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Net-metering and net-billing in photovoltaic self-consumption: The cases of Ecuador and Spain

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ABSTRACT

Solar Photovoltaics has become one of the cheapest sources of electricity, with the potential to expand further through distributed generation. PV self-consumption can empower electricity customers, transforming them into prosumers, but its success relies on appropriate regulations, especially in the treatment of surplus electricity, being net-metering and net-billing the most common remuneration mechanisms. As the number of such PV systems increases, regulation needs to evolve and may affect profitability.

The purpose of this research is to take advantage of the Spanish experience, establishing key points that can improve the regulation in Ecuador and other countries. The operation of these remuneration schemes is studied through an economic analysis for a wide range of residential customers, highlighting the low profitability of small PV installations, which are not profitable for the average consumer in Ecuador. Grid parity is reached in Spain over 3 kW and in Ecuador only for the highest electricity consumers. Although the net-billing model is more effective in promoting PV self-consumption in the medium and long term, it requires additional conditions, such as those in Spain. Some recommendations are proposed, e.g. additional support with progressive tax reductions, simplication of permits and the introduction of collective self-consumption.

Introduction

Solar photovoltaic (PV) has become one of the cheapest electricity sources in countries with good solar resources [1]. The self-consumption of PV electricity (PVSC) allows to partly satisfy the users' electricity demand in a more active way, as well as providing a more environmentally friendly generation, avoiding greenhouse emissions. The increase of PVSC allows prosumers to become involved in energy transition, with greater competition in electricity generation [2]. The benefits of PVSC are included in the Sustainable Development Goals of the United Nations Development Program. Specifically, Goal 7 “Affordable and clean energy” states that investment in energy sources such as solar energy is vital to achieve this. Goal 11, “Sustainable Cities and Communities”, also has clear benefits from using a locally produced energy source, which helps community resilience. The use of a renewable energy source such as solar energy, replacing the consumption of fossil energy sources, is also a pillar of Goal 13, “Climate action”. Good conditions for self-consumption are being achieved in many countries, but the success of PVSC depends on fair regulations that allow for a proper design and implementation.

Because of reaching grid parity [3], the self-consumption of PV-produced electricity is gaining attention in most countries [4]. An extensive review of research on PV self-consumption in residential systems is summarized in [5], where self-consumption, self-sufficiency and other metrics as well as the framework of grid interaction and load matching are defined. The traditional definition of SC is referred to the PV electricity consumed within a 15-minute timeframe [6]. This definition is not the best for many consumers who are also producers, so-called prosumers, such as the residential sector, due to the mismatch of production and consumption. The economic compensation of the surplus energy fed into the grid is difficult and there are different support policies, being net-metering and net-billing the most important [7].

At a global level, prosumers are expected to represent a significant part of PV installed capacity [8]. This fact is driving a shift from Feed in Tariff (FIT) support policies to net-metering and net-billing schemes [9,10]. In these regulated arrangements, the surplus electricity fed into the grid is rewarded with credits that can be applied to offset consumption. Under net-metering, the credit is at the level of retail electricity price. In net-billing, the credit is at a lower level, in many cases around the wholesale electricity price. In recent years, a large number of residential, small-scale commercial and industrial installations have

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Nomenclature

Symbols

A	Avoided costs, (€)
C	Compensated costs, (€)
E_{cons}	Energy consumption, (kWh)
E_{in}	Imported energy, (kWh)
E_{PV}	PV-produced energy, (kWh)
E_{sc}	Self-consumed energy, (kWh)
E_{srpl}	Surplus energy, (kWh)
S	Saved costs, (€)
$R^{1..24}$	Rolling credit, (kWh)
Pr	Price of electricity, (€)

Abbreviations

DSM	Demand Shift Management
FiT	Feed in Tariff
HVAC	Heating, Ventilation and Air Conditioning
IRR	Internal Rate of Return
LCOE	Levelized Cost of Energy
NPV	Net Present Value
OTC	Over The Counter (market)
PVGIS	Photovoltaic Geographical Information System
PVPC	Voluntary Price for Small Consumers
PVSC	Photovoltaic Self-Consumption
RD	Royal Decree
REE	Red Eléctrica de España
RES	Renewable Energy Sources
SC	Self-Consumption
SPV	Photovoltaic System
TROI	Time of Return of Investment

benefited from net-metering or net-billing policies. By 2019, more than 70 countries were incorporating these policies as a means of compensating homeowners who feed their surplus electricity into the distribution grid [11]. But on the other hand, there have also been several setbacks and cancellations in the application of the net-metering policy. For example, several states and provinces of India, Canada and the United States have cancelled or modified the application of the net-metering regulations. In particular, a retrospective study conducted by the California Public Utilities Commission established that the net-metering regulation in place since 2016, called NEM 2.0, was profitable only for participants, but not for ratepayers. Moreover, it was concluded that this regulation causes an increase in the bills of non-participants, and that the participants do not suffer this increase thanks to their generation with the application of the compensation law [12].

Therefore, the net-metering/net-billing landscape is diverse and evolves following the rising number of PVSC installations. The present study aims to conduct an analysis on these photovoltaic self-consumption remuneration schemes, being based on two countries representative of different geographical and economic areas: Ecuador and Spain. These countries are appropriate case studies for this research because of the following differences. Type of electricity source: hydroelectricity in Ecuador, high dependence on gas in Spain. Structure of the electricity sector: public companies in Ecuador and liberalised in Spain. Structure of retail tariff by consumption bands in Ecuador, and TOU in Spain. Moreover, PV experience is recent in Ecuador and long-term in Spain, resulting in large differences in critical mass of the sector, supply chain and public and professional awareness.

In the case of South America, the operation of self-consumption systems presents similar problems to those found in Ecuador. This means that the potential of prosumers is under-exploited [13]. A clear example of this is Chile, which in recent years has gained great prestige for the installation of large solar plants but has problems with the profitability of low-power systems; in fact, of all residential potential, only approximately 3% has been exploited. This has led to a regulatory shift from net billing to net metering to improve the deployment of decentralised PV technology, particularly at the residential scale [14]. The problems affecting the profitability of PV self-consumption systems are repeated in neighbouring countries, such as Peru [13], Colombia [15], Brasil [16,17], among others. An extensive review of support policies [18] points out that net-metering schemes are spreading in all of these countries. A recent study on Ecuador [19] shows that in 2018, grid parity was not yet reached because the LCOE of PV was above retail tariffs and proposed net-metering as an incentive mechanism for promoting PVSC.

Despite the long-term background [20] of solar energy in Spain, the performance of the new regulation of self-consumption [21] and especially its profitability is still not sufficiently clear. While the research based in the IRR of PVSC in [22] shows that the new regulation makes PVSC profitable, the profitability of PVSC in Spain is compared to other European countries in [23] resulting the worst-performer with the longest TROI. This analysis to the regulations is also raised in [24], which states that for the case of Spain, a self-consumption system for a single-family house is not profitable under current regulations, neither with self-consumption with storage, nor with sale to the grid. A recent study [25] explained that with a net-metering system the return on investment of PV self-consumption systems in Spain would be reduced by one third and proposes it as the best option for residential prosumers. However, according to data from the main association of the PV sector in Spain [26], the annual installed capacity did double in 2021 compared to the previous year. A total of 1203 MW were installed, and residential self-consumption increased from 113 MW in 2020 to 385 MW in 2021.

It is therefore necessary to shed light on these results through further research. The aim of this work is to establish the key points for increasing the profitability of PV installations by comparing the economic performance of the aforementioned surplus remuneration schemes in order to identify the best cost-effectiveness conditions for residential PVSC systems over a wide range of residential customers. Due to the seemingly contradictory results on cost-effectiveness in Spain, the research has been conducted in Ecuador and Spain over a wide range of PV installation size and annual household electricity consumption values.

The paper is structured as follows. Section 2 presents the background information for both countries, including the electricity sector framework and self-consumption regulations in force in Ecuador and Spain. Section 3 presents the methodology used for the economic study of residential PVSC in both countries. The results are exposed in Section 4, including a sensitivity analysis and they are discussed in Section 5. Finally, the conclusions are given in Section 6.

Background

The regulation of electricity self-consumption in a country is conditioned by various economic, social, geographical, and political factors. For these reasons, the analysis of the structure and operation of the electrical system directly impacts the policies and regulations established for the implementation of PVSC systems. This section details this information in general and specifically for both countries.

The electricity sector framework in Ecuador and Spain.

One of the reasons for choosing these two countries was the differences in the existing structures in the electricity sector. While in Ecuador the companies are mainly state-owned, in Spain the market is liberalized.

In Ecuador, the evolution of the Ecuadorian electricity sector can be found in [27], being currently configured in two structures: institutional and commercial [28], as detailed in Table 1.

Spain has had a liberalized market since 1997 [31], splitting electricity activities and free access to the grid by transposition of the EU Directive 96/92/EC [32]. In 2007, the Spanish and Portuguese electrical systems merged to form the Iberian Electrical Market (MIBEL), allowing Spain to take part in the EU Internal Energy Market.

The operation of the electrical system is consolidated into four structured components, as shown in Table 2. The activities of electricity generation and commercialization are liberalized, thus being subjected to competition, while the activities that are not liberalized are electricity transport, distribution, and operation This situation has allowed for greater competition in the market, which means that the consumer can choose freely between the conditions offered by more than 600 companies.

Electricity production and consumption

Another reason for choosing these countries is the difference between electricity production and consumption. Fig. 1 shows the evolution of energy consumption in both countries over several years, which indicates the trend in both parameters.

