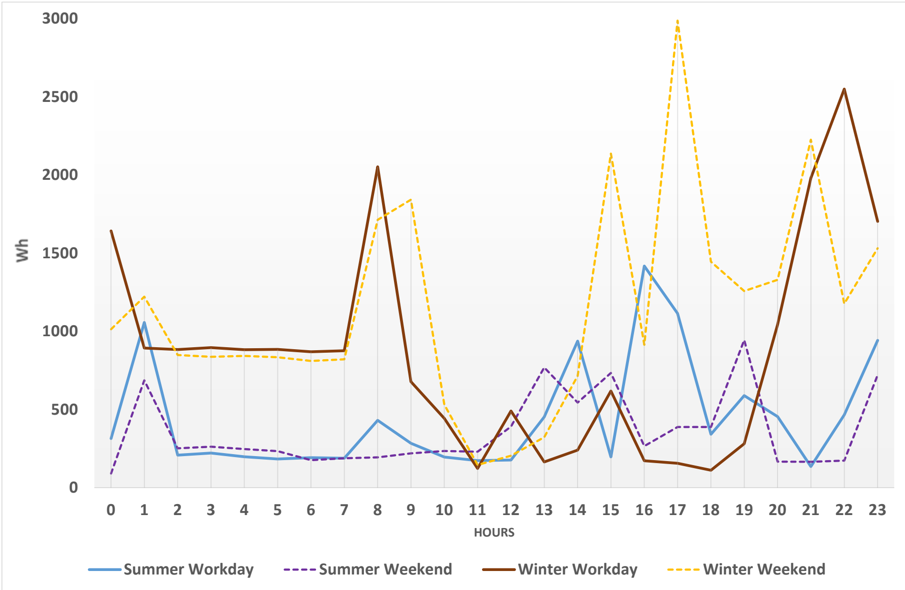

Figure 4. Work and holiday consumption profiles during summer and winter in the Case Study.

As a first step of the analysis, the monthly bill is calculated considering that the house is in Valencia, Spain; then in Veracruz, Mexico; and finally in Bogota, Colombia. Subsequently, we evaluate the effect on bill that 2 kW PV installation in house produces on monthly bill.

4.2.1. Initial Scenario Consumers without PV

Spain

As the market is deregulated, an average price for energy and contracted power is established from different offers made in April by different commercial companies. A reference price for contracted power of EUR 40/kW/year and an energy price of EUR 0.15/kWh are established. With these prices, the annual bill is as follows:

Demand: 4.4 kW $\times$ EUR 40/kW/year = EUR 176.0.

Energy: EUR 0.15/kWh $\times$ 2873 kWh = EUR 430.9.

Annual total EUR 606.9

Mexico

Applying energy steps in Table 3, at year end 1336 kWh are consumed in basic, 758 kWh in Intermediate low and 779 kWh in Extra (during winter months only). The annual amount of the electricity bill in Veracruz is EUR 238.83.

Colombia

Bogota city is 2716 masl [84], therefore, the CS subsistence consumption assigned to residential consumers is 130 kWh monthly.

Annual bills for residential consumers according to economic level are shown in Table 6.

Table 6. Annual residential consumer bill according to economic level.

Level	1	2	3	4	5	6
EUR	326.7	353.1	445.4	484.9	581.9	581.9

Table 5 shows that annual bills for level 5 and 6 consumers are similar to Spanish consumers; on the other hand, level 1 consumer pay more than Mexican consumer.

4.2.2. PV Consumer Scenario

The study evaluates the installation of a 2 kW PV system in each of three cities. It is assumed that panels have optimal alignment and inclination, and total system losses of 14%. In Valencia, the annual PV production reaches 3191 kWh, in Veracruz 3024 kWh and in Bogota 2742 kWh The monthly energy produced in these three cities is shown in Figure 5.

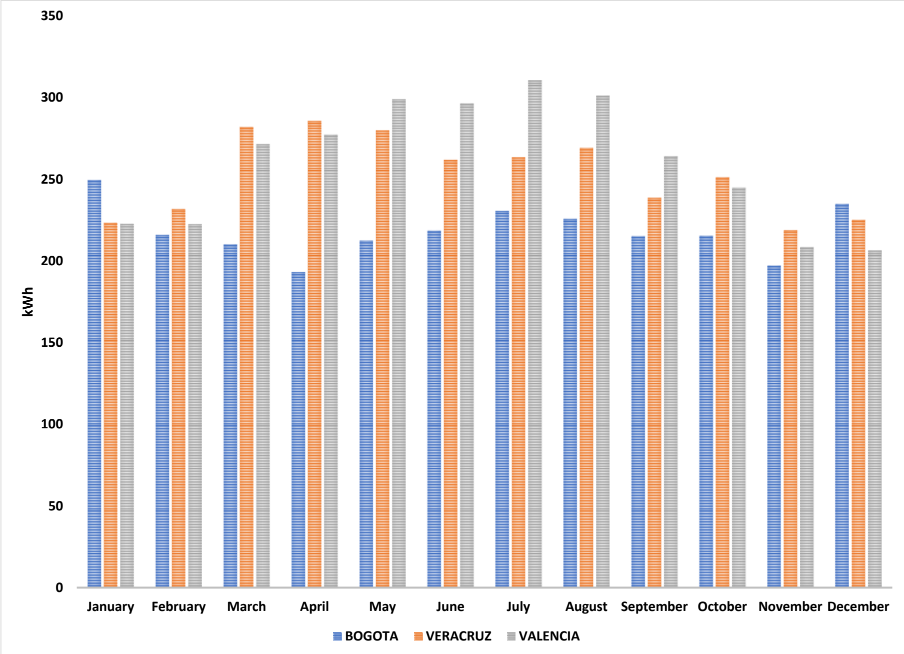

Figure 5. Monthly energy produced in case study cities.

Figure 4 shows that PV generation in Valencia is higher in summer, while Veracruz generates slightly more in spring; meanwhile, in Bogota, PV generation is more stable, with higher production in winter. PV generation during summer typical days in the three analyzed cities is shown in Figure 6, while Figure 7 shows same variables during winter.

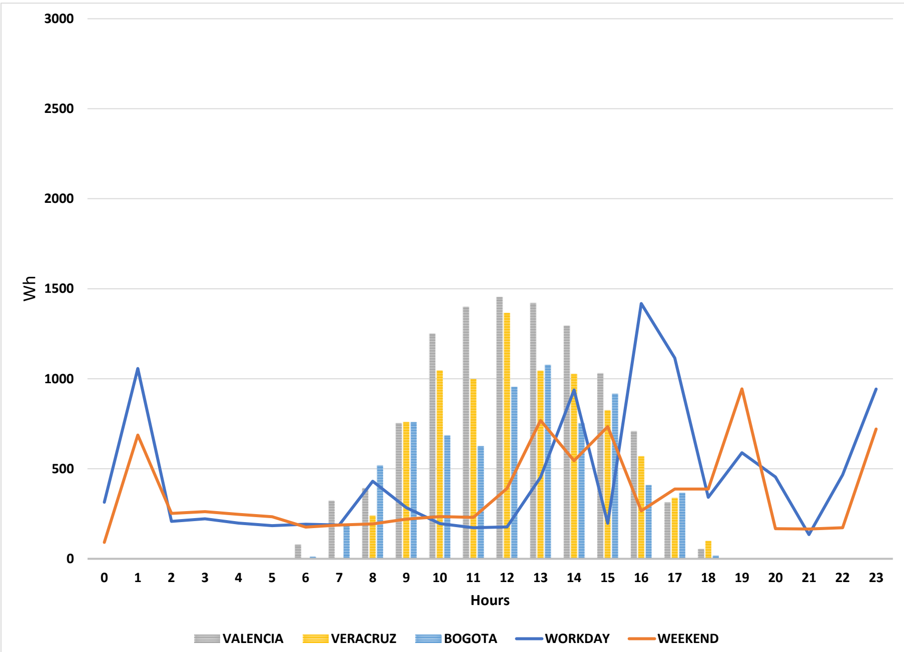

Figure 6. PV generation and consumption profiles in summer.

