Investment Determinants in Self-Consumption Facilities: Characterization and Qualitative Analysis in Spain

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Abstract:

Self-consumption energy facilities are presented as viable and sustainable solutions in the energy transition scenario in which many countries are immersed. However, they rely on dispersed and private investments in the territory. Given the uneven growth in the number of self-consumption facilities in Europe, the main objective of this study is to identify and measure the investment determinants in self-consumption facilities. To this end, the main influential incentives and barriers are identified through the aggregate analysis of the regulatory framework for self-consumption in several European countries, and the empirical characterization of Spanish facilities as a multiple case study, to define the common features of the investments made. The technical, economic, and financial characterization of real self-consumption facilities in climatic zones of southern Europe is a significant contribution of the present work. There are few samples of this type in the studies published to date, which have mainly been prepared from case studies or statistical data without identifying particular facilities. Cost-related variables have been identified as the most important variables in private investment decisions, and potential influential factors on these variables that could be regulated have been pointed out as relevant. It is also worth highlighting the elaboration of an analytical framework based on this conceptual approach, which has been proven to be useful to depict regulatory scenarios and to compare the positioning for the development of self-consumption systems in different countries. A model that transfers the influence of the determining factors to the deployment of self-consumption under specific regulatory scenarios has been developed and applied to the case of Spain. As a general reflection, to increase the adoption of this kind of technology and encourage consumers to make private investments, policies for renewable energy must consider self-consumption and microgeneration as the main axis, by increasing the availability of energy when necessary. For instance, the promotion of energy storage from these kinds of facilities could receive priority treatment, as well as rewarding the electricity surplus in the interests of security of supply in a period of energy transition towards a new, more sustainable model. Incentive schemes, aids to compensate for the additional costs resulting from the battery storage or easing restrictions in terms of contracted power would foreseeably increase the rates of adoption of the technology, favoring its faster development in terms of research and development and product innovation.

Article

Investment Determinants in Self-Consumption Facilities: Characterization and Qualitative Analysis in Spain

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Keywords: self-consumption; solar energy; investments; remuneration policies; prosumers; drivers and barriers

1. Introduction

The most developed countries are immersed in an energy transition that, in a few decades, will be a new paradigm in energy supply on a planetary scale. In this new scenario, when defining investments in the sector, new elements are added to the usual reliability and price factors, such as the reduction of emission levels, production decentralization, the energy storage capacity at a large scale, changes in consumption patterns, or transport electrification in line with an energy market in a low carbon economy. The progress made by the COP21 (See https://www.un.org/sustainabledevelopment/cop21/ (accessed on June 2018)) agreements reached in Paris reinforces this perspective from the view of a globalized economy and commits the governments of the signatory countries to take it on and promote it with concrete policies.

The complementarity of systems and technologies will be essential to accomplish the sustainability objectives and, given the multidimensional nature of the process, economic and social transformations will acquire higher relevance in view of the need for new technologies, products, services, organizations, norms, and practices to gradually replace the previous ones [1,2].

In the European Union (EU), where the energy transition is largely characterized by global warming, renewable sources are going to be essential [3], as well as the active participation of stakeholders and in particular of consumers, as the European Commission recognizes in its call to develop strategies for its empowerment [4]. Likewise, the consumer will have a relevant role in the evolution of this new energy model, from the choice of supplier in a very competitive market to the production of its own energy supply–also called self-consumption.

According to the general definition [5], self-consumption is considered a process by which a consumer—residential, commercial, or industrial—produces and consumes their own energy (hence the term prosumer), being able to cover their own needs partially or totally. The energy produced is used instantaneously, or later if the installation incorporates storage equipment such as accumulator batteries or other systems such as hydrogen [6]. The self-consumption modality that presents the greatest challenges is that which contemplates the possibility of obtaining a return for the electricity that is produced and not consumed, that is delivered into the grid. These returns can be in the form of income if the injected electricity is considered a commercial transaction (net-billing), or in the form of the right to consume electricity from the grid when it is considered a storage system (net-metering).