Both total energy consumption and electricity consumption per capita in Spain are more than three times higher than in Ecuador. However, while energy consumption in Spain has been decreasing since 2008, in Ecuador there has been an increase of 15.3% in total energy, and 44.6% in electricity [33,35]. Furthermore, the electricity consumption by sectors for both countries is different, as it is shown in Fig. 2. While in Ecuador (Fig. 2(a)) there is a high proportion of consumption in the residential sector, in Spain (Fig. 2(b)) there is a higher consumption in the industrial and commercial sectors.

Regarding the electricity prices, Ecuador has seen a slight increase to around 10 c$/kWh. In Spain, the price for residential consumers has risen up to 22.39 c€/kWh, while the one for commercial and industrial consumers has fallen to around 7.86 c€/kWh [36]. This significant difference can be explained based on technical reasons (buying in high volume, consumption in valley hours) and a greater competition between retailers in the commercial and industrial sectors.

Table 1
Structures that make up the Ecuadorian electricity sector.

Institutional	
Institution	Description / Features
Ministry of Energy and Non-Renewable Natural Resources	Formulating, managing and evaluating energy public policy and mining of the country [29].
Agency for Regulation and Control of Energy and Natural Resources Non-Renewable (ARCERNNR)	Regulates and controls the strategic sectors of electricity, hydrocarbons and mines (Formerly ARCONEL) [30].
National electricity operator (CENACE)	Technical operator of the National Interconnected System (S.N.I.) and commercial administrator of energy block transactions.
Specialized Institutes	Scientific and technological research, innovation and development in renewable energy and energy efficiency
Business	
Ecuador Electric Corporation CELEC EP	Generation and transmission of electrical energy. One transmission company (Translectric) Twelve generation companies.
National Electricity Corporation CNEL EP	Commercialization, and distribution of electricity in the Coast Region. Covers 44% of the territory and 45% of the population.
Electric Companies (state-run businesses)	Generation, distribution, and commercialization. Nine companies that are not part of CNEL, providing electricity to 55% of the population.

Table 2
Structures that make up the Spanish electricity sector [33].

Generation	
Institution	Description / Features
Electricity generation companies.	Companies of diverse sizes generating electricity from conventional and renewable sources. 41,133 companies registered [34]
Transport	
Red Eléctrica de España (REE)	According with Ley 17/2007, operates Spanish high voltage electricity network. It transports electricity from generators to distributors and international electricity exchange.
Distribution	
Electricity distribution companies	They carry out electricity distribution with voltages <220 kV from high voltage transmission networks to the consumers or other distribution networks.
Market	
MIBEL OMIE-OMIP	Wholesale market, spot market, futures and derivatives markets. International interchanges. Agents: electricity producers, retailers, reference retailers, direct consumers, load managers, market aggregators.
OTC markets	Bilateral agreements, PPA (Power Purchase Agreements), etc.
Electricity retailers.	Retail market. There is a regulated market (reference retailers) with the “small consumers voluntary price” (PVPC) and a free market (free retailers) with differentiate tariffs and discounts for the consumers.

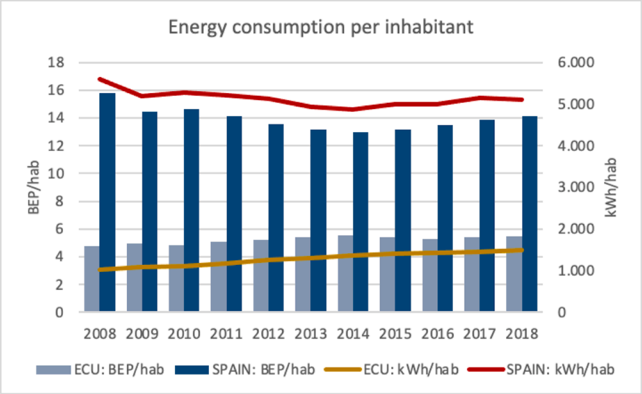
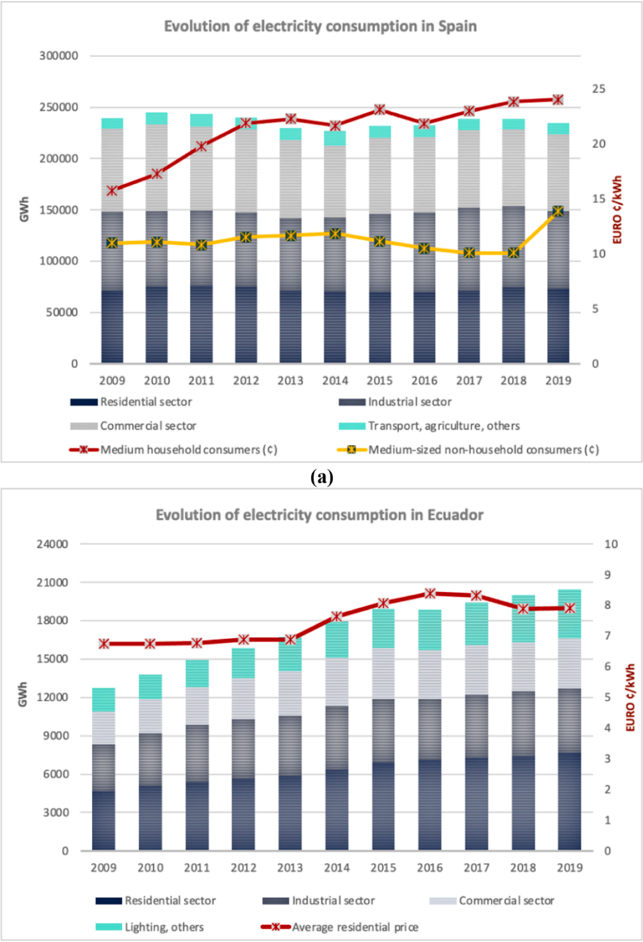


Fig. 1. Total energy and electricity consumption in Ecuador and Spain [36–39].

In terms of electricity generation, in Spain there are more than 5,000 companies, but three of these, namely Endesa, Iberdrola and Naturgy, produce 66% of the total electricity. Electricity distribution is organized geographically, with more than 300 companies being involved in the process. However, most of the energy is distributed by five companies: E-Redes (EDP), Viesgo, I-DE (Iberdrola), UFD (Naturgy), E-Distribución (Endesa) [33,40].

Regarding the electricity sources, Ecuador presents excellent conditions for hydroelectricity (rainfall and orography), which accounts for 87.71% of the energy produced, while solar PV only add up to 0.15% [41]. On the other side, Spain has an electricity mix with 56% of installed power coming from renewable energy sources: 25.7% wind energy, 16.3% hydroelectricity and 6% solar PV [42]. Among non-renewable energy sources, the higher installed power, namely 23.5%, corresponds to gas combined cycles. In 2020, the energy production in Spain looked as follows: 23% from nuclear generation and 22% from



(a)

(b)

Fig. 2. Evolution of electricity consumption by sector and average retail price in (a) Spain and (b) Ecuador.

wind energy. In 2020, 69% of the electricity demand in Spain was supplied by CO_2 free technologies.

The solar resource

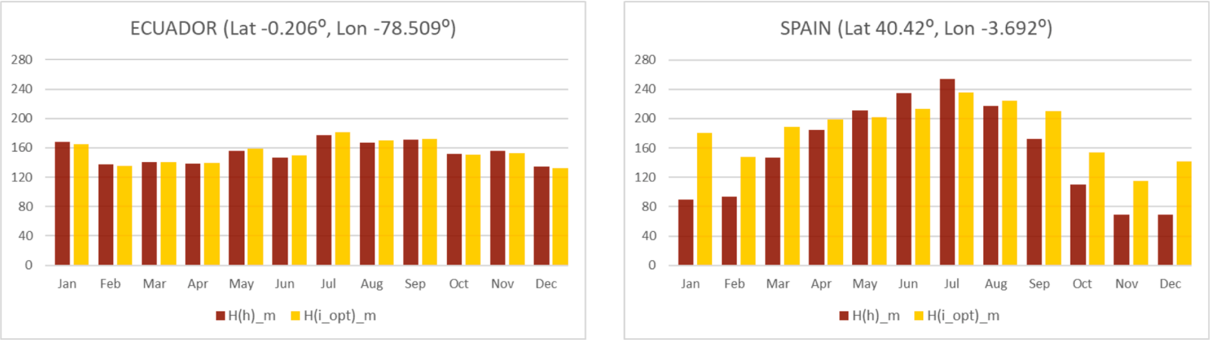
Both countries enjoy good solar resources, with an annual horizontal irradiation of 1846 kWh/m^2 in Quito, Ecuador, and 1,852 kWh/m^2 in Madrid, Spain, according to PVGIS-NSRDB database [43]. Ecuador has excellent conditions for solar energy, with a nearly perpendicular incoming irradiation at noon, all year round. This allows for a stable solar irradiance, as shown in Fig. 3(a). By contrast, Spain faces significant seasonality, but with proper orientation it is possible to reach a higher and more stable annual PV production, as seen in Fig. 3(b). While Ecuador presents a very stable behaviour throughout the year, Spain's latitude leads to significant seasonality but allows a higher annual production with a proper inclination of the modules.

Self-consumption regulations in Spain and Ecuador

Spanish policies to support PV generation began in the late 80′s. Over the years, several regulatory standards have been applied. The FiT model was adopted with the Royal Decree 436/2004 [44], resulting in an exponential growth until 2008. During this initial period PV self-consumption was not considered; it was allowed, but there were no promotion measures and policies. The first regulation of SC was adopted with the RD 900/2015 [45]. This Decree established grid costs and costly fines for self-produced energy, so it discouraged potential prosumers from installing PVSC [46]. The new regulatory framework currently in force in Spain was approved in 2018–2019 [47,48]. Among the new features introduced, it is worth highlighting that individual and shared (collective) self-consumption are allowed; moreover, it states that the user and the owner of the PV installation can be different individuals or legal entities [49]. In addition, individual self-consumption can be with or without surplus, which means that the surplus energy generated can be fed into the distribution grid or not. By its nature, shared self-consumption can only be with surplus, as it uses the distribution network. A fundamental aspect of economic profitability is the remuneration of surpluses. Although the sale of surplus electricity is allowed, this option implies the payment of certain taxes and charges for the electricity produced, in addition to the obligation to declare general taxes, as it is an economic activity. This fact limits its scope to companies because a residential user sees it as a considerable complication.