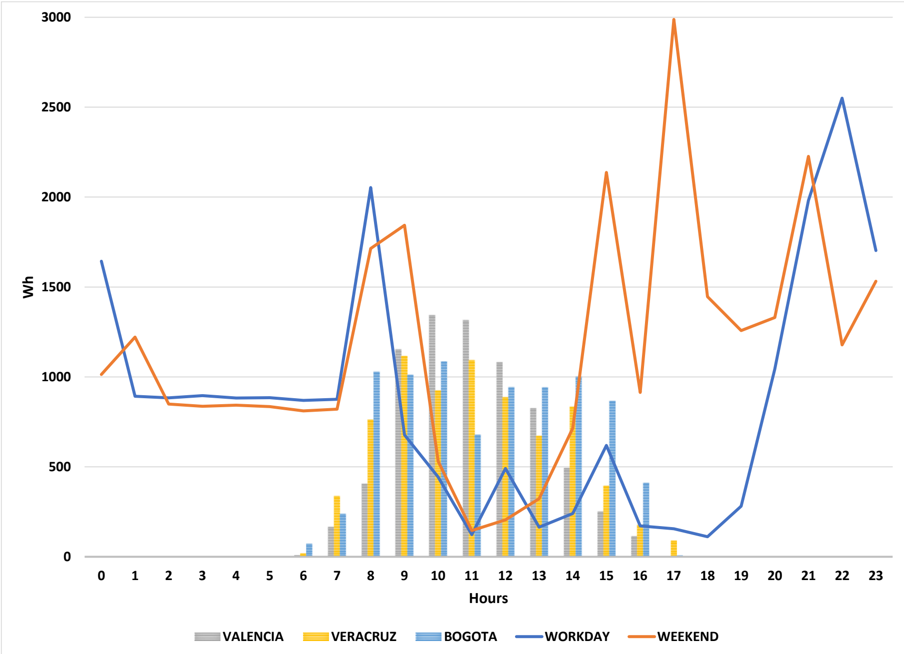

Figure 7. PV generation and consumption profiles in winter.

Figures 6 and 7 show that, during summer and winter seasons, during middle hours of day, excess production occurs, being more evident during summer.

Valencia Profit Analysis

The first step for economic analysis is to calculate the self-consumed energy and surplus that is sold to commercial company. Figure 8 shows surpluses over the year in Valencia.

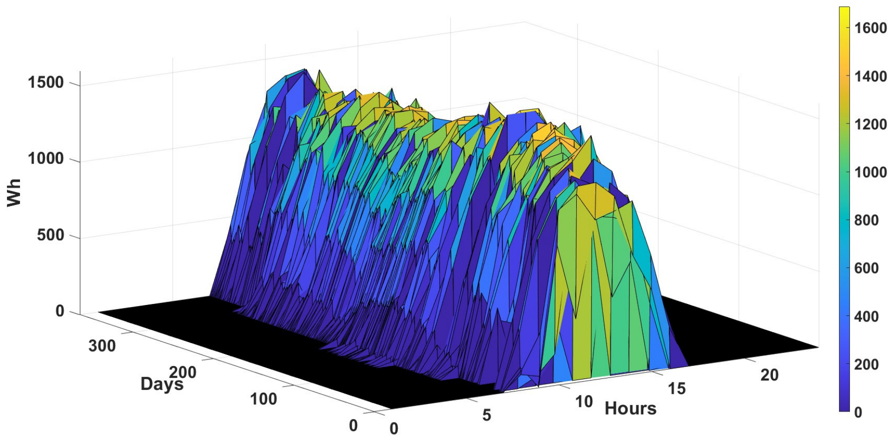

Figure 8. Surpluses exported to the grid over the year in Valencia.

Figure 8 shows that there are abundant surpluses throughout the year, with significant peaks in winter.

In Valencia, the PV system generates 3191 kWh, allows savings from grid consumption 904 kWh, while injecting 2287 kWh surplus to grid. Taking into consideration that surplus compensation price is 50% above purchase price, savings obtained are as follows:

Self-consumption savings: EUR 0.15/kWh × 904 kWh = EUR 135.60.

Sale earnings: EUR 0.075/kWh × 2287 kWh = EUR 171.53.

Annual bill is reduced from EUR 606.9 to EUR 299.8, i.e., 50% saving on the total annual bill. During the year 111% of the energy consumed is produced, i.e., customers offset 100% emissions associated with their conventional energy consumption from grid and a little more. The PV system avoids 511 kg of CO_2 emissions. Economic optimization of PV system requires demand profiles to balance surplus and saved energy in conjunction with the most appropriate compensated tariff.

Veracruz Profit Analysis

PV generation and accumulated surpluses monthly registered are shown in Figure 9.

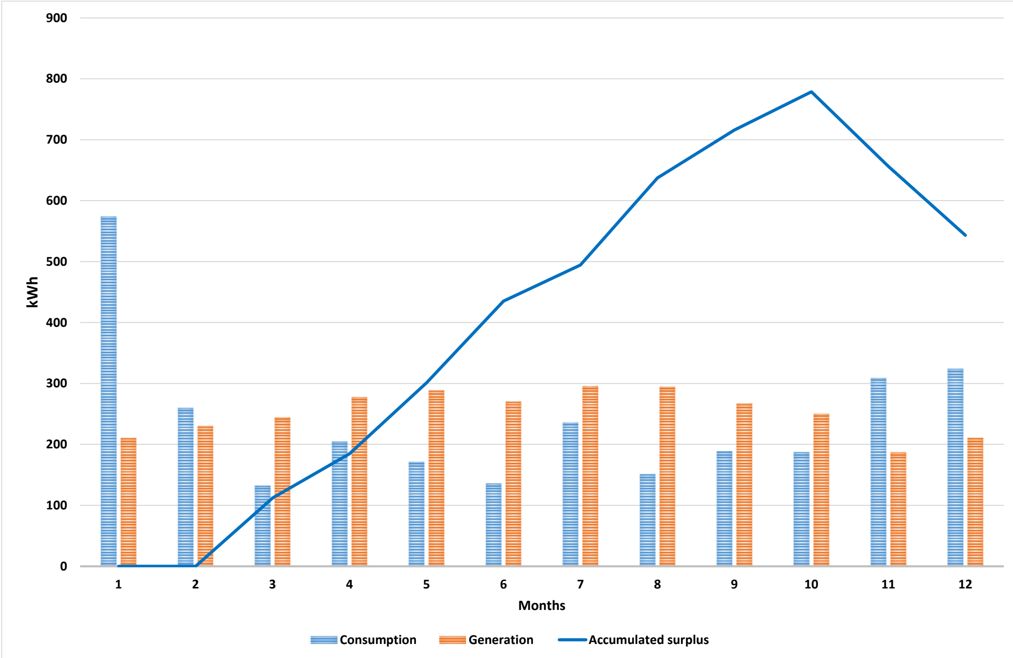

Figure 9. Consumption, generation and accumulated surplus profiles in Veracruz.

In Figure 9 it is observed that no surplus is registered in first two months, but from the third month on, surpluses are accumulated, with 543 kWh of positive balance at year end. Energy accumulator is reset at year end; therefore, accumulated energy is paid at corresponding Local Marginal Price, which is very similar to basic energy block price, thus, obtaining an additional profit of EUR 25.25.

Only in the first two months 393 kWh are billed only, and during rest of year, no energy is billed. Annual bill is reduced from EUR 238.83 to EUR 17.23, i.e., 93% bill savings.

105% of energy consumed is produced during the year, i.e., the customer offsets emissions associated with conventional energy consumption from the grid and a little more. The PV installation avoids 1315 kg CO_2 emissions.