Self-consumption solutions allow consumers to participate actively in the energy transition through an effective option for stimulating consumer private capital with lower expectations in terms of rates of return compared to conventional financial investors in the energy sector, which contributes to a sustainable energy transition. In addition to this, self-consumption represents a flexibility mechanism for demand through storage solutions, smart devices, and more flexible contracts for consumers, helping to reduce generation peaks with consequent congestion problems and benefiting the network operators [5].

In this field, the energy policies adopted in the EU have contributed positively to technological renewable energy development and the reduction of their costs.

These policies allow us to analyze the evolution of self-consumption facilities facing specific strategies, to understand the behavior of prosumers as investors, and can partially explain the differences that exist in self-consumption technology penetration among EU countries—a field in which investigations are still required. In fact, the definition and measurement of determinants that motivate investments and their relationship with specific plans for promoting self-consumption, as well as the characterization of facilities or the behavior of investors, are still important subjects of study [7–10].

Previous studies on electric microgeneration in the domestic, commercial, and industrial fields [8,11] provide the basis for the study of investments in self-consumption facilities. Some authors focus their works on European countries where network parity has been achieved [12], so self-consumption with photovoltaic systems can be economically interesting—not only in residential [13] but also in productive sectors, where new incomes could arise [14]. Likewise, competition in the retail market and market transformation

has been studied, as well as the entry into the market of suppliers offering new services in a circular business model and in response to more deep-seated levels of private and public green purchases [15]. Nevertheless, it can be said that the research is still needed, and that empirical studies of many facilities are not numerous so far.

On these bases, the main objective of this study is to identify and measure the investment determinants in self-consumption facilities. To this end, the main influential drivers and barriers in self-consumption determinants are classified through a previous analysis of the applicable legislation. For the first time, an analytical framework for the evaluation of the policies as a means of promoting self-consumption systems is proposed. This framework has been proven to be useful to compare the positioning of the development of self-consumption systems in different countries, and the elaboration of scenarios. Then, the characterization of real facilities and a sensitivity analysis of the most determining technical and economic factors of investments in these facilities, in a European country as a case study (Spain), are carried out. The characterization of self-consumption facilities in climatic zones of southern Europe is a significant contribution, with few samples of this type existing in the studies published to date, which have mainly been prepared from case studies or statistical data from unidentified individual facilities.

This paper is structured as follows: Section 2 explains the research methodology and develops the analytical framework to be used for interpreting the data. Section 3 introduces the results of the empirical research and the application of the proposed approach. Finally, Section 4 discusses the influence of the determining factors for private investment in self-consumption in hypothetical scenarios and summarizes the key aspects for the definition of specific promotion plans. Shortcomings of the proposed approach and future lines of research are also introduced.

2. Materials and Methods

As it is represented in Figure 1, the present work is developed first from an analysis of the background from which the research questions and analytical framework are defined. Next, empirical research is carried out through the characterization of self-consumption facilities as a multiple case study, based on the comparative results of many projects to define the common features of the investments made [16]. This combined research allows a conceptual approach that contributes to the establishment of a framework for the analysis of the influence on the investment decision by factors that could be regulated. This framework is included in a model that transfers the influence of the determining factors to the deployment of self-consumption and can be used to forecast the evolution of the self-consumption sector under specific regulatory scenarios.
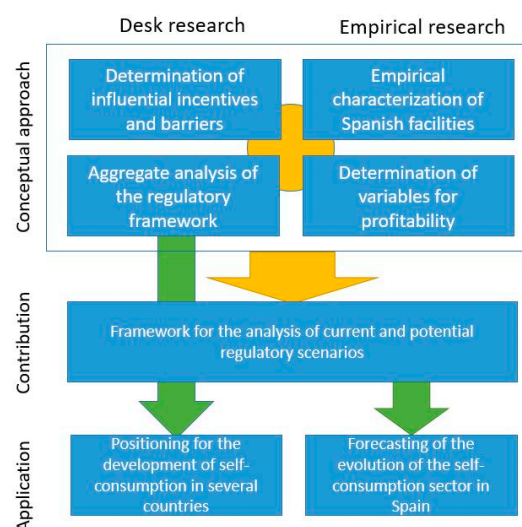

Figure 1. Flow chart depicting the applied methodology and results.