Therefore, the solution adopted by the legislator is the simplified compensation mechanism, which follows the net-billing model and is applicable for capacities under 100 kW. This implies that each month a balance is made between the energy taken from the grid, according to the retail price, and the energy fed into the grid. The latter is valued according to the price set by the electricity system operator, which is slightly lower than the wholesale market price. This value is available on the ESIOS website [50]. An important section of the regulation that affects profitability is that negative balances are not allowed in the energy term of the bill, encouraging a proper sizing of PV installations. It should be noted that the power of the PV installation is defined as the nominal power of the inverter, and that it is possible to install a higher power than that contracted for consumption (contrary to the 2015 RD).

In Ecuador, the existing legislation is still in its infancy, as it officially started in 2018 through the regulation ARCONEL 003/18. Currently, regulation ARCERNNR-001/2021 is in force, which allows generation for PV self-consumption of up to 1 MW [51]. It follows the net metering



(a)

(b)

Fig. 3. Monthly Irradiation (kWh/m^2) for Ecuador (a) and Spain (b) with horizontal (red) and optimal (yellow) angle irradiation.

model, enabling a balance between incoming and surplus energy. At the end of each month, the energy delivered to the grid is discounted from the energy consumed from the grid. In case of a negative balance, a rolling credit of the accumulated surplus energy is generated for a maximum of 2 years so the surplus energy discharged to the grid does not materialise in any financial amount. Three years after the publication of the regulation that enables self-consumption with connection to the grid, based on official data issued by ARCERNNR, the results obtained have not reached the initial expectations. There is a low number of registered installations, which may be due to several factors: the number of administrative procedures necessary for the implementation of the systems and the mode of compensation, among others. By way of summary, Table 3 presents a comparison of the key points of current SC regulation in both countries.

Additional supporting policies and regulations

In addition to the regulatory framework, promotion policies have great influence on the penetration of self-consumption models [52]. These policies mainly focus on economic subsidies and soft loans to promote renewable energy production [53,54]. These additional supports are framed in various technical and political environments. In the case of Spain, there are bonuses in some municipal taxes, which guarantee important bonuses for PVSC in a growing number of municipalities [55]. These bonuses are referred to the taxes named ICIO and IBI:

- ICIO (Construction, Installations and Works Tax) represents between 2% and 4% of the material execution cost of the work. Several regions offer a 50% exemption from this tax, and some municipalities extend the exemption to 95%.
- IBI (Real Estate Tax) is a tax that is paid annually and to which many municipalities apply an exemption for several years. This exemption can amount to $1000 € - 2000 €$.

In Spain there is currently COVID recovery funding available for SC installations [56]. A direct subsidy of 600 €/kW is available for residential SC installations < 10 kW and 490 €/kWh for battery storage. It is mandatory to consume more than 80% of the electricity produced and the storage is limited to 2 kWh/kW.

Another factor in the promotion of PVSC systems is how permissive the process of installing and using a PV system is: complex and time-consuming processes increases soft costs, discouraging potential users.

Table 3
Comparison between present regulation of self-consumption in Spain and Ecuador.

Item	Spain	Ecuador
Decree / Regulation	RD 244/2019	ARCERNNR-001/21
Definition	The consumption by one or more consumers of electrical energy from generation facilities close to and associated with the consumption	Self-dispatch: Condition of an SDGA, by means of which its owner can generate electricity autonomously.
Modalities	1. Without surplus. 2. With surplus:	Distributed generation system for consumer self-sufficiency regulated (SGDA by acronym in Spanish)
Shared SC	Yes	No
Operational renewal	Unlimited.	25-year operating period, renewal it is possible.
Surplus compensation	Net billing with no rolling credit Sell of the surplus through an agent in the market or PPA.	Net metering with two years of rolling credit.
Compensation reset period	One month	Two years

While the timing is comparable in both countries, in Spain the procedures are carried out with public and private institutions [57], as it is shown in Fig. 4; but in Ecuador all procedures involve public companies (Fig. 5).

In Spain, the regulation in force simplifies the procedures for installations with surplus up to 100 kW connected to a low-voltage distribution grid by eliminating the need to apply to the distribution company for access and connection permits. Surplus installations with an installed generation capacity of 15 kW or less are also exempted from obtaining these permits if they are located on urbanised land. In many regions there are also simplified processes for installations without surplus of any size.

In Ecuador, the ARCERNNR-001/2021 regulation incorporates bureaucratic procedures that can delay the commissioning of PV systems. According to official data for October 2021, only 114 PV systems have been officially registered for self-consumption in the form of surplus feed-in tariffs [58]. In contrast with data from private companies in charge of the design and implementation of these systems, there has been a significant increase in the demand for new PVSC systems. Still, the lack of official registration of the systems does not allow adequate monitoring of their evolution. This is because the current regulation allows self-consumption systems without the need for permits when the system does not discharge surpluses into the electricity grid, without establishing any limitation on their generation power.

Methodology

The study is based on the economic valuation of the energy exchanged with the grid and the energy saved through self-consumption for a wide range of prosumers with different annual consumptions and PV installed power, following the procedure outlined in the diagram of Fig. 6. Using reference profiles for PV production and electricity consumption, a double sweep in PV nominal power and annual consumption is performed. For each point, the specific PV-produced energy E_{PV} profile is calculated from the reference profile and the nominal PV power and the specific energy consumption E_{cons} profile is calculated from the reference profile and the annual consumption. The energy balance yields the data of imported E_{in}, self-consumed E_{sc} and surplus E_{srpl} energies, which are used in conjunction with the electricity tariffs to compute the annual economic balance. This balance results in the annual savings that are used as cashflow for the calculation of the standard economic indicators.

In these two countries there are many different customers that can use PVSC systems. The starting point for the study is defined by the energy needs of each customer, quantified in the annual electricity consumption. This range is wide. Even if the average consumption for residential users is of 2,500 kWh in Ecuador and 3,500 kWh in Spain (6,000 kWh for single-family dwelling) [59], there are also many users in both countries with annual consumptions of up to 15,000 kWh, usually linked to HVAC. As such, the range of annual consumption under study is set between 2,000 kWh and 15,000 kWh for both countries. Considering the solar resource in Ecuador and Spain (typically 1,500 kWh produced per kW installed), the range of the PVSC systems under study is set up between 1 kW and 10 kW.

Country-specific regulations must be taken into account for performing the calculations. In the Ecuadorian case, the net-metering scheme is carried out on a monthly basis, and the residential tariff has a fixed value independent of time and day so the required reference profiles for the PV production and the electricity consumption are monthly. The reference profile for the PV production has been obtained from the PVGIS-NSRDB database. It is presented in Fig. 3 and corresponds to the city of Quito. In the case of Spain, the situation is more complex, having a TOU tariff with different hourly prices, so the reference profiles must be hourly. Based on the load profile of the average Spanish residential customer for the year 2019, available on the webpage ESIOS, the hourly electricity consumption E_{cons} is profiled for each

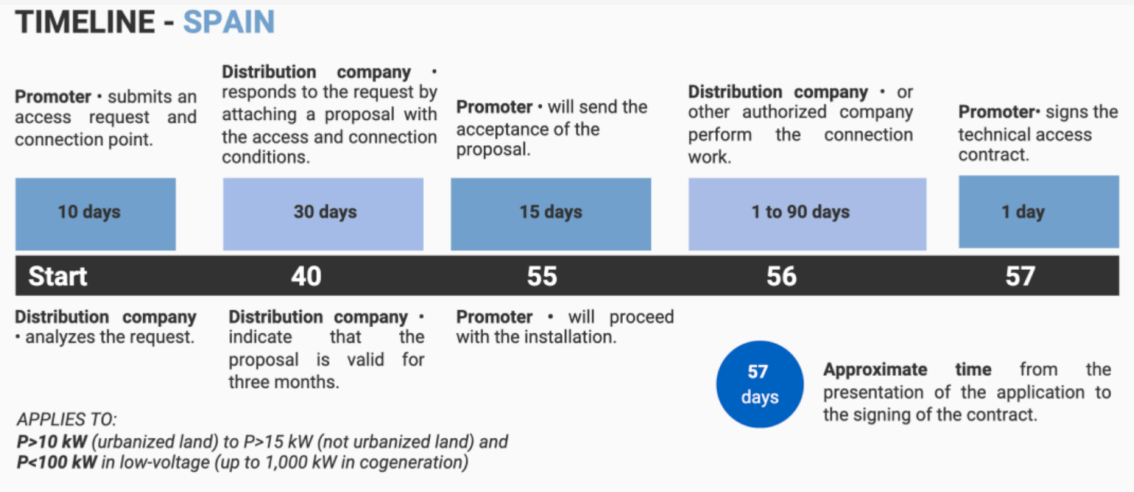


Fig. 4. Timeline of the duration of the permitting process of a PVSC system in Spain.