In Veracruz's case, Net Energy metering is advantageous since all kWh generated have same value as kWh imported. Although all kWh consumed have same price within a tariff block, there are different blocks; therefore, in order to optimize the payback period, it is normally sought to reduce only kWh with higher value in tariff.

It is evident that from an economic point of view, in this case study, it is convenient to reduce the installation size to reduce amount of energy that is "sold at Local Marginal Price" at end of year when the accumulator is reset to zero, which allows to reduce the investment and its payback.

Bogota Profit Analysis

The PV system in Bogota generates 2742 kWh, self-consumes 922 kWh, imports 536 kWh, and injects 1819 kWh, exchanging 1415 kWh and selling 404 kWh. Monthly evolution of energy exchanges and energy consumption throughout the year are shown in Figure 10.

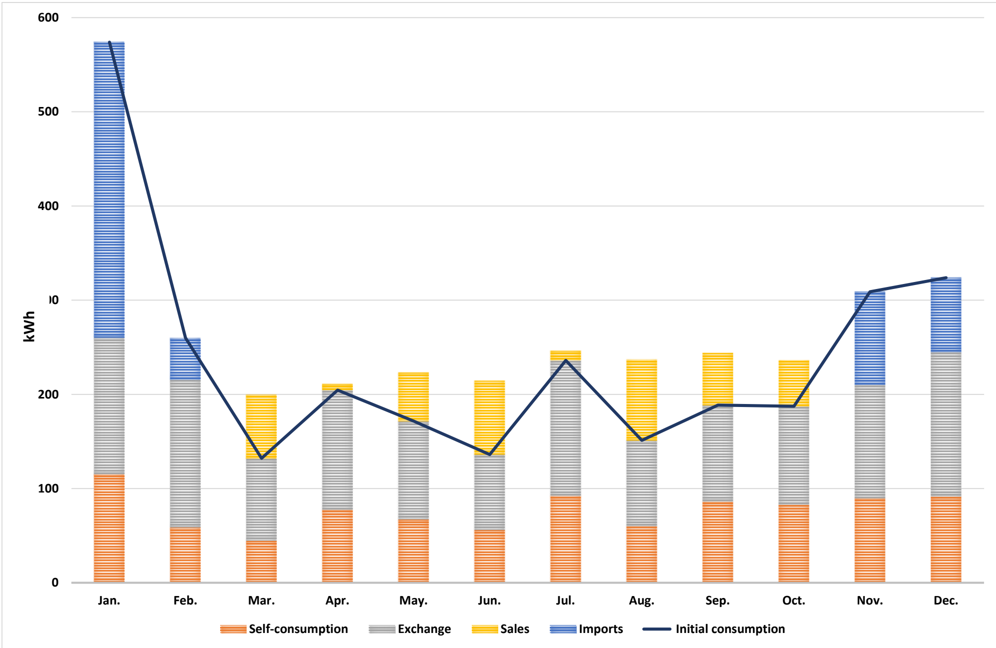

Figure 10. Monthly consumption profile and energy exchanges evolution with the PV system in Bogota.

Figure 10 shows that during winter, energy production is lower than demand, therefore, monthly bills include payment for energy imported from the grid, while during rest of year, higher production allows energy sales at end month. 95% of energy consumed is produced during the year, i.e., consumers compensate a little less than all emissions associated with their conventional energy consumption from grid. The PV installation avoids 346 kg CO_2 emissions.

For economic benefits evaluation, it is necessary to use CU, for imported and exchanged energy, the energy cost purchased on the market G, to evaluate energy sold, and the marketing cost Cv, for exchanged energy. The amount of these prices in the period August 2022 to July 2023 are shown in Table 7 [85].

Table 7. G, CU, and Cv monthly prices during analyzed period.

Month	G EUR/kWh	CU EUR/kWh	Cv EUR/kWh
August 2022	0.0501	0.1607	0.0137
September 2022	0.0528	0.1616	0.0135
October 2022	0.0609	0.1616	0.0140
November 2022	0.0618	0.1616	0.0144
December 2022	0.0562	0.1634	0.0139
January 2023	0.0631	0.1660	0.0140
February 2023	0.0681	0.1695	0.0140
March 2023	0.0807	0.1729	0.0152
April 2023	0.0645	0.1753	0.0168
May 2023	0.0596	0.1772	0.0161
June 2023	0.0832	0.1785	0.0154
July 2023	0.0752	0.1795	0.0159

Table 7 shows an annual increment by 10.4% in CU price, whereas G price increased by 33.3% and Cv price increased by 13.8%.

However, while energy generated by PV systems is always same, regardless of consumer's economic level, economic savings change depending on customer's tariff level. Table 8 shows savings obtained at each level.

Table 8. Annual residential consumer bill by economic level.

Level	1	2	3	4	5	6
Initial Cost EUR	326.7	353.1	445.4	484.9	581.9	581.9
Final Cost EUR	47.2	53.7	76.3	86	104.9	104.9
Saving %	85%	85%	83%	82%	82%	82%

Table 8 shows that in all levels, minimum savings 82% are obtained. Also in all levels, profits of EUR 29 are obtained for 404 kWh sales and EUR 20 are paid to commercial company for exchanging 1415 kWh.

5. Discussion

A summary of results obtained during study case and some indicators of interest are presented in Table 9.

Table 9. Comparative summary of case study results.

Variable	Spain	Mexico	Colombia
Tariff mechanism	Net Billing	Net Metering	Hybrid
Term Demand EUR	176	0	0
PV Generated energy kWh	3191	3024	2742
kg CO_2 savings	511	1315	346
Initial Cost EUR	606.9	238.83	326.7~581.9
Final Cost EUR	299.8	17.23	47.2~104.9
Saving EUR	307.1	221.6	279.5~477
Saving %	51%	93%	86~82%
Investment	1662	2263	2367
Number of minimum salary months to invest	1.5	7.3	9.1
Payback Years	6.5	10.2	10.2~6.0

Results clearly show that Net metering offers more benefits than Net billing, with savings over 80% in Mexico and Colombia, and only 51% in Spain. Lower savings in Spain are explained by fixed payment of demand term, 29% on final bill.

First inequality produced by DRES in Mexico and Colombia occurs because electricity market operating costs are not shared equitably, since consumers do not pay for Demand term.

Another inequity appears in Spain, because demand term paid is not related to peak demand contribution, which is unfair to all consumers, however, consumers with DRES are doubly disadvantaged because their generation used to meet system demand is not considered. In 2022, on July 14 at 2 p.m. the hourly/instantaneous peak demand occurred, moment in which residential consumers' PVs were close to maximum generation.

Another highlight is Mexico's payback period, which results in highest payback due to lowest energy costs among all three countries. Colombian consumers in levels 3 and 4 have a slightly higher payback period than a Spanish consumer; for consumers in levels 1 and 2 this period is around 10 years, only consumers in levels 5 and 6 have a shorter period. It is evident that the price of energy is a key factor in making the investment in a photovoltaic system profitable. Residential consumers with low energy consumption are "excluded" to participate in fighting climate change due to poor profitability of their DRES, an issue that is aggravated if energy prices are low, which can be identified as an environmental inequity.

Regarding investment required to purchase a photovoltaic system, Table 9 shows that PV equipment is more expensive in Mexico and Colombia, which combined with differences in monthly minimum salaries, requires a greater economic effort to purchase the PV system. Low-income consumers are excluded again from DRES benefits because they cannot acquire PV kits, which is a social inequity. Socioeconomic environment, development level, and political aspects condition the aforementioned factors.

Following, inequities and challenges to be faced are specifically detailed for each country.

5.1. Spanish Case

- Are electricity market operating costs shared with equity?