According to the literature, it can be affirmed in general terms that the adoption of innovative systems in a territory is determined by various elements, such as the inherent characteristics of the innovation, the social system structure where the adoption takes place, the diffusion, and the level of information in the territory, and the time frame [17,18].

In the framework of institutional theory [19], several authors postulate that, in addition to the rational decision of the investor, non-financial factors affect the adoption of new energy technologies [20–22], and decision-making to invest in renewable energies [9] or the application of environmental management criteria [23]. To this end, it is essential to analyze the decision-making process of investors with the objective of identifying the main determinants of their choices, particularly for those groups of investors with short-term horizons, as they are especially sensitive to institutional and related agent pressure.

In recent years, agent-based simulation models (ABM) have been widely used to simulate the inherent complexity of the adoption process of innovative photovoltaic installations [7], defining the utility function of these investors as four factors linear one: advertising, social environment, income level, and period of investment recovery [24].

It should also be considered for the benefit-cost analysis of these facilities that, in the environmental literature, it has been found that a household can value a product even if it does not consume it [25] and, therefore, in the case of self-consumption, it may be relevant for the evaluation of the investment to take into account the perception of households of the environmental component of these facilities. It should be noted that even households with a lower income can support environmental activities for a zero-emissions future in a similar way to higher income households [26].

It can be considered as widely accepted that the decision to invest in self-consumption photovoltaic systems would be influenced by economic factors such as household incomes or the investment recovery period, but also by the self-interest of minimizing the effect of possible increases in electricity prices. To these economic motivations, the desire to reduce the energy dependence of the network and to contribute to the reduction of environmental impacts can be added. However, the priority over other criterion appears more clearly in studies based on the answers provided by potential or present investors.

In summary, based on the previous studies and to analyze the possible impact on the future development of self-consumption facilities, the factors that would influence the decision of investors can be classified into attitudinal type factors and contextual type factors. In the first group there would be factors such as the perception of the households, environmental beliefs, uncertainties, and non-monetary costs. All of these can be modified through dissemination and information campaigns. In the second group, social factors such as income level and demographic characteristics, as well as economic factors such as the equipment costs, the electricity tariff, the demand profile, and the compensation of an electricity surplus would be included. Contextual factors configure the framework in which investments can be analyzed from a monetary point of view.

In the scientific literature, the aim of these investments to contribute to improving the environment plays a secondary role in most of the published studies [8,27,28]. Leenheer et al. [29] proposed a different perspective in which the main motivation is not economic, since through a sample of 2000 Danish households surveyed, the obtained economic benefit was less relevant than other investor motivations. However, it is worth mentioning that this was a study on households that did not have the installation yet, and the authors concluded that the economic motivation would be basically moderating the relationship between intention and behavior. Therefore, it is an issue that continues to be the object of study, and while it has motivated the work of some authors, papers are still few in number so far.

In this area, Balcombe et al. [8] used qualitative research through 291 surveys to investors in a microgeneration to identify the main motivations of saving or making money with the installation, increasing independence, and protecting themselves from an increase in the price of energy in the

future. Similarly, the 197 respondents of the study of Jager [30], who were all owners of a photovoltaic installation, placed economic and environmental reasons at the same level of priority.

In the work of Engelken et al. [28] on a sample of 395 households in Germany, economic benefits and autonomy were also identified as priority factors, followed by environmental awareness and affinity with technology. Likewise, the majority of the 200 German households surveyed by Korcaj et al. [27] were potentially willing to install self-consumption photovoltaic systems if costs were low. The authors concluded that there was a need to promote energy storage systems that increase independence and economic savings, while reducing the perception of risks through a standardization system.

Social motivations also appear in some studies, with some of the analyzed investment determinants including the obtaining of social status [27], the establishment of networks [30], or the effects of between pairs [31].