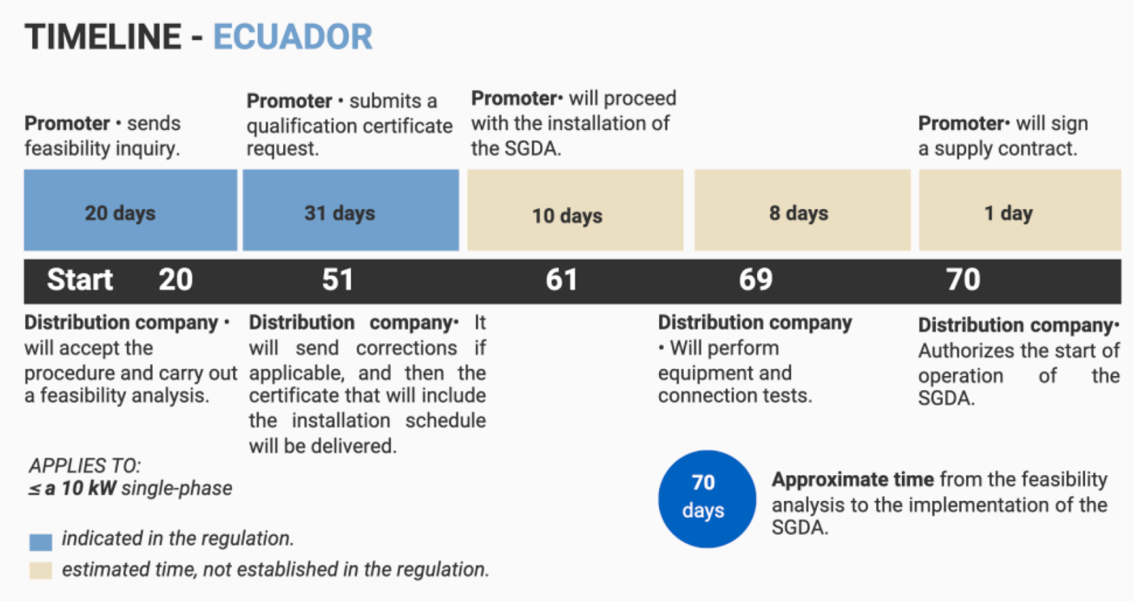


Fig 5. Timeline of the duration of the design and legalisation process of a PVSC system in Ecuador.

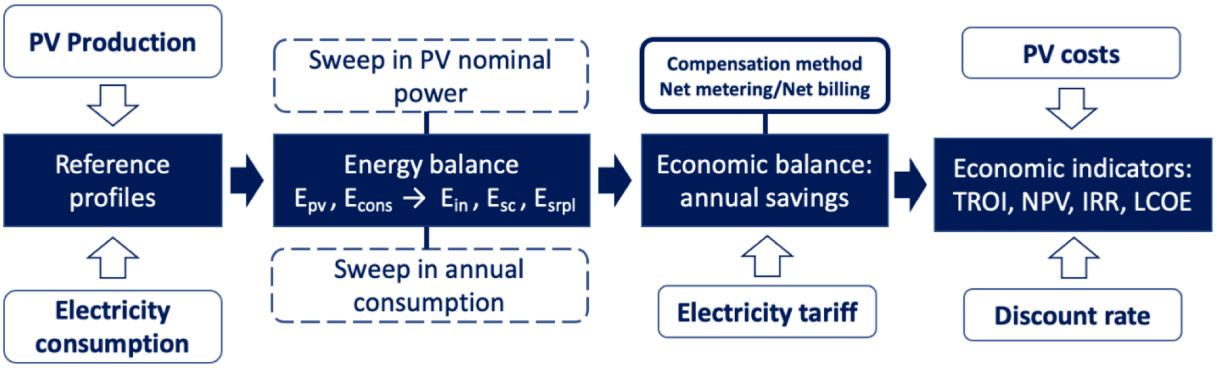


Fig 6. Methodology scheme for the economic study over a wide range of annual consumption and PV sizes in both countries.

annual total consumption. The hourly profile for the PV energy production is obtained from the data acquired during the year 2019 in a PVSC system at the University of Salamanca, located in the city of Ávila, with an annual production of 1,500 kWh/kWp and representative of this type of PVSC systems in Spain. The reason for using data from one installation instead of a synthetic database is because wholesale market prices and electricity demand are partly influenced by weather conditions, which determine the PV production. In this way, the analysis is more accurate to the conditions of a real installation.This particular installation has been chosen because it has data obtained every second and it is in the centre of Spain, so it is representative of all the installations in the country. The hourly PV production for each size of PVSC E_{PV} is calculated by scaling this hourly profile.

The following subsections set out in detail the calculation of the energy balances and electricity tariffs applicable in both countries before moving on to the calculation of the economic balances. These annual balances provide the cash flow values for the calculation of the economic indicators.

The reference consumption profiles and prices in Spain correspond to year 2019. Due to the COVID-19 pandemic, both consumption and prices have been distorted, with lower electricity consumption and prices in 2020, which have risen with high volatility in the prices for 2021. The prices of solar modules and some materials have also risen, but the growth in the size of the residential market and the increased competition has kept the prices stable. Furthermore, the scenario is one of a higher discount rate. Therefore, a sensitivity analysis is carried out to take these conditions into account.

Energy balance

The energy balance for a typical residential user is shown in Fig. 7. The energy consumed E_{cons} comes from the grid (E_{in}) and from the PVSC system (E_{sc}). If the PV-produced energy is greater than the energy consumed, there is a surplus energy E_{srpl} fed to the electrical grid and no energy is taken from the grid, otherwise there will be an energy taken from the grid E_{in} and all the PV-produced energy will be self-consumed ($E_{sc} = E_{PV}$) with no surplus energy E_{srpl} fed into the grid. The starting data for the energy balance are the consumed energy E_{cons} and the PV-produced energy E_{PV}: from these values the energy taken from the grid E_{in}, the self-consumed energy E_{sc} and the energy fed into the grid E_{srpl} are calculated according to Eq. (1), (2). Depending on the sign of this balance there will exist an energy surplus to be fed into the distribution grid (Eq. 3).

$$E_{cons} = E_{in} + E_{sc} \tag{1}$$

$$E_{PV} = E_{sc} + E_{srpl} \tag{2}$$

$$E_{cons} - E_{PV} = E_{in} - E_{srpl} \tag{3}$$

$$if\ E_{PV} > E_{cons} \Rightarrow E_{in} = 0\ ;\ E_{srpl} > 0$$

$$if\ E_{PV} < E_{cons} \Rightarrow E_{in} > 0\ ;\ E_{srpl} = 0$$

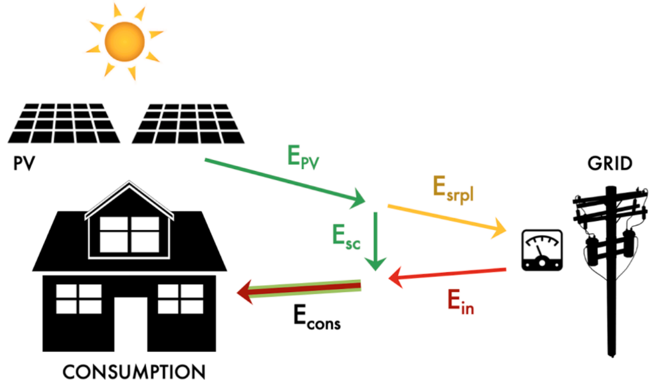


Fig 7. Definition of the energy interchanges used for the calculations.

Electricity tariffs

In Ecuador, the price of electricity is set by the board of the ARCERNNR (formerly ARCONEL) and is valid for one calendar year. The final value of the electricity billing is established through the addition of several elements, namely the amount of energy, electrical output, losses in transformers, marketing, and penalties for low power factor. These values, in turn, depend on: the sector to which they belong (residential, commercial or industrial), voltage level, monthly consumption, and geographical location [60]. For 2020, a residential consumption of 2,500 kWh per year presented an approximate cost of 0.084 €/kWh, placing Ecuador among the countries with the lowest electricity tariffs in Latin America and the Caribbean, as indicated by ECLAC in its report [61]. The tariff schedule for electricity consumption is configured so that residential customers with the lowest consumption pay the lowest price; this cost increases progressively as consumption increases, as shown in Table 4. To this cost is added a single monthly amount of 1.414 $ per customer for marketing expenses and complementary values such as the contribution to Public Lighting and a tax to the Fire Brigade. It is important to note that the electricity in Ecuador is exempt from VAT.

In Spain, the electricity prices have risen, reaching a cost of 22.39 c€/kWh in 2020 for residential consumers [36]. The residential tariff is composed of a fixed access term (regulated and proportional to the maximum contracted power) and a variable energy term that includes the cost of electricity in the wholesale market, tolls (generation and distribution costs), charges (RES support policies, overcharges of the Balearic and Canary Islands electrical systems, financing of tariff deficit, and other costs) and commercial profit. Tolls are established by the CNMC (National Commission for Markets and Competition) and charges are established by the National Government. The electricity bill includes a 5.11% electricity tax and 21% VAT (see [49] for a more detailed description of the Spanish bill). Different retailers offer a fixed price or two period plans and the regulated tariff PVPC, indexed to the hourly wholesale electricity price. In addition, new tariffs have become effective in June 2021. The new residential tariff 2.0TD is a time of use tariff with three pricing periods that replace all the 2.x tariffs [63]. This regulatory change follows the EU Directive 2019/244 [64] and establishes higher prices for periods of higher electricity consumption in order to promote a shift in demand among the customers, as exposed in Table 5. The “tolls and charges” item adds up to the wholesale electricity price and to the commercial costs, which are around 0.020 €/kWh.

Economic balance

As explained before, Ecuador has implemented a net-metering scheme with 2 years of rolling credit. The customer will be able to

Table 4
Tariff charges in Ecuador for the low and medium voltage residential sector for the year 2021 [62].

City of Quito (Empresa Eléctrica Quito S.A.)		
Consumption Ranges (kWh/month)	Energy charges ($/kWh)	Energy charges (€/kWh)
1 – 50	0.078	0.066
51 – 100	0.081	0.069
101 – 150	0.083	0.071
151 – 200	0.097	0.082
201 – 250	0.099	0.084
251 – 300	0.101	0.086
301 – 351	0.103	0.088
351 – 500	0.105	0.089
501 – 700	0.128	0.109
701 – 1000	0.145	0.123
1001 – 1500	0.171	0.145
1501 – 2500	0.275	0.234
2501 – 3500	0.436	0.371
Upper range	0.681	0.579

Table 5
Hourly distribution of the new Spanish time of use tariff 2.0TD.