Despite generating 111% of energy consumed annually, savings percentage is lowest amongst three countries, 69% savings in energy term and 51% savings in bill. Net Billing mechanism with purchase price of exported energy considerably lower than import price limits savings. Demand term use in tariffs obliges consumers to contribute to recovering electric system operating costs, without considering support to cover demand peaks that occur in summer, which usually take place between 13:00 and 15:00 h.

With regard demand term, it is possible include another inequity issue because low-income consumers and especially extremely low-income consumers with low energy consumption, pay for network use "demand term" equal to large energy consumers, causing an important percentage of monthly bills correspond to network usage fees. In this regard, government has developed subsidies for paying consumers' bills under energy poverty conditions. In 2020, average residential consumer had 4.1 kW demand term [86], and if 26.6 M dwellings in 2022, the total contracted power amounts to 109 GW, if maximum instantaneous demand in 2023 was 39.1 GW and the historical maximum was 45.5 GW in 2007, it is appropriate rethinking definition of demand term amount.

- Does current tariff system motivate all residential consumers in similar ways?

DRES use per se excludes residential consumers in apartment buildings due space limitations for installation and additional resources for grid connection. Residential consumers with detached houses have easier to reduce carbon footprint compared to apartment dwellers. In 2011 a total 23.9 M buildings, 8.76 M exclusively for residential use. By end 2022 are 26.6 M residential dwellings, over 18 M of which are regular dwellings. From these, 7.28 M dwellings have annual consumption between 751–2000 kWh, almost 5 M dwellings between 2001 and 3000 kWh and 6.6 M dwellings with annual consumption between 3001 and 5000 kWh [87]. In 2022, 200,500 dwellings will have DRES installed [78].

The government is promoting the development Energy Communities where residential consumers who lack space for DRES installation can participate and benefit from their use economically and environmentally, unfortunately, at the end 2023 there are only 291 Energy Community projects in Spain with 67,479 kW [88].

Other studies consider that current tariff in self-consumption modality is not attractive for rural environment since payback periods are longer than 12 years [89].

Electricity price decrease in 2023 compared to 2022 reduces expected savings and prolongs investment payback period. Subsidies for DRES installation needs to be maintained in following years since they are a catalyst to increase residential installed capacity.

- Are DRES kits affordable for society overall?

PV kit prices are lowest among three countries compared, as well as minimum salary months required for their acquisition. In addition, subsidies are offered to residential consumers willing to install PV kits, varying from 15% to 40% of eligible installation costs. Spain's Gini index is 0.349, very similar to European average, while having a 20.4% Poverty headcount ratio at national poverty lines in 2021 and 3% Poverty headcount ratio at $6.85 a day in 2020.

- Is DRES environmental benefit significant for climate change mitigation?

Spanish electricity market has an important contribution from renewable energy, resulting in CO_2 electric emissions factor of 0.16 tCO_2/MWh, which results for Spanish consumers 125% CO_2 emissions of Colombian consumers and only 36% Mexican consumer's emissions, see Table 2. One additional objective of DRES promotion by Government is to achieve energy independence, to avoid price problems derived from international conflicts.

- Renewable energy use for buildings decarbonization causes inequity in consumers?

Not in terms of recovery of electricity market operating costs. Only inequity detected is related to fact that it is more complicated and costly for consumers in apartments to use DRES.

5.2. Mexican Case

- Are electricity market operating costs shared with equity?

The first major inequity arising from current tariff mechanism allows consumers with DRES not to contribute equitably to recovery electricity market operating costs, consumers without DRES subsidize them. Therefore, it is necessary to add a new element to tariff mechanism, so that consumers with DERS contribute to recover operation costs. End 2022 there were 42.14 M low energy residential consumers and 112 k DAC consumers [90], in 2019 there were 470 k DAC consumers, this reduction was caused surely by DRES and more efficient appliance use [91]. However, overall implementation of demand-side term to entire population requires a very extensive analysis because it may lead to socially unacceptable situations [52].

- Does current tariff system motivate all residential consumers in similar ways?

Energy price is low due to high subsidy from Federal Government. In 2023 subsidy amounted to EUR 3830 M [92]. In 2015 a study indicates that 40% subsidy is received by 20% highest income population [91]. In 2023 another study indicates an equity problem in subsidy distribution and system operating costs, increasing socioeconomic inequality [50].

Low and medium consumption residential consumers, 99.7% overall, are practically excluded from DRES use because of low energy costs due to the subsidy, which reduces economic benefits and extends investment payback period. Only DAC consumers find it profitable purchasing them.

Energy Communities do not exist in Mexico, which keeps inequity by excluding a vast majority consumers from contributing to fighting climate change using DRES.

- Are DRES kits affordable for society overall?

PV Kit prices in Mexico are higher than Spain's despite lower salaries. Several minimum salary months are required to purchase PV Kit in our case study, which makes it impossible for low- and medium-income consumers to buy them. Inequality in wealth distribution is high, with a Gini index of 0.454 and a 36.3% Poverty headcount ratio at national poverty lines in 2022 and a 33% Poverty headcount ratio at $6.85 a day in 2020. Only high-income consumers can afford it.

- Is DRES environmental benefit significant for climate change mitigation?

Mexican electricity market has an important fossil energy contribution with CO_2 emissions factor of 0.435 tCO_2/MWh, in our case study, the Mexican consumer produces 344% of Colombian emissions and 271% of Spanish emissions, see Table 2. Mexico ranks 11th in CO_2 emissions worldwide, Mexican per capita electricity consumption is 52% of Spanish electricity consumption, however, Mexican CO_2 emissions from electricity are 149% of Spanish emissions. Electricity consumption per capita in Mexico has grown almost constantly over last 30 years, therefore it is very important increase DRES use in order to reduce electricity emission factor.

- Renewable energy use for buildings decarbonization causes inequity in consumers?

Yes, there is great inequity in electricity market operating cost sharing. Another important inequity is that DRES use is restricted to high-income consumers due to expensive PV kits, low monthly salaries, and high investment recovery period. In addition, consumers in apartment buildings cannot participate because they do not have space for DRES installation.

5.3. Colombian Case

- Are electricity market operating costs shared with equity?

Hybrid tariff mechanism used, a mix Net Metering and Net Billing, allows consumers with DRES to make significant savings on their bills; however, is not equitable with other consumers because reduces their contribution to market operation cost recovery. Tariff structure based on economic levels is unbalanced due decreasing consumer contributions for DRES use, which increases current economic deficits in electric system operation. Subsidy to the electrical tariff in 2023 amounts EUR 470M [93].

- Does current tariff system motivate all residential consumers in similar ways?

Contributing consumers, levels 5 and 6, are strongly motivated to use PV Kit, since paying higher energy price in case study, still more expensive than in Spanish case. Consumers level 4 have a higher kWh price than Spanish consumers, therefore, they are also motivated to install DRES. Motivation of the other consumers depends on the amount of energy that exceeds CS.

Similar to Spain, consumers living in apartment buildings are affected in their willingness to make DRES use. There are 16 M dwellings, 10 M of them are detached houses and 5.2 M apartment. 78.7% of dwellings have residential use [94]. By 2023 end, Government has launched Energy Communities operation to increase and facilitate DRES use [95].

Economic level allocation system is not entirely efficient by not included economic income of households' residents, resulting incorrect subsidy allocations [96].

- Are DRES kits affordable for society overall?

Colombia has highest PV Kit prices among three countries, while it has lowest minimum salary among three countries. Several months of minimum salary are required to purchase PV Kit in our case study, making it impossible for low and medium-income consumers buy them. Inequality in wealth distribution is high, with a Gini index of 0.535 and 39.3% Poverty headcount ratio at national poverty lines in 2022 and 39% Poverty headcount ratio at $6.85 per day in 2021. Only high-income consumers can afford it.

- Is DRES environmental benefit significant for climate change mitigation?