The still incipient status of these investments in some countries has motivated the analysis of drivers and barriers in self-consumption. Among the latest investigations, the low rates of return on investment are frequently mentioned as one of the main obstacles to the take-off of these facilities in all EU countries [8]. However, some authors have demonstrated the profitability of photovoltaic systems in the residential sector in various scenarios, depending on the combination of supply and demand involving a significant increase in the self-consumption of energy [32]. These research studies reached the conclusion that, when market maturity is accomplished, a subsequent phase to the incentives can be initiated in which they will no longer pay aids to electricity generated from renewable sources, entailing a reduction in the specific tax burden applied to consumers and companies.

Among the works focused on the barriers, Michaels and Parag [33] analyzed a 509-respondent sample, and although the results showed some peculiarities of the Israeli context, universal barriers were identified including trust in the institutions that supervise the programs, health care and data protection problems, the high initial cost, social norms, the economic incentive structure, and reduction of energy demands. They concluded that financial incentives could solve some of these barriers.

In another quite clarifying study, Palm [34] tried to identify the reasons why the photovoltaic self-consumption facility evolution in Sweden was very different in different municipalities, and identified the role played not only by the prosumers but also by the rest of the stakeholders. They mentioned, for example, the driving role played by the utilities with the purchase of the electricity surplus, and by the installers with the sale and dissemination of turnkey facilities.

It is important to consider that motivations and incentives may vary with the market situation [35]. Thus, Palm [36] showed that at the time when the sale of the generated electricity was permitted in Sweden and the regulation was expanded, the investor in self-consumption facilities perceived new barriers related to an increase in administrative burdens and the difficulty of finding information about the market agents, which led to a higher interest in turnkey facilities. In fact, "planned value" is an individual and intrinsic characteristic of the investor and includes not only the cost of equipment and installation, but also non-monetary costs such as the cost of searching for information and uncertainty about future performance, operation and maintenance needs, and the perception of quality, sacrifice and opportunity cost [37,38].

In any case, we must bear in mind that the inherent business of self-consumption facilities is largely defined by each country's regulations through permitted return schemes, a fact that in principle could be explained by the disparate penetration of self-consumption existing among EU countries. The case of Spain is particularly noteworthy because of the small number of facilities to date.

To classify the corresponding drivers and barriers to self-consumption facilities induced by regulations, the legal framework in several EU countries—specifically Germany, Spain, Italy, France, and Portugal—was analyzed.

The selection of these mentioned countries responds to two criteria: on the one hand, their special relevance in the EU in terms of population, and on the other hand, their expectations of self-consumption investments because of their geographical location, since they are mostly

located in center-south Europe and because of the solar radiation levels that make them suitable for these installations.

The analysis was carried out in two phases. Firstly, the existence of a specific legislative framework that allows and orders the implementation of self-consumption facilities. Secondly, the possible extension of this right to third parties is taken into consideration; that is, whether the country regulations allow for solutions in which the owner of the self-consumption facility is different from the holder or holders that consume the generated electricity. In this sense, the idea is to find out specifically if the implementation of facilities based on power purchase agreements (PPA) as well as shared self-consumption facilities would be authorized—a very favorable and feasible solution in countries with mostly horizontal properties. Appendix A Table A1 summarizes the main characteristics of the different policies supporting self-consumption and the schemes they contemplate, especially those related to net-metering and net-billing, in the countries of southern Europe and in Germany as a reference for this type of facility.

In summary, Germany is the country that stands out for installed photovoltaic power because of the reduction of the prices of facilities and the high electricity rates. As a general point, it is worth mentioning that in this country there are progressive surcharges for self-consumption and other renewable facilities calculated on self-generated electricity, though facilities with an installed power of less than 10 kWp and an annual generation of less than 10 kWh are exempt [39].

It can be held that the European country of the Mediterranean Arc that is exemplary in the promotion of self-consumption is Italy, where surcharges are also available to the facilities to contribute to the electrical system costs (except for installations of less than 3 kWp), and with reduced annual fees for the facilities. In addition, in this country the installations connected to the network have the right to receive remuneration for the injected energy that is compensated for by the cost of the consumed electricity from the network [39].