Hours	1–8	9–10	11–14	14–18	19–22	23–24
Period	“Valley”	“Flat”	“Peak”	“Flat”	“Peak”	“Flat”
Tolls and charges (c€/kWh)	0.006	0.042	0.135	0.042	0.135	0.042

discount the amount of energy that is delivered to the grid and reduce their monthly consumption, which will allow them to access a lower cost of electricity, as shown in Table 4. The credit management process of surplus energy can be expressed as presented in Eq. 4:

$$S_j = \left(E^j_{in} - E^j_{srpl} + \sum\nolimits_{i=1}^{24} R^{j-i} \right) \bullet P_{ret} \tag{4}$$

$$R^j = 0 \ if \ E^j_{in} - E^j_{srpl} > 0$$

$$R^j = E^j_{in} - E^j_{srpl} \ if \ E^j_{in} - E^j_{srpl} < 0$$

Where S_j *is the economic saving for the* j^{th} *month,*

$E^j_{in} - E^j_{srpl}$ *are the energies taken from the grid and the surplus.*

$R^{1..24}$ *is the* $24-$ *month rolling credit*

and P_{ret} *the retail price of electricity*

The calculation of the savings is made based on the values presented in Table 4, which were issued by the regulatory entity for the year 2020. The economic benefit is obtained by a monthly comparison of the energy consumed by the residence and the energy produced by the PVSC system. If the energy delivered by the PVSC to the grid is higher than the energy taken from the grid, a credit of this surplus energy in kWh is managed for the following month.

The analysis for Spain will be based on data corresponding to the year 2019 and is done as follows. For the economic evaluation, the hourly prices corresponding to the energy bought from the grid and the price of the surplus energy are provided by Spanish TSO REE in the aforementioned ESIOS web page. In accordance with the simplified compensation method, the economic savings are calculated on a monthly base as the sum of two parts: the avoided costs *A* of the hourly self-consumed electricity valuated at the retail price P_{ret}, as expressed in equation (3) and the savings *S* in the monthly bill due to the surplus energy fed into the grid according to the simplified compensation mechanism *C* expressed in equation (4). It is important to remember that the regulation states that the energy term in the monthly bill cannot be negative.

$$Avoided: A = \sum_{i=1}^{n} \left(E^i_{PV} - E^i_{srpl} \right) \bullet Pr^i_{ret} \tag{5}$$

being i the i^{th}*hour of the month*

Pr^i_{ret} *the retail price of electricity on the* i^{th} *hour*

$$Compensated: C = \sum_{i=1}^{n} E^i_{srpl} \bullet Pr^i_{srpl} \forall \sum_{i=1}^{n} \left(E^i_{in} \bullet Pr^i_{ret} - E^i_{srpl} \bullet Pr^i_{srpl} \right) \geq 0 \tag{6}$$

$$C = \sum_{i=1}^{n} E^i_{in} \bullet Pr^i_{ret} \forall \sum_{i=1}^{n} \left(E^i_{in} \bullet Pr^i_{ret} - E^i_{srpl} \bullet Pr^i_{srpl} \right) \langle 0$$

being E^i_{in} *energy taken from the grid,*

and Pr^i_{srpl} *the price of surplus electricity on the* i^{th} *hour.*

If the monthly value of surplus is lower than the value of the purchased electricity, the saving in the bill will be the value of the surplus. Otherwise, the saving will be the value of purchased electricity. This mechanism ensures that the economic amount in the monthly bill is not negative.

The annual sum of the monthly economic savings (Eq. (7)) is the cashflow used for the calculations in the economic study.

$$S(avings) = A(voided) + C(ompensated) \tag{7}$$

Cost of PVSC installations.

In Ecuador, the equipment acquisition amounts to 70% to 85% of the total cost. Most of these components are imported and charged with duty. The remaining portion includes labour and soft costs. The total cost in Ecuador is showed in Fig. 8(a) and it is below 1.50 €/W for sizes above 3 kW. In Spain, the equipment costs are lower due to lower duties and higher market competition, but labour and taxes are higher. The total cost for powers above 5 kW is lower in Spain than in Ecuador, as shown in Fig. 8(b).

In this study, the costs include hardware, labour, local taxes, connection fees and VAT. It is important to note that there are fixed costs that have a greater impact on small installations. The total costs during the lifetime of the PVSC include an inverter replacement in the 12th year. As these are small installations, operational costs are assumed to be zero, and the annual maintenance cost is estimated at 1% of the initial cost. This cost ranges between 10 and 22 €/kW yearly and is in line with published results [65]. Finally, considering the usual warranties given by PV manufacturers and extensive research [66], a 0.8% annual degradation of the PV modules is also taken into account.

Economic indicators

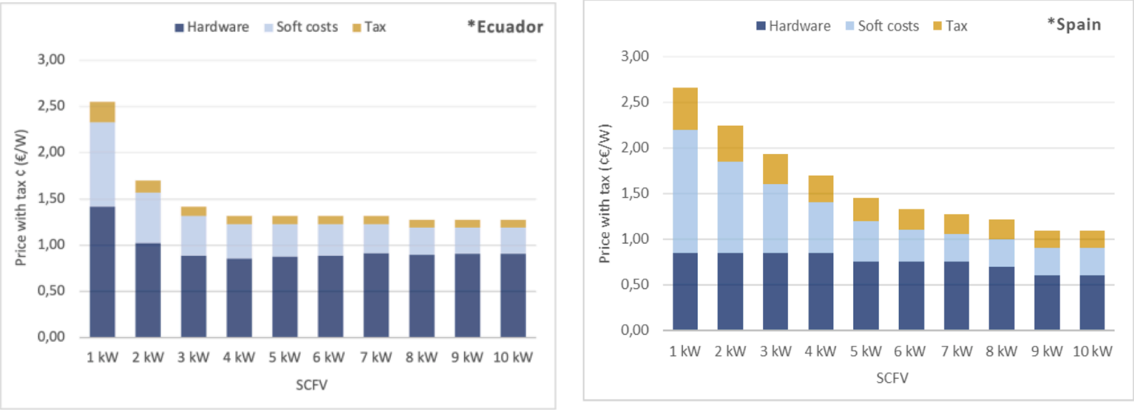
The economic indicators are calculated on the basis of the cash flows and costs set out above. The other parameters needed for the calculations are the lifetime of the installation and the discount rate in each country. The regulations of PVSC in force in Ecuador and in Spain states an operational time of 25 years, with the possibility of renewal. For this reason, we will assume a lifetime of 25 years. The discount rate for Ecuador is 7%. The discount rate for Spain is chosen as 3%, following recent data for the Euro Area [67].

Time of return of investment

The TROI is calculated for both countries. Among the methods aimed at calculating the cost-benefit, TROI is one of the most widely used to compare the benefits of a programme with the same costs per unit, per person, or aggregated for the programme as a whole. In our case, TROI is a cost-benefit driven economic method, but it is also widely used to calculate [68]: Average net benefit, Median benefit, Return on investment (ROI): how much is produced for how much invested? Like any other investment valuation based on cost-benefit, TROI is subject to a context of uncertainty. Moreover, the higher the risk to be assumed by the investor, the higher the return. Concerning TROI, we can assume that the risk negatively affects the value, and this risk is increased by adjusting the cash flows to future terms.

Net Present value

Investment decisions are at the heart of any investment project. To construct the appropriate economic structure, one way of assessing the viability of the investment is the calculation of the Net Present Value. The NPV technique is defined as the discounted value of all cash flows at the source at a discount rate that matches the cost of capital. For our study, what we do is to value the foregone cost of the investment project (i.e., the initial outlay) at a point in time, as well as the expected



(a) (b)

Fig. 8. Cost of residential PVSC in (a) Ecuador and (b) Spain.

satisfaction in the future (i.e., the expected cash flows). We choose the current point in time as the point at which both the outlay and the cash flows should be valued, so we apply a discounting process. To apply this discounting process, we incorporate the discount rate, which is the opportunity cost of the project, known as the cost of capital.

Internal rate of return

Another widely established criterion concerning investment decisions is the so-called IRR. IRR is defined as the discount rate that equals the NPV of the investment to 0. In our project, we are looking for the relative return of our investment project, as opposed to the NPV, which we represent by setting an absolute return. It is worth noting that IRR is one of the most widespread measures of profitability approximations since it provides a more intuitive idea of the adequacy of what is expected from an investment. It is a value that we can easily compare with interest rates, which is one of the main components that determine the cost of capital in each project.

Levelized cost of electricity

The levelized cost of energy (LCOE) is an abstraction that serves as a ranking tool to compare the cost-effectiveness of electric generation technologies, removing biases between them [69]. LCOE can be calculated using this expression (8):

$$LCOE = \frac{\sum_{t=0}^{T} C_t/(1+r)^t}{\sum_{t=0}^{T} E_t/(1+r)^t}$$

$$\text{where } C_t \text{ are the costs, } E_t \text{ the energy produced, } r \text{ the discount rate.} \tag{8}$$

Sensitivity analysis

As was mentioned before, in addition to the usual uncertainties there are added problems after the recovery from the COVID-19 pandemic. The general increase in prices may lead to a higher cost of capital scenario, which translates into an increase in the discount rate, affecting economic profitability. In addition, the sharp increase in electricity prices experienced in Spain will be also taken into account. The average retail price of electricity in year 2019 is 0.110 €/kWh and 0.050 €/kWh for the surplus electricity, and in year 2021 of 0.177 €/kWh for the retail price and 0.110 €/kWh for the surplus electricity fed into the grid.