Colombian electricity market has an important contribution of renewable energy having CO_2 emissions factor 0.1263 tCO_2/MWh, in our case study a Colombian consumer generates 29% of a Mexican consumer's emissions and 79% of a Spanish consumer's emissions. Colombia produces 0.3% of global CO_2 emissions, one third of Spain's CO_2 emissions per capita and half of Mexico's. Colombia's electricity system must face challenges to cover energy demand in coming years [47], PV distributed generation deployment can help mitigate economic impact on residential consumers, but it is necessary provide financial instruments to make it possible [97] since high PV kit costs make it impossible for low and medium-income consumers contribute to fight against climate change.

- Renewable energy use for buildings decarbonization causes inequity in consumers?

Yes, inequity can be seen in electricity market operating costs. Energy prices are also inequitable since energy prices do not depend on the consumer's income level. Another inequity is DRES use limitation to high-income consumers due to high PV kit prices, low monthly salary, and longer investment recovery period.

During the research, a series of results were obtained that contain elements of scientific novelty:

1. The only use of electricity market technical variables is clearly insufficient to evaluate DRES use equity; social, economic, and environmental variables are necessary for a complete evaluation of building decarbonization strategies. Holistic view can increase DRES use and serve to reduce social and economic inequity that affects vulnerable consumers.
2. The first observed inequity is that small and medium consumers in Mexico and Colombia are discriminated in fighting climate change using DRES since it requires a

considerable economic effort due to high PV kit costs compared to existing salaries, a situation that is aggravated by inequitable income distribution in these countries.

3. Another constraint for DRES use for low and medium-income consumers is the lack of potential locations to install it. In Spain, the majority of the population lives in apartment buildings, a situation that excludes them from DRES direct use; a comparable situation occurs in larger Mexican and Colombian cities.
4. The DRES tariff mechanisms applied in Mexico and Colombia are inequitable. Firstly, because they only stimulate the participation of large energy consumers with high economic incomes. And secondly, because they absolve such consumers to contribute to electric market operation costs recovery, increasing economic pressure on consumers with low economic incomes. This inequity can be compensated through the application of the demand term; however, this new tariff term must be carefully designed to avoid increasing inequity in operation costs distribution, damaging consumers with low consumption and low incomes. In Spain, it is necessary to analyze the demand term design, since it is unrelated to system concurrent demand, and it negatively affects consumers with low consumption or energy poverty situation since this term can represent a significant amount of bill.

6. Conclusions

This study has analyzed the mechanisms of integration of distributed renewable energy systems (DRES) in homes applied in Spain (Net Billing), Mexico (Net Metering) and Colombia (Hybrid). This article has developed holistic analysis of DERS use in society, beyond electric system technical variables used to evaluate only equity to recover system operating costs. We believe that social complexity must be included in analysis in order to achieve more DRES use and reduce current inequities in the possibility of their use and contribution to fight against climate change. Our analysis has been conducted using different societies and electricity markets, indicating its applicability to any electricity market regardless of its technical, economic, social, and environmental characteristics.

DRES use as a strategy for decarbonization of buildings is inequitable if tariff mechanism is only volumetric, kWh, demand term use decreases this inequity. Social-economic participation is inequitable if PV kit costs involve high minimum salaries, extraordinarily long payback periods, or if installation is not possible. In terms environmental benefits, global benefits are greater in those countries with higher CO_2 emission factors.

In three countries, decarbonization impact on housing resulting from a 2 kW Photovoltaic Installation (PV) is evaluated, while renewable generation are similar in each of three cities study case, around 3000 kWh, avoided CO_2 emissions are very different because each country has a different electric CO_2 emissions factor. In Mexico CO_2 reduction is almost 4 times the Colombian reduction, and 2.5 times the Spanish reduction.

Economic profits for consumers are higher in countries with Net Metering and Hybrid mechanisms, Mexico, and Colombia. Energy savings percentage decreases due to Net Billing and Spain's bill decreases less due to Demand Term inclusion.

Barriers to DRES implementation in Mexico and Colombia are observed with regard purchase of PV equipment, and PV equipment sales are less competitive. In addition, lower salaries force homeowners who wish to reduce their environmental impact make greater economic efforts. A more global vision in the case study shows that CO_2 footprint is not only related to society's energy intensity; Spain, with twice per capita electricity consumption compared to Mexico, has a 30% lower CO_2 footprint. If electricity consumption grows in Colombia and Mexico, it is interesting to promote DRES in Mexico, since electricity in Mexico has a CO_2 emissions factor 340% higher than Colombia.

Potentially interested consumers in decarbonizing homes are consumers with high energy bills due either high energy consumption or energy prices, who are economically able to make investments. In the case of the Mexican and Colombian markets, DRES installation reduces or eliminates their contribution to less favored consumers. In Mexico's case, these consumers benefit the subsidy by consuming cheaper energy from the grid. In

Mexico and Colombia, equity problems are observed, since larger and richer consumers are not paying adequately for grid reliability.

In the case of Spain, demand terms oblige residential consumers to contribute to cover electric system operating costs. In the case of Colombia and Mexico, it is necessary to modify tariffs for large consumers who have grid support; however, the political, economic, and social situation makes its development and implementation difficult.

For decarbonizing homes with small and medium energy consumption, programs to finance the implementation of DRES need to be developed. In addition to financing, it will be necessary to update DRES participation mechanisms to achieve equity in sharing electric system operation costs. A proper decarbonization strategy for buildings using DRES must involve all consumers actively, as well as contribute to social and economic development of underprivileged consumers.

Future research on the topic of this article may involve the development of a quantitative evaluation methodology to analyze equity levels in the DRES use in electricity markets and provide guidelines to improve equity in its use, also, it is recommendable to analyze energy commercialization mechanisms in Energy Communities considering equity among members.

Author Contributions: I.V.-S., E.P.-L., V.L.-M. and J.M.-R., Conceptualization, I.V.-S. and E.P.-L.; Funding acquisition, E.P.-L.; Methodology, E.P.-L., V.L.-M. and J.M.-R.; Software, I.V.-S.; Validation, I.V.-S., V.L.-M. and J.M.-R.; Writing—original draft, I.V.-S. and E.P.-L.; Writing—review & editing, I.V.-S., E.P.-L., V.L.-M. and J.M.-R. All authors have read and agreed to the published version of the manuscript.

Funding: This research and APC was funded by the Generalitat Valenciana within the ValREM Project (CIAICO/2022/007).

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

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

References

1. International Energy Agency. *World Energy Outlook 2022*; IEA Publications: Paris, France, 2022.
2. International Energy Agency. *There's More to Buildings than Meets the Eye: They Hold a Key to Net Zero Emissions*; IEA Publications: Paris, France, 2023.
3. International Energy Agency. *Efficient Grid-Interactive Buildings. Future of Buildings in ASEAN*; IEA Publications: Paris, France, 2023.
4. Ansarin, M.; Ghiassi-Farrokhfal, Y.; Ketter, W.; Collins, J. A review of equity in electricity tariffs in the renewable energy era. *Renew. Sustain. Energy Rev.* **2022**, *161*, 112333. [CrossRef]
5. Organisation for Economic Cooperation and Development; International Energy Agency. *Electricity Market Reform an IEA Handbook*; IEA Publications: Paris, France, 1999.
6. U.S. Department of Energy. DOE_Benefits_of_Demand_Response_in_Electricity_Markets_and_Recommendations_for_Achieving. February 2016; [En Línea]. Available online: https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE_Benefits_of_Demand_Response_in_Electricity_Markets_and_Recommendations_for_Achieving_Them_Report_to_Congress.pdf (accessed on 2 November 2023).
7. Hunt, S. *Making Competition Work in Electricity*; John Wiley & Sons: Hoboken, NJ, USA, 2002.
8. International Renewable Energy Agency (IRENA). *Innovation Landscape Brief: Time-of-Use Tariffs*; IRENA: Masdar City, United Arab Emirates, 2019.
9. Iberdrola Clientes, S.A.U. Iberdrola Hogar y Luz. Available online: https://www.iberdrola.es/luz/plan-estable-100 (accessed on 6 November 2022).
10. Endesa Energía, Endesa S.A. Tarifa Plana de Luz y Gas. Available online: https://www.endesa.com/es/unica/tarifa-plana-luz-gas (accessed on 6 November 2022).
11. Comisión Federal de Electricidad, Esquema Tarifario Vigente. 2023. Available online: https://app.cfe.mx/Aplicaciones/CCFE/Tarifas/TarifasCRECasa/Casa.aspx (accessed on 6 November 2023).
12. Ministerio Para la Transición Ecológica y el Reto Demográfico, Contratación y SuministroPrecio Voluntario Para el Pequeño Consumidor. 2023. Available online: https://energia.gob.es/electricidad/contratacion-suministro/Paginas/precio-voluntario.aspx (accessed on 6 November 2023).
13. Iberdrola Clientes, S.A.U. Plan Tres Periodos. 6 November 2022. Available online: https://www.iberdrola.es/luz/plan-tres-periodos (accessed on 6 November 2023).