In Portugal, Law 153/2014 allows the connection to the grid of renewable facilities below 200 kW and with an annual limit of 20 MW, facilitating self-consumption by legalizing the sale of an electricity surplus to the grid. The limit of an installed facility capacity is established according to the contracted power. This Law seeks a paradigm shift that helps maximize local electricity production, favoring a more direct market structure free of subsidies. However, the regulation protects the electricity system by a provision of compensation once the self-consumption penetration reaches 1% of the installed capacity. The surplus that is injected into the network is remunerated at 90% of the average price of electricity in the majority market. The remaining 10% is used to compensate for commercial energy costs and the purchase guarantee. The new remuneration mechanism is based on an auction model [40].

The Spanish self-consumption regulatory framework was one of the most restrictive in Europe for quite time, despite Spain having the highest rates of solar radiation in the EU [41]. In 2012, through the so-called "Moratorium on renewable energies", established in Royal Decree law 1/2012, January 27, the pre-assignments of remuneration and the economic incentives were removal of new installations for electricity production from cogeneration, renewable energy sources, and waste.

Later, the regulatory framework for self-consumption in Spain was established fundamentally with the promulgation of the Royal Decree 900/2015, October 9, which regulates the administrative, technical, and economic conditions of the supply of electricity from self-consumption and production from self-consumption [42]. This Royal Decree made possible the legal continuation of self-consumption facilities that had been carried out before its publication. It is worth mentioning that, after the publication of the Royal Decree 900/2015, an incipient jurisprudence (Constitutional Court Sentence 68/2017, 25 May 2017, which estimated the appellant's recourse regarding articles 4, 19, 20, 21 and 22, regarding the so-called "shared self-consumption", and in the needs for National registration of self-consumption facilities. This Sentence annuls the third paragraph of the Fourth article, which prohibited a generator from connecting itself to the internal network of several consumers; Sentence of the Supreme Court 3531/2017 that supports, at the request of the

appellants, the existence of fixed and variable charges for self-consumption facilities, for compensating the backup that the electricity system provides to the consumer at the moment that the contribution of the generation is insufficient and must resort to network supply) has been generated in the matter that will let new normative developments in the near future be opened, at the nation level as at the regional level, since the regional registration of this type of facility is required.

To use and interpret the information, an analytical approach is proposed. Having read the different regulations, common aspects were ascertained and classified according to the topic that is taken into account, and if they play as drivers or barriers. Next, with the goal of making a comparative analysis of the legal framework in each country, and in addition to detecting the existence of the previous disaggregated factors, each incentive and barrier is assigned a score according to the level at which the regulation limits or favors self-consumption in each country. The scale selected for this purpose is between -3 and $+3$, with the lowest score representing the measures that hinder self-consumption with higher intensity, and the highest representing the measures that favor self-consumption implantation (This classification of the qualitative approach has been carried out by the authors as members of the research team through the average of the individual valuations of the legal frameworks).

Regarding the advantages and incentives, the following aspects were considered and categorized as drivers:

- Driver_1: Aspects unrelated to the surplus electricity sale, among which are the economic savings of self-consumption obtained by the installation owner of accreditations for the generated green energy or for the fossil energy savings and, consequently, vouchers, deductions or bonuses that the holder can receive.
- Driver_2: Aspects related to the self-generated electricity surplus sale: if it is possible to inject the electricity surplus, and if it is possible to charge for this injected electricity and what formula is used for calculating the income.

Likewise, the time duration and geographic scope of the incentives and their possible effects are analyzed.

- Driver_3: Regarding the duration of a possible compensation for the generated and injected electricity into the distribution network: whether this compensation is in real time, on a daily basis, or through a net energy or economic balance (that is, if injected energy into the network can be netted at any time without economic liquidation or includes it).
- Driver_4: If the compensation for not consumed and injected self-generated electricity could be demanded in a location different from the place where the self-consumption installation is located.
- Driver_5: Regarding the duration of the compensations and incentives framework that the regulation must promote this type of facility.
- Driver_6: Regarding additional incentives that either facilitate their implementation or represent a certain advantage, such as incentives to incorporate energy storage systems.