Therefore, a sensitivity analysis has been designed and will be carried out as follows: instead of the common analysis of defining three scenarios: likely, optimistic and pessimistic, a two-stage analysis is designed for Spain to assess the increase in the discount rate and in the electricity prices. First, it will be carried out on the basis of the probable scenario of an additional 2% increase in the discount rates of the benchmark calculations. Second, an additional sensitivity analysis is performed using electricity prices for the year 2021 provided by the Spanish TSO on the ESIOS website. For Ecuador the second part is not needed because the electricity prices are regulated and are stable due to the high share of hydroelectricity generation. The price of PV modules has experienced a rise after the COVID 19, but the PV costs have remained stable in Ecuador and Spain due on the one hand to the high level of stock in the installation companies because of the low number of PV installed in Ecuador and, on the other hand in Spain for the opposite reason: the big growth in the residential market and the specialization and competition between PV installers have reduced soft costs.

Results

Time of return of investment

The TROI is presented for both countries as contour plots for the range of annual electricity consumption and size of the PVSC under study in Fig. 9. It is found that the TROI is long for the average user, especially in the case of Ecuador. For the average single-dwelling user in Spain the TROI is under 10 years for PV power under 7 kW, and under 12 years for the average consumer (for PV power under 3 kW), which can be acceptable considering that the projected lifetime of PVSC is at least 25 years. For a wide range of annual consumption above 10,000 kWh, the situation is more favourable, with the TROI being lower than 7 years in Ecuador and 8 years in Spain. In Ecuador, this is the result of the progressive increase in electricity prices in line with the consumption, while in Spain this is due to the higher proportion of self-consumed electricity at a higher price at the expense of a lower proportion of compensated electricity at a lower price. The dotted and dashed line indicates the annual production expected for each PV power for an annual yield of 1,500 kWh/kW. Adequately dimensioned installations are expected to be in the upper part of the plane, above this line. The installations below this line would produce more electricity than is consumed, and this electricity would not be valued in a net-metering scheme and at a low price in net-billing.

Net Present value

The NPV is calculated for both countries considering a lifetime of 25 years for Ecuador and Spain, and the discount rates of 7% for Ecuador and 3% for Spain. For the average user, the results show no profitability in Ecuador and fair profitability in Spain. For higher consumptions, the profitability is fair in Ecuador and good in Spain.

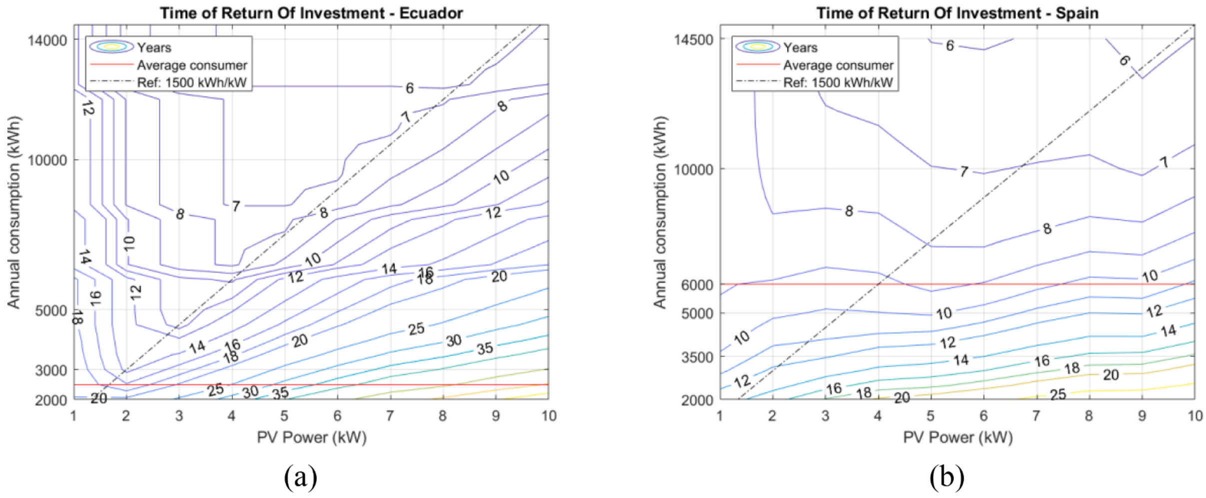


Fig. 9. TROI of PVSC systems for different annual consumption and PV installed powers. Selecting the annual consumption, this plot allows to find the PV power range that yields the shortest TROI. (a) Ecuador, (b) Spain. The red line in both graphics corresponds to the average residential consumption (single-family home for Spain). The highest consumptions are found when heat pumps are used for heating and cooling. The dash-dot line relates the annual production for each PV power with the annual yield of 1,500 kWh/kW as a reference.

Internal rate of return

The IRR is presented in Fig. 11. The results coincide with those from the NPV analysis, namely good profits for bigger electricity consumers in both countries, but only in Spain for the average consumer (almost all consumers). It should be noted that given the discount rates of 7% in Ecuador and 3% in Spain, the corresponding interest rates that serve as a benchmark for feasibility are 7.5% and 3.1% respectively.

Levelized cost of electricity

In Fig. 12 the LCOE for (a) Ecuador and (b) Spain is represented under different scenarios. The blue lines correspond to a 25-year lifetime and the discount rates for each country (3% for Spain and 7% for Ecuador). For Ecuador, the LCOE is also calculated with a discount rate of 3% in order to ensure an accurate comparison with Spain. It is clear that Spain has reached grid parity for powers greater than 3 kW, but Ecuador has not. This is due to the low retail electricity prices, and the higher discount rate. According to the electricity tariffs in Ecuador, structured in bands of consumption, grid parity is reached only for the band of consumption above 500 kWh/month, as is indicated in Table 4.

In Spain, the current simplified compensation method under the current net-billing scheme states that the surplus electricity is valuated at a price slightly lower than the wholesale price. In Fig. 11(b) it can be seen that the LCOE is within this range for PV powers higher than 3 kW.

Sensitivity analysis

The results of the sensitivity analysis on an additional 2% in discount rates are shown in Fig. 13. For Ecuador the NPV is reduced between 200 € and 1,400 €, slightly reducing the profitability threshold. For Spain the NPV is reduced between 400 € and 2,000 €, reducing the profitability threshold (approximately shifting the NPV zero-line 500 kWh upwards).

Regarding the significant increase in the price of electricity in Spain, an additional sensitivity analysis has been performed over the increase in the discount rate. The result is that the effect of the increase in the discount rate is completely cancelled out, with an increase in NPV between 500 € and 4000 €. The change in NPV is shown in Fig. 14, and the effect is that PVSC systems larger than 2 kW are cost-effective for annual consumption above 2000 kWh. Due to the large percentage of hydroelectric power in Ecuador, an increase in energy prices is not envisaged.