14. OGE Energy Corp. Pricing Options SmartHours. 2023. Available online: https://www.oge.com/wps/portal/ord/residential/pricing-options/smart-hours/!ut/p/z1/lZDNDoIwEISfhSfo0NaKxxqQVk1KjRTsxXAiJIoejM9vryD-sLdNvtnZGeJJTXzfPLu2eXS3vrmE_eTFmapUqG0Ok5gDh13HjG5SxYyOSTUEjJMZLOPJstgfAQjiZ-lzu1sEPTLpOGcA-0-PDyMx0_8d8N_PV8SPLJxMQwIhjF4 (accessed on 6 November 2023).
15. EDF Particuliers. EDF Particulier OPTION TEMPO. 2023. Available online: https://particulier.edf.fr/fr/accueil/gestion-contrat/options/tempo/details.htmlEDFParticuliers (accessed on 6 November 2023).
16. Bigerna, S.; Bollino, C.A. Ramsey prices in the Italian electricity market. *Energy Policy* **2016**, *88*, 603–612. [CrossRef]
17. Ministerio Para la Transición Ecológica y el Reto Demográfico. Available online: https://www.fide.es/wp-content/uploads/2020/07/Texto-del-Proyecto-de-Real-Decreto-1.pdf (accessed on 6 November 2023).
18. SaskPower. Power Supply Rates—Residential. 2023. Available online: https://www.saskpower.com/Accounts/Power-Rates/Power-Supply-Rates (accessed on 11 November 2023).
19. Poullikkas, A.; Kourtis, G.; Hadjipaschalis, I. A review of net metering mechanism for electricity renewable energy sources. *Int. J. Energy Environ.* **2023**, *4*, 975–1002.
20. Smith, K.M.; Koski, C.; Siddiki, S. Regulating net metering in the United States: A landscape overview of states' net metering policies and outcomes. *Electr. J.* **2021**, *34*, 106901. [CrossRef]
21. Soto, E.A.; Bosman, L.B.; Wollega, E.; Leon-Salas, W.D. Peer-to-peer energy trading: A review of the literature. *Appl. Energy* **2021**, *283*, 116268. [CrossRef]
22. N.C. Clean Energy Technology Center at N.C. State University. Database of State Incentives for Renewables & Efficiency USA. 2023. Available online: https://www.dsireusa.org/ (accessed on 10 November 2023).
23. Dufo-López, R.; Bernal-Agustín, J.L. A comparative assessment of net metering and net billing policies. Study cases for Spain. *Energy* **2015**, *84*, 684–694. [CrossRef]
24. Koumparou, I.; Christoforidis, G.C.; Efthymiou, V.; Papagiannis, G.K.; Georghiou, G.E. Configuring residential PV net-metering policies—A focus on the Mediterranean region. *Renew. Energy* **2017**, *112*, 795–812. [CrossRef]
25. International Centre for Settlement of Investment Disputes. Portigon AG v. Kingdom of Spain (ICSID Case No. ARB/17/15). 19 April 2023. Available online: https://icsid.worldbank.org/cases/case-database/case-detail?CaseNo=ARB/17/15 (accessed on 11 November 2023).
26. Global Private Capital. The Portigon v. Spain Decision: Upholding International Law Protections for Financial Instruments. Available online: https://www.globalprivatecapital.org/app/uploads/2021/06/The-Portigon-v.-Spain-Decision.pdf (accessed on 11 November 2023).
27. Think GeoEnergy. Geothermal to Keep FIT in Japan, While Auction System is Introduced for Solar and Wind, 9 8 2019. Available online: https://www.thinkgeoenergy.com/geothermal-to-keep-fit-in-japan-while-auction-system-is-introduced-for-solar-and-wind/ (accessed on 11 November 2023).
28. Ren21. *Renewables 2020 Global Status Report*; REN21 Secretariat: Paris, France, 2020.
29. Athawale, R.; Felder, F. *Chapter 10—Residential Rate Design and Death Spiral for Electric Utilities: Efficiency and Equity Considerations, de Future of Utilities Utilities of the Future*; Academic Press: Cambridge, MA, USA, 2016; pp. 193–209.
30. Felder, F.A.; Athawale, R. The Life and Death of the Utility Death Spiral. *Electr. J.* **2014**, *27*, 9–16. [CrossRef]
31. Guo, B.; Weeks, M. Dynamic tariffs, demand response, and regulation in retail electricity markets. *Energy Econ.* **2022**, *106*, 105774. [CrossRef]
32. Satchwell, A.; Cappers, P.; Goldman, C. Customer bill impacts of energy efficiency and net-metered photovoltaic system investments. *Util. Policy* **2018**, *50*, 144–152. [CrossRef]
33. Clastres, C.; Percebois, J.; Rebenaque, O.; Solier, B. Cross subsidies across electricity network users from renewable self-consumption. *Util. Policy* **2019**, *59*, 100925. [CrossRef]
34. Picciariello, A.; Vergara, C.; Reneses, J.; Frías, P.; Söder, L. Electricity distribution tariffs and distributed generation: Quantifying cross-subsidies from consumers to prosumers. *Util. Policy* **2015**, *37*, 23–33. [CrossRef]
35. Blank, L.; Gegax, D. Do residential net metering customers pay their fair share of electricity costs? Evidence from New Mexico utilities. *Util. Policy* **2019**, *61*, 100973. [CrossRef]
36. Cohen, R.; Khermouch, G. The Giant Headache That Is Net Energy Metering. *Electr. J.* **2013**, *26*, 6.
37. Hledik, R. Rediscovering Residential Demand Charges. *Electr. J.* **2014**, *27*, 82–96. [CrossRef]
38. Gagnon, P.; Sigrin, B.; Gleason, M. *The Impacts of Changes to Nevada's Net Metering Policy on the Financial Performance and Adoption of Distributed Photovoltaics*; National Renewable Energy Laboratory: Denver, CO, USA, 2017.
39. DSIRE Insight. DSIRE Insight Status of State Net Metering Reforms. 25 May 2021. Available online: https://www.dsireinsight.com/blog/2021/5/25/status-of-state-net-metering-reforms (accessed on 14 November 2023).
40. CBC. Solar Companies Face Uncertain Future after Cancellation of Net Metering Program. 21 September 2019. Available online: https://www.cbc.ca/news/canada/saskatchewan/solar-net-metering-program-saskatchewan-1.5291359 (accessed on 11 November 2023).
41. SaskPower. Net Metering after November 2019 (saskpower.com). 2023. Available online: https://www.saskpower.com/Accounts/Billing/Your-Power-Bill/How-to-Read-Your-Bill/Net-Metering-After-November-2019 (accessed on 14 November 2023).
42. SaskPower. Net Metering before November 2019 SaskPower. 2023. Available online: https://www.saskpower.com/Accounts/Billing/Your-Power-Bill/How-to-Read-Your-Bill/Net-Metering-Before-November-2019 (accessed on 11 November 2023).