Next, factors that may discourage or hinder the implementation of self-consumption facilities were taken into consideration as barriers:

- Barrier_1: Limitations on the self-consumption generation capacity or existence of power ranges with different regulatory implications.
- Barrier_2: Existing limits to incorporation of the new self-consumption installations (for example, annual or as a percentage in reference to the of total generation power of the country).
- Barrier_3: Economic obligations of self-consumers related to the maintenance, operation, and sustainability of the transport and distribution network.
- Barrier_4: Existing general costs, such as rates for self-consumption, or specific costs to each installation such as, for example, the existence of a network backup charge.

- Barrier_5: Restrictive regulatory requirements regarding the connection, regulation, and measurement of facilities, as well as the technical instructions for the electrical installation.

Table 1 classifies the drivers that may influence self-consumption in each country, while in Table 2 the barriers are presented.

Table 1. Regulation impact on the set of drivers for self-consumption.

	DRIVERS	Germany	Spain	Italy	France	Portugal	Remarks
Driver_1	Other income	0	0	0	0	1	Green credits
Driver_2	Injection income	2	0	3	2	−1	More positive is considered if income is higher than the whole market price
Driver_3	Third party right extend	3	−1	1	−3	1	More positive is considered when greater extended
Driver_4	Geographic compensation	0	0	0	0	0	
Driver_5a	Framework duration (short term)	0	0	0	0	0	
Driver_5b	Framework duration (long term)	2	3	3	2	2	More positive is considered if longer
Driver_6	Other drivers	1	0	0	1	0	Incentives for accumulation batteries
	AGGREGATED SCORE	**8**	**2**	**7**	**2**	**3**	

Table 2. Regulation impact on the set of barriers for self-consumption (own elaboration).

	BARRIERS	Germany	Spain	Italy	France	Portugal	Remarks
Barrier_1	Particular limits	0	−1	−1	3	−1	More negative if installation power must be less than or equal to contracted power
Barrier_2	Aggregated limits	−1	1	3	3	−2	More negative if limits
Barrier_3	T&D charges	3	−3	−1	3	−1	More negative if surcharges
Barrier_4	Additional costs and restricted codes	−1	−3	3	−1	−3	
Barrier_5	Others	−1	−1	0	−1	0	If surcharges for accumulation batteries
	AGGREGATED SCORE	**0**	**−7**	**4**	**7**	**−7**	

Finally, the result of the previous approach is shown in Figure 2, which displays the aggregate positioning of barriers and drivers in each country in terms of the implementation of self-consumption facilities:
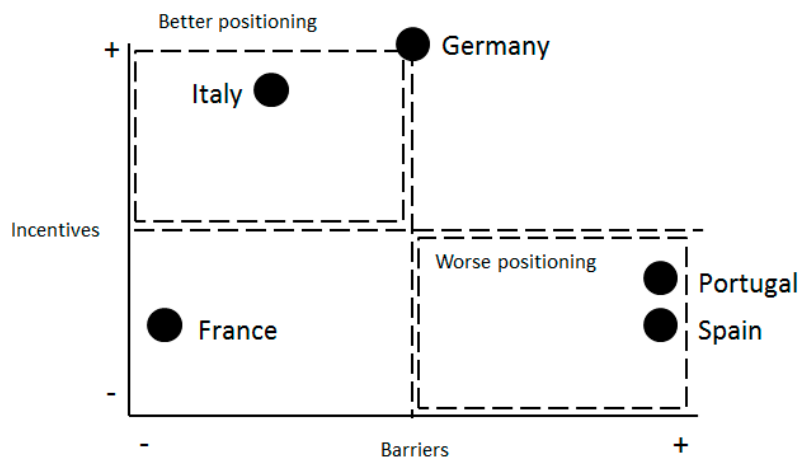
Figure 2. Current positioning for the development of self-consumption systems (own elaboration).

It can be observed that the best position for self-consumption support is accomplished by Italy, as a result of its regulations containing net-metering, feed-in-tariff (FiT) income, and a stable regulatory framework that reduces the effect of possible obstacles to the installation of this type of plant.