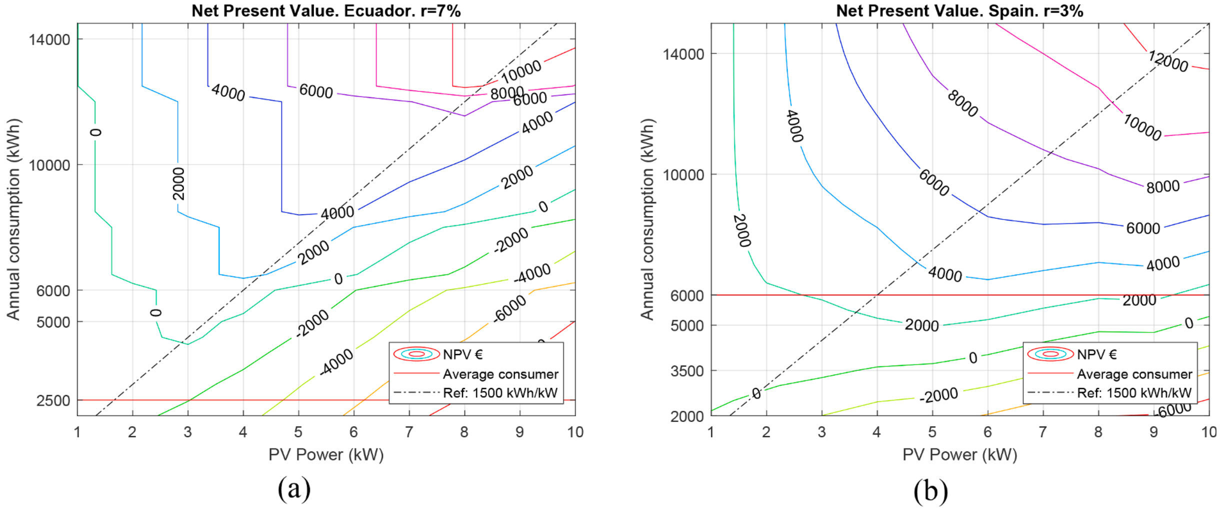
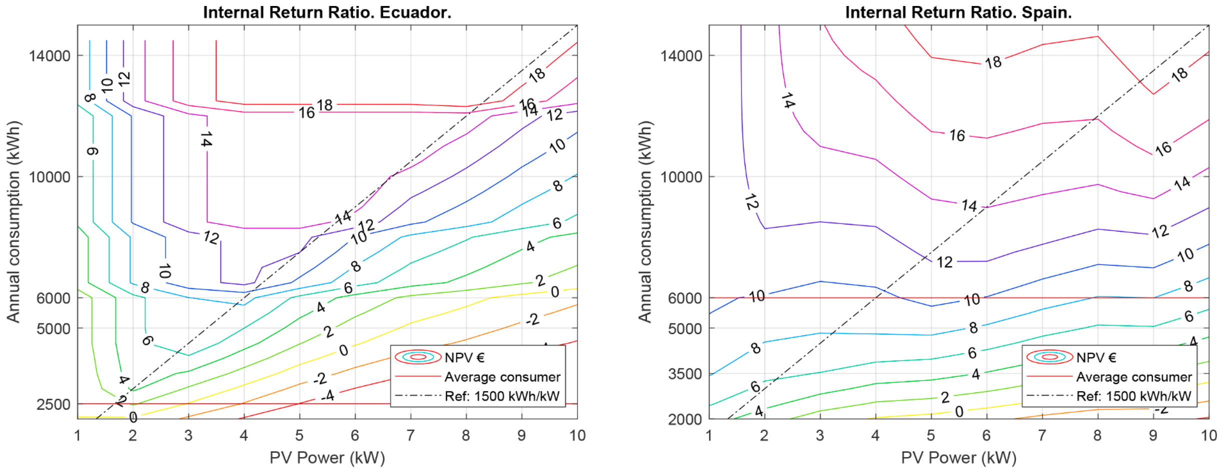
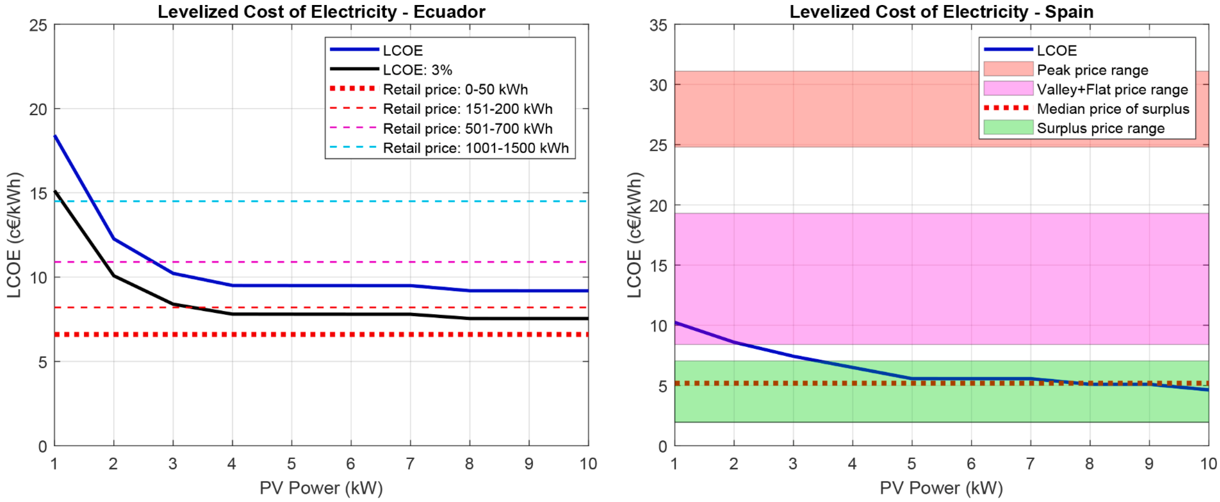


Fig. 10. Net present value of PVSC systems in € for different PV installed powers and annual consumption. (a) Ecuador: 7% discount rate (b) Spain: 3% discount rate.



(a) (b)

Fig. 11. Internal Return Ratio of PVSC systems for different PV installed powers and annual consumption. (a) Ecuador (b) Spain.



(a) (b)

Fig. 12. LCOE of PVSC systems in €/kWh for different PV installed powers. (a) Ecuador: the retail price for some consumption bands is shown as a reference. The LCOE calculated with a discount rate of 3% is also shown for comparison with Spain (b) Spain: Both the retail and surplus price ranges are shown. As the later range is wide, the median price of surplus is shown for an adequate comparison.

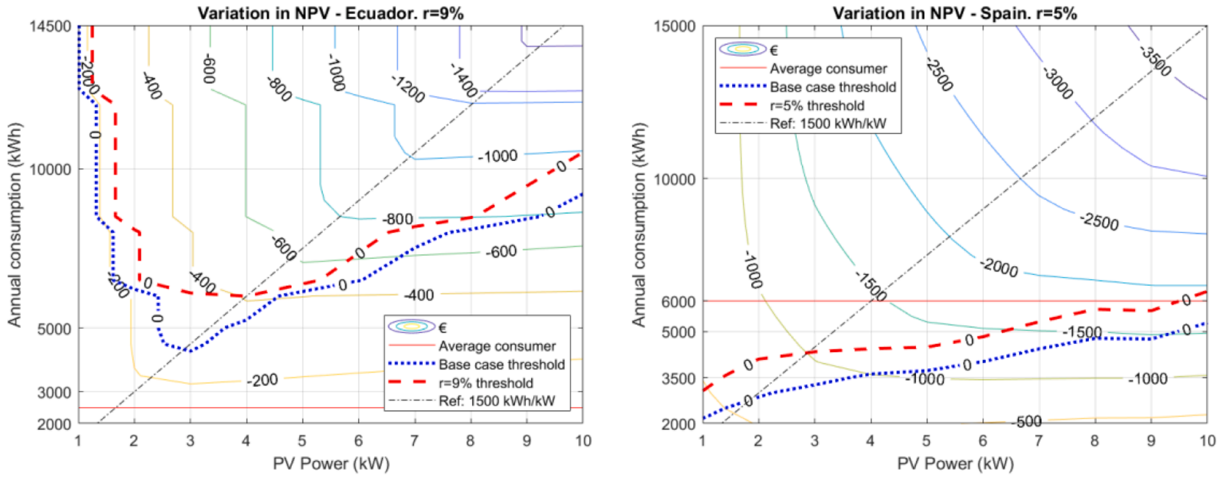
Effect of alternative electrical tariffs in Ecuador

One important issue is the band structure of the electrical tariffs in Ecuador and the possibility of its replacement for a TOU or a fixed-price retail rate. On the one hand there is the possibility to choose a TOU tariff for certain consumers in the commercial segment. This tariff consists of two periods, from 0 h AM to 8 h AM is the cheapest period and from 8 h AM to the end of the day is the most expensive period. We carried out the study for Ecuador under these conditions, but the results were not relevant. The price difference between periods is smaller than in Spain and, most importantly, due to Ecuador's latitude the day length is very stable throughout the year and the solar output in the cheap period is very small. Other possibility is to substitute the price bands structure for a fixed retail price. The medium residential retail price for Ecuador is of 0.0956 €/kWh, meaning that it is lower than the LCOE of PVSC in Ecuador as it is shown in Fig. 12 (a) and cost-effectiveness is debatable. The calculations have been performed in these conditions and the variation compared to the base case is shown in Fig. 15. The NPV is greatly reduced, and it is under 2,308 €, being unprofitable for PV powers under 2,5 kW. This is because in the Ecuadorian net-metering scheme the energy discounted is that of higher bands, more expensive, and therefore more profitable.

Discussion

The analysis identified that the viability of the PVSC systems in each remuneration scheme is also significantly affected by the functioning of the electricity system in each country. Ecuador presents an energy market managed by the national government, which has led to low retail prices that have not changed significantly over the last few years [60]. In contrast, as it is shown in Fig. 5, a liberalized market in Spain has generated higher prices for the residential sector. Ecuador has a large proportion of hydroelectric generation, which allows for stable electricity prices. Spain has a high dependence on natural gas, which results in high volatility of electricity prices, with a large increase in prices in recent times [36].

The economic analysis shows a different profitability of PVSC in these countries. In Spain there is fair profitability, as the TROI is under



(a)

(b)

Fig. 13. Change in Net Present Value with an additional 2% over the reference discount rate. (a) Ecuador (b) Spain. The threshold for positive NPV is indicated for the base case (blue) and for the case with discount rate increased (red).

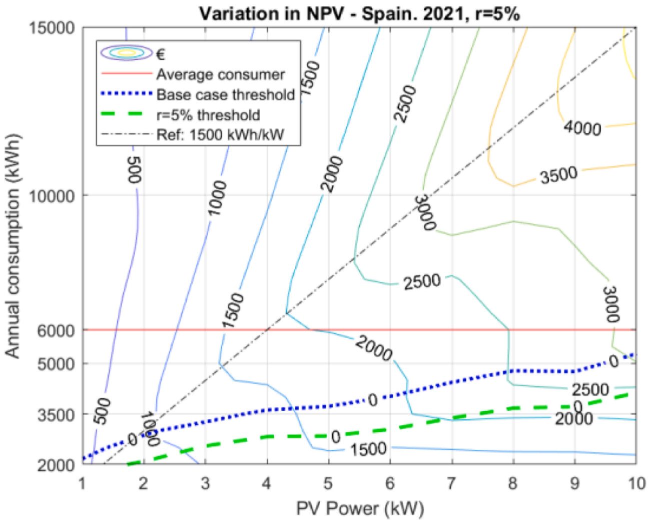


Fig. 14. Change in Net Present Value for Spain with a discount rate of 5% and the electricity costs of year 2021. The threshold for positive NPV is indicated for the base case (blue) and for the case with discount rate and electricity prices increased (green).

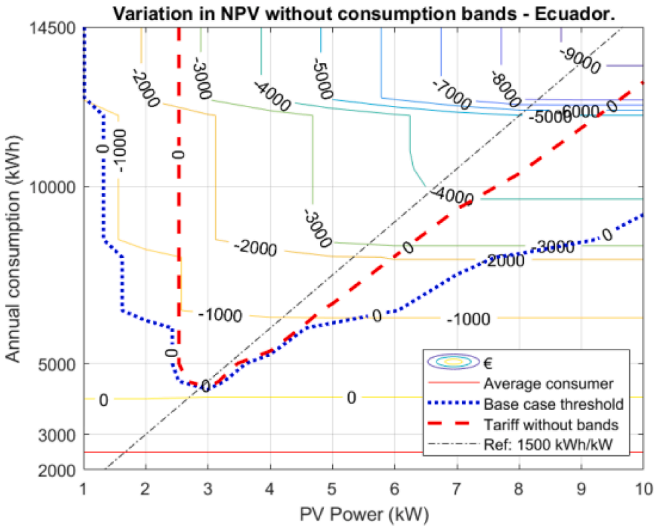


Fig. 15. Change in Net Present Value for Ecuador if the structure in consumption bands were replaced with a fixed rate of 0.0956 €/kWh.