43. Passey, R.; Haghdadi, N.; Bruce, A.; MacGill, I. Designing more cost reflective electricity network tariffs with demand charges. *Energy Policy* **2017**, *109*, 642–649. [CrossRef]
44. Haro, S.; Aragonés, V.; Martínez, M.; Moreda, E.; Morata, A.; Arbós, E.; Barquín, J. *Chapter 12—Toward Dynamic Network Tariffs: A Proposal for Spain, de Innovation and Disruption at the Grid's Edge*; Academic Press: Cambridge, MA, USA, 2017; pp. 221–239.
45. Dameto, N.M.; Chaves-Ávila, J.; Román, T.G.S. Revisiting Electricity Network Tariffs in a Context of Decarbonization, Digitalization, and Decentralization. *Energies* **2020**, *13*, 3111. [CrossRef]
46. Ordóñez, Á.; Sánchez, E.; Rozas, L.; García, R.; Parra-Domínguez, J. Net-metering and net-billing in photovoltaic self-consumption: The cases of Ecuador and Spain. *Sustain. Energy Technol. Assess.* **2022**, *53*, 102434. [CrossRef]
47. Asociación Nacional de Empresas Generadoras. Desde 2025, Colombia Tendría Déficit en Oferta de Energía. 2023. [En línea]. Available online: https://www.andeg.org/2022/04/04/desde-2025-colombia-tendria-deficit-en-oferta-de-energia/ (accessed on 12 November 2023).
48. Guzman, L.; Henao, A. Are the current incentives sufficient to drive the use of solar PV in the Colombian residential sector?—An analysis from the perspective of the game theory. *Energy Strategy Rev.* **2022**, *40*, 100816. [CrossRef]
49. Osorio-Aravena, J.C.; de la Casa, J.; Töfflinger, J.A.; Muñoz-Cerón, E. Identifying barriers and opportunities in the deployment of the residential photovoltaic prosumer segment in Chile. *Sustain. Cities Soc.* **2021**, *69*, 102824. [CrossRef]
50. Chueca, E.; Weiss, M.; Celaya, R.; Ravillard, P.; Ortega, B.; Tolmasquim, M.T.; Hallack, M. Early adopters of residential solar PV distributed generation: Evidence from Brazil, Chile and Mexico. *Energy Sustain. Dev.* **2023**, *76*, 101284. [CrossRef]
51. Grande, G.; Islas, J.; Rios, M. Technical and economic analysis of Domestic High Consumption Tariff niche market for photovoltaic systems in the Mexican household sector. *Renew. Sustain. Energy Rev.* **2015**, *48*, 738–748. [CrossRef]
52. Hancevic, P.I.; Nuñez, H.M.; Rosellón, J. Electricity Tariff Rebalancing in Emerging Countries: The Efficiency-equity Tradeoff and Its Impact on Photovoltaic Distributed Generation. *Energy J.* **2022**, *43*, 1–2. [CrossRef]
53. Grupo Banco Mundial. Banco Mundial Datos Población 2022. 2023. Available online: https://datos.bancomundial.org/indicador/SP.POP.TOTL (accessed on 13 November 2023).
54. International Energy Agency. International Energy Agency Countries and Regions. 2023. Available online: https://www.iea.org/countries (accessed on 13 November 2023).
55. Red Eléctrica de España. Emisiones y Factor de Emisión de CO_2 EQ. DE LA GENERACIÓN. 2023. Available online: https://www.ree.es/es/datos/generacion/no-renovables-detalle-emisiones-CO2 (accessed on 1 April 2023).
56. Secretaría de Medio Amniente y Recursos Naturales. Factor de Emisión del Sistema Eléctrico Nacional 2022. Available online: https://www.gob.mx/cms/uploads/attachment/file/807500/aviso_fesen_2022.pdf (accessed on 1 April 2023).
57. XM, 20 1 2022. [En Línea]. Available online: https://www.xm.com.co/noticias/4591-factor-emision-matriz-energetica-2021 (accessed on 15 August 2023).
58. World Bank Group, World Bank DataBank 2023. Available online: https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=MX (accessed on 15 November 2023).
59. Ministerio de Trabajo y Economía Social, Noticias Servicio Público de Empleo Estatal. 2023. Available online: https://www.sepe.es/HomeSepe/que-es-el-sepe/comunicacion-institucional/noticias/detalle-noticia.html?folder=/2023/Febrero/&detail=El-salario-minimo-interprofesional-publicado-para-2023-se-establece-en-1080-euros (accessed on 15 November 2023).
60. Secretaría del Trabajo y Previsión Social, SALARIOS MÍNIMOS 2023, 1 12 2022. Available online: https://www.gob.mx/cms/uploads/attachment/file/781941/Tabla_de_Salarios_M_nimos_2023.pdf (accessed on 13 November 2023).
61. Ministerio del Trabajo. Ministerio del Trabajo Prensa. 15 December 2022. Available online: https://www.mintrabajo.gov.co/prensa/comunicados/2022/diciembre/-1.160.000-ser%C3%A1-el-salario-minimo-para-2023-y-auxilio-de-transporte-por-140.606 (accessed on 11 November 2023).
62. Autosolar Energy Solutions SLU. Kit Solar Residencial. 2023. Available online: https://autosolar.es/kits-solares-conexion-red/kit-solar-residencial-2500w-12500whdia-growatt (accessed on 15 November 2023).
63. STAE Sociedad de Renta Libre de Capital Variable. Kit Interconexión a Red CFE 2.75 kW. 2023. Available online: https://www.tiendasolar.mx/kits-cfe/kit-interconexion-a-red-cfe-2-75kw-genera-en-promedio-825kw-al-bimestre-43-detail.html (accessed on 15 November 2023).
64. Autosolar Energía de Colombia S.A.S. Kit Solar Red. 2023. Available online: https://autosolar.co/kits-solares-red/kit-solar-ongrid-2500w-10200whdia-growatt (accessed on 15 November 2023).
65. Red Eléctrica de España. Red Eléctrica de España. 2023. Available online: https://www.ree.es/es (accessed on 1 April 2023).
66. Comisión Nacional de los Mercados y la Competencia. Listado de Comercializadoras de Electricidad. Available online: https://sede.cnmc.gob.es/listado/censo/2 (accessed on 1 April 2023).
67. Comisión Federal de Electricidad. Comisión Federal de Electricidad. 2023. Available online: https://www.cfe.mx/Pages/default.aspx (accessed on 1 April 2023).
68. Secretaría de Hacienda y Crédito Público. México, Oficio SHCP 349-B-1-204 TFSB Domésticas y Factor de Ajuste 2023. 9 December 2022. Available online: https://app.cfe.mx/Aplicaciones/CCFE/Tarifas/TarifasCRECasa/Acuerdos/AcuerdosCasa.aspx (accessed on 1 April 2023).
69. Comisión Federal de Electricidad. Tarifas 2023 DAC. Available online: https://app.cfe.mx/Aplicaciones/CCFE/Tarifas/TarifasCRECasa/Tarifas/TarifaDAC.aspx (accessed on 1 April 2023).