Germany has more advantages and incentives for self-consumption plant installation (FiT income, facilities for the realization of PPA and shared self-consumption, and a stable regulatory framework for 20 years), although the introduction of charges for facilities above 10 kWp make its situation worse than Italy.

The comparative analysis of France lets us consider it as a country that hardly imposes obstacles for self-consumption installation (without charges for maintenance of the transport and distribution network, and without limitations or ranges of power) but restrictions on the extension of the rights for self-consumption to third parties make the other advantages provided by France worse, due to accumulator aids and the timing of their incentives.

Portugal and Spain show the worst position because of their transport and distribution network maintenance charges, the imposition of additional costs ("sun tax" in Spain, registration costs in Portugal), and the annual limitation quota for Portugal of 20 MW for new facilities. Revenues for surplus energy injected into the network are paid at the wholesale market price in Spain, and at 90% of the wholesale market price or based on an annual auction in Portugal. Portugal incorporates better treatment of the implementation of facilities by third parties, but nevertheless the duration of the legal framework of self-consumption has a limitation of 20 years that Spain does not impose.

Based on the previous analysis, and to define the self-consumption investment determinants and thus to advance the knowledge in this field to favor the decision-making process, the following research questions are posed:

- (R1) What are the common characteristics of the investments made in self-consumption facilities in Spain, and how can their impact be measured in investors' decision-making?
- (R2) What are the determining factors for profitability and how can they improve the positioning of self-consumption facilities?

Most of the research work on regulation and the impact of self-consumption activity in Spain to date has focused on the comparative analysis of different alternatives in terms of the profitability of the facilities [43], its incidence on public collection [41], the return periods for investments [44], the electricity costs for photovoltaic self-consumption [45,46] or, more generally, the data-based evolution of photovoltaics at the national level [47,48].

In a case study on the profitability of photovoltaics in Spain, a 17–18-year payback period was considered [44]. Likewise, the profitability of self-consumption photovoltaic systems was evaluated for the Italian regulatory framework by carrying out a survey of 750 companies with systems of between

3 kW and 1 MW. Using the discounted payback time as an economic feasibility indicator, return periods from 5 to 6 years were found for residential installations, from 6 to 8 years for large systems (1 MW), and above 12 years for smaller commercial and industrial facilities [49]. Results are also available in Italy for the relevance of aids and incentives for photovoltaic self-consumption [50]. Disparities in these feasibility results could be linked with the different types of installations.

There are many different definitions of net-metering and net-billing schemes depending on the specific economic and engineering criteria involved [51]. Net-metering can be considered as both self-consumed electricity and surplus electricity being valued at the same retail price; or, otherwise, net-billing can be considered the surplus electricity being valued at a price lower than the price at which it is purchased on the network. It is defined as "exclusive self-consumption" when the surplus of electricity is not at all remunerated [52].

Another determining factor is the level of maturity of the market. Some mathematical models define the break-even-point of the increase of self-consumption, which is the point at which residential PV battery systems become economically viable in a mature market. Energy storage systems are useful only when the relationship between supply and demand permits them to induce a significant increase of energy self-consumption [32]. However, the uncertainties in consumption forecasting models must also be taken into account [10]. In general, greater deviations are observed due to the application of an unrealistic consumption profile, and the effect on the forecasts depends mainly on the volume of taxes on self-consumption and the relationship between the production of photovoltaic energy and annual consumption.

As for the application methodology and the variables under study, another topic of interest is the cost of storage. In this area, results achieved through a simulation made from a data sample of 30 households are used to determine the degree of electrical self-consumption, as well as the costs and economic benefits of the facilities, demonstrating that households consume on average 49% of the electricity generated, not including the contribution of batteries [53]. With a subsidy of capital equivalent to the cost of a small battery (2 kWh), it has been demonstrated that these systems would be economically viable without any doubt for the average household. Therefore, small to medium capacity batteries need attention in energy policy aimed to promote microgeneration, in view of the future rise in electricity prices.

In addition, results obtained in previous studies indicate that, under the current conditions in Spain, the direct economic impact of the self-consumption of photovoltaic energy on the total revenues of the government and the electricity system is positive for investments in the residential segment, insignificant for