10 years, the NPV positive and the IRR over 8% for single-dwelling consumers and TROI under 12 years, NPV positive and IRR higher than 5% for the average consumer. In Ecuador, none of the economic indicators are favourable for the average consumer, with TROI over 18 years, negative NPV and low or even negative IRR. There are several factors that explain this situation in Ecuador, that has not improved since the work in [19]. On one side, the proper PVSC for low energy consumption is a small size one, which is also more expensive. In addition, the duties on PV equipment in Ecuador make PVSC systems more expensive. On the other side, in Ecuador the energy is strongly subsidized in the first consumption sections, so there are little savings here.

In both countries, the best profitability is found for the users with a higher energy demand. For an annual consumption above 8,000 kWh the TROI is under 8 years in both countries, and both NPV and IRR are more favourable. The differences between the two countries emerge from the economic support mechanism for PVSC – net-metering in Ecuador and net-billing in Spain. Even if net-metering can be seen as a more favourable scheme for PVSC, in the long term, it can actually discourage the production of more energy that is consumed, because it is not rewarded. On the contrary, the net-billing simplified compensation mechanism in force in Spain, allows to oversize the PVSC, as the balance that must be positive is the economic one because the prices of the surplus are lower than those of the electricity purchased from the distributor. This is reflected in a wider range of profitable PV sizes for a given annual consumption, as shown in Figs. 8–10. These results compare well with previous research. Lopez Prol and Steininger [22] found lower profitability for the residential sector than commercial and industrial but and a higher potential due to the highest prices of the electricity for this consumers. The work in [23] is based on a PV size of 3 kW and the profitability is studied for occupancies between 1 and 4 residents (between 2,200 kWh and 3,300 kWh annually) and it is found that PVSC is not profitable for 1 resident occupancy (2,200 kWh/year) but it was profitable for 4 residents (2,800 kWh/year). A recent research [25] is based on four cases of study, two of them are 5 kW individual households with consumptions of 2,200 kWh and 2,700 kWh annually and found that the Spanish net-billing scheme was not profitable for them.

The analysis of LCOE brings a different picture for the two countries. While in Spain it is lower than the retail electricity price for PVSC sizes above 3 kW and even lower than the median value of electricity surplus fed into the grid for sizes above 5 kW, in Ecuador for sizes under 3 kW the LCOE is only lower than the electricity price for the consumption sections above 700 kWh/month (8,400 kWh/year) and for sizes above 3 kW is only lower for the consumption section above 500 kWh/month (6,000 kWh/year). It is important to remind that due to the consumption bands tariff structure, the savings due to SC only apply to the amount of electricity consumed in the upper sections and for the electricity consumed in the lower sections the SC electricity is more expensive that of purchased from the grid. So, this LCOE value limits the profitability of PVSC to big-consumption residential customers. The higher costs of financing for Ecuador reflects in a higher LCOE. In Fig. 12(a), it is shown the effect of applying the same discount rate of 3% as Spain, which would reduce the LCOE to the extent that grid parity would be reached for the consumption band above 200 kWh/month.

The sensitivity analysis shows a low impact of the rise in the discount rate expected in the current economic situation for both countries. The big increase in electricity prices in Spain is added to the sensitivity analysis, showing that with these premises PVSC is profitable for almost the whole range under study. This is supported by the impressive increase in the number of PVSC installed in 2021 (385 MW in 2021 vs 113 MW in 2020).

Regarding the welfare of self-consumption, there is concern that the regulations make it more profitable to wealthy consumers. The economy of scale makes small PVSC more expensive, thus being detrimental to low-income consumers. There are several possible promotion measures such as local tax and/or VAT exemptions which, in case of being progressive, can facilitate universal access to these PVSC systems. The subsidies in place in Spain are very generous but the limitation of self-consumption >80% of the electricity produced by PV is difficult to achieve in case of low electricity consumption. A lump sum subsidy would be more effective because it would mitigate the higher cost of small installations, as well as being easier to process for installers and the administration. Another important aspect is that PVSC systems fit well with single family homes but not with condominiums. In the newest Spanish regulation, this aspect is solved by allowing shared self-consumption. Such an approach can help to reach a wider social spectrum of PVSC users. This form of self-consumption is still in its initial phase, but new regulatory developments such as dynamic sharing coefficients can attract more users. These dynamic coefficients mean that the share of PV energy production is not constant for the partners in the PVSC system, but the share is established for each hour of the whole year, thus ensuring that the users with different patterns of consumption can share the PV production in an optimal way, for example in a condominium with both permanent and holiday residents. In addition, shared SC leads to more competitive prices due to the higher sizes of these installations. Some problems are being detected in Spain concerning the slowness of the administrative processing of these installations, with delays of several months over the timetable of Fig. 4.

Considering the future large-scale integration of PVSC, the net-billing scheme together with the variable prices for the electricity bought and the surplus gives the appropriate market signals to incentivize self-producing electricity when it is more valuable. This encourages smart habits for use of energy, DSM strategies or the design of PVSC using non-conventional orientations in buildings [70]. This strategy requires the widespread use of smart energy meters, which in Spain currently cover almost all consumers [34]. However, this may not be possible in many countries, as in the case of Ecuador.

Our new research is focused on optimal sizing of PVSC system in the residential, commercial, and industrial sectors and evaluating the economic performance of several industrial cases of study. Future research directions are aimed at studying experiences in shared self-consumption and coupling PV with batteries.

Conclusions

Research has been carried out on the profitability of a wide range of residential prosumers in Ecuador and Spain under net-metering and net-billing schemes to identify the ranges of annual consumption and installed power that allow for the viability of self-consumption. These results provide a broader picture and put into context previous research that exhibited seemingly contradictory results.

The results from Ecuador indicate that there is only economic viability for high electricity consumptions, above 6,000 kWh/year. Two factors are identified for this result: high prices of PV due to the small size of the market and the high tariffs, and especially the price band structure of electricity prices, with very low prices in the lower bands (reaching up to 4c$/kWh for the lowest consumption band), which strongly limits the profitability of self-consumption. Three years after its implementation the expected results are not being obtained, with an official register of only a few systems installed under the current regulation.

By contrast, in Spain, lower tariffs for imports and an economy of scale due to a bigger market generate lower total costs of PVSC systems, and high retail electricity prices aid to reach grid parity. This research identifies cost-effective PV power and consumption ranges: the economic indicators are favourable for the average consumer (3,500 kWh/year) and PV power < 5 kW and very profitable for consumption above 6,000 kWh/year (the average consumption of single-dwelling homes) and all PV sizes. For electricity consumption below 2,000 kWh/year the SC is found to be not profitable.

The main driver for a widespread adoption of PVSC is economic. Net-metering and net-billing policies alone are not enough when grid-parity is not yet achieved. As it is seen in Ecuador, the higher price of electricity in the higher segments of consumption makes PVSC competitive, thus favoring access to this technology only for part of the customers. The economic and political costs of upgrading to hourly tariffs (smart meters deployment and subsidy reform), in addition to the lower price of electricity, are factors limiting the implementation of the net-billing model in countries with similar retail tariff structures. For countries with more mature self-consumption markets, such as Spain, net-billing policies allow the promotion of smarter PVSC systems by economically favoring the coupling of PV production with the demand, and diminishing the energy interchanges with the grid, avoiding further costs in the distribution of electricity. The recent change in electricity tariffs in Spain, with higher prices during periods of high demand, and the significant increase in electricity prices, have given an extra boost to self-consumption. In conclusion, both methods are valid and useful under specific circumstances: net-metering at an early stage, as in Ecuador, and net-billing at a more mature stage, as in Spain.

As a summary, the following recommendations could be made for Ecuador and other countries with the aim of promoting SC and the development of the PV sector, which will allow for greater competitiveness and will result in lower costs, which could lead to a virtuous circle such as the one currently being experienced in Spain.

- Firm support for self-consumption: the restrictive regulations that were approved in Spain in 2015 were a brake on this, paralysing the sector.
- Simplification of costly and time-consuming administrative procedures, especially in small installations.
- Maintain net-metering for the time being as it is easier for prosumers to understand, although in the long run net-billing offers greater advantages and should be taken into consideration. With the current retail tariffs structured in consumption bands, SC is profitable for a significant part of the consumers, which can help the consolidation of a nascent PV sector.
- Introduction of shared SC to allow access for small consumers. The net-metering scheme also allows for easy accounting between participants.

- Support for small installations with progressive fiscal incentives.

In Spain, although SC is very successful, it is also difficult for small installations. Shared SC is a good solution, but it is not without problems that need to be solved, such as lengthy bureaucratic procedures and the optimization of sharing coefficients in the net-billing scheme.

CRediT authorship contribution statement

Ángel Ordóñez: Conceptualization, Formal analysis, Investigation, Methodology, Data curation, Writing – original draft. **Esteban Sánchez:** Conceptualization, Formal analysis, Investigation, Methodology, Data curation, Writing – original draft, Supervision. **Lydia Rozas:** Investigation, Writing – original draft. **Raúl García:** Funding acquisition, Project administration, Writing – review & editing. **Javier Parra-Domínguez:** Formal analysis, Investigation, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Esteban Sanchez Hernandez reports a relationship with INNOVA SL that includes: consulting or advisory.

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