70. Comisión de Regulación de Energía y Gas—CREG Colombia, Comisión de Regulación de Energía y Gas—Colombia. Estructura del Sector; 23 January 2023. Available online: https://creg.gov.co/publicaciones/7819/estructura-del-sector/ (accessed on 14 August 2023).
71. Comisión de Regulación de Energía y Gas—CREG Colombia, CREG. Directorio de Empresas. Available online: https://creg.gov.co/publicaciones/12562/directorio-de-empresas/ (accessed on 14 August 2023).
72. CREG. Comisión Reguladora de Energía y Gas, Comisión Reguladora de Energía y Gas. 21 December 2007. Available online: http://apolo.creg.gov.co/Publicac.nsf/Indice01/Resolucion-2007-Creg119-2007 (accessed on 16 August 2023).
73. Función Pública Departamento Administrativo de la Función Pública Colombia, Ley 142 de 1994. 11 July 1994. Available online: https://www.funcionpublica.gov.co/eva/gestornormativo/norma_pdf.php?i=2752 (accessed on 15 August 2023).
74. Dirección Técnica de Gestión de Energía Superintendencia Delegada Para Energía y Gas Combustible, Boletín Tarifario. 1 April 2022. Available online: https://www.superservicios.gov.co/sites/default/files/2022-10/Bolet%C3%ADnTarifarioEnerg%C3%ADaTrimestre12022VF.pdf (accessed on 15 August 2023).
75. Ministerio de Minas y Energía. Colombia, Resolución 355 de 2004. 8 July 2004. Available online: https://www.alcaldiabogota.gov.co/sisjur/normas/Norma1.jsp?i=14315#:~:text=RESOLUCI%C3%93N%20355%20DE%202004%20(Julio%2008)%20Por%20la,en%20concordancia%20con%20el%20Decreto%20255%20de%202004, (accessed on 14 August 2023).
76. Agencia Estatal Boletín Oficial del Estado, Real Decreto 900/2015. 9 October 2015. Available online: https://www.boe.es/eli/es/rd/2015/10/09/900 (accessed on 1 April 2023).
77. Agencia Estatal Boletín Oficial del Estado. Real Decreto 244/2019 Condiciones Autoconsumo de Energía Eléctrica. 5 April 2015. Available online: https://www.boe.es/diario_boe/txt.php?id=BOE-A-2019-5089#:~:text=Real%20Decreto%20244/2019,%20de%205%20de%20abril,%20por,t%C3%A9cnicas%20y%20econ%C3%B3micas%20del%20autoconsumo%20de%20energ%C3%ADa%20el%C3%A9ctrica (accessed on 1 April 2023).
78. Unión Española Fotovoltaica. El autoconsumo Fotovoltaico Instalado en España Creció un 108% Respecto a 2021. 23 January 2023. Available online: https://www.unef.es/es/comunicacion/comunicacion-post/el-autoconsumo-fotovoltaico-instalado-en-espana-crecio-un-108-respecto-a-2021 (accessed on 1 April 2023).
79. Autoconsumo de Energía. Available online: https://energia.gob.es/electricidad/autoconsumo-electrico/Paginas/preguntas-frecuentes-autoconsumo.aspx (accessed on 1 April 2023).
80. Instituto para la Diversificación y Ahorro de la Energía. Comunidades Energéticas. Available online: https://www.idae.es/ayudas-y-financiacion/comunidades-energeticas (accessed on 1 April 2023).
81. Comisión Federal de Electricidad, Contrato de Interconexión para Hogar. Available online: https://www.cfe.mx/hogar/nuevocontrato/pages/contratacion_interconexion_hogar.aspx (accessed on 1 April 2023).
82. Comisión Reguladora de Energía. Resolución de la Comisión Reguladora de Energía Sobre Contratos de Generación Distribuida. 7 March 2017. Available online: https://dof.gob.mx/nota_detalle.php?codigo=5474790&fecha=07/03/2017#gsc.tab=0 (accessed on 1 April 2023).
83. Comisión de Regulación de Energía y Gas—CREG Colombia, Resolución No. 30 de 2018. Regulación de Actividades de Autogeneración a Pequeña Escala y Generación Distribuida en el SNI; 26 February 2018. Available online: https://creg.gov.co/public_html/info/creg/media/tmp/pdf99888.pdf (accessed on 14 August 2023).
84. Topographic-map.com, Mapa topográfico Bogotá. Available online: https://es-co.topographic-map.com/map-lvxcz/Bogot%C3%A1/?center=4.60315,-74.06258&zoom=15&popup=4.60003,-74.06665 (accessed on 16 August 2023).
85. Superservicios, Superintendencia de Servicios Públicos Domiciliarios, Información tarifaria del Servicio Público de Energía Eléctrica Para el Comercializador Integrado al Operador de Red JULIO 2023, 7 2023. Available online: https://www.superservicios.gov.co/ (accessed on 29 August 2023).
86. Comisión Nacional de los Mercados y la Competencia, Promoción de Competencia, Energía. 4 December 2020. Available online: https://www.cnmc.es/prensa/cnmc-panel-energ%C3%ADa-20201204 (accessed on 29 August 2023).
87. Instituto Nacional de Estadística, Censos de Población y Viviendas 2011. 2021. Available online: https://www.ine.es/jaxi/Datos.htm?path=/t20/e244/edificios/p02/&file=00007.px (accessed on 12 November 2023).
88. Instituto para la Diversificación y Ahorro de la Energía, Visor de Comunidades Energéticas. Available online: https://informesweb.idae.es/visorccee/ (accessed on 29 August 2023).
89. Dasí-Crespo, D.; Roldán-Blay, C.; Escrivá-Escrivá, G.; Roldán-Porta, C. Evaluation of the Spanish regulation on self-consumption photovoltaic installations. A case study based on a rural municipality in Spain. *Renew. Energy* **2023**, *204*, 788–802. [CrossRef]
90. Comisión Federal de Electricidad, Informe Anual 2022, Comisión Federal de Electricidad, 2023. 27 April 2023. Available online: https://www.cfe.mx/finanzas/reportes-financieros/Informe%20Anual%20Documentos/Informe%20Anual%20Portal.pdf (accessed on 29 August 2023).
91. Hernandez, M.; Patino-Echeverri, D. Electricity consumption, subsidies, and policy inequalities in Mexico: Data from 100,000 households. *Energy Sustain. Dev.* **2022**, *71*, 186–199. [CrossRef]
92. el Lun, A.A. Energy21. Subsidio Eléctrico Costará más que Programas Sociales Insignia en 2023. 19 September 2022. Available online: https://energy21.com.mx/electricidad/2022/09/19/subsidio-electrico-costara-mas-que-programas-sociales-insignia-en-2023 (accessed on 2 November 2023).

93. La República. Existe un Déficit de $4,4 Billones en Presupuesto de 2023 para Subsidios de Luz y Gas. 1 September 2022. Available online: https://www.larepublica.co/economia/faltan-4-4-billones-en-presupuesto-de-2023-para-subsidios-de-luz-y-gas-dicen-gremios-3437801#:~:text=Los%20gremios%20del%20sector%20el%C3%A9ctrico%20le%20advirtieron%20al,pr%C3%B3ximo%20a%C3%B1o%20le%20faltar%C3%ADan%20 (accessed on 21 November 2023).
94. Departamento Administrativo Nacional de Estadística. Geoportal DANE. 2023. Available online: https://geoportal.dane.gov.co/geovisores/sociedad/cnpv-2018/?lt=4.456007353293281&lg=-73.2781601239999&z=5 (accessed on 11 November 2023).
95. Ministerio de Minas y Energía, Comunidades Energéticas. 22 December 2023; [En Línea]. Available online: https://www.minenergia.gov.co/es/comunidades-energeticas/ (accessed on 29 August 2023).
96. Peña, M. Gobierno les Quitaría Subsidios de las Facturas de luz en 2023 a Quienes no los Necesitan. 20 September 2022. Available online: https://www.bluradio.com/nacion/gobierno-les-quitaria-subsidios-de-las-facturas-de-luz-en-2023-a-quienes-no-los-necesitan-rg10 (accessed on 12 November 2023).
97. ALópez, R.; Krumm, A.; Schattenhofer, L.; Burandt, T.; Montoya, F.C.; Oberländer, N.; Oei, P.-Y. Solar PV generation in Colombia—A qualitative and quantitative approach to analyze the potential of solar energy market. *Renew. Energy* **2020**, *148*, 1266–1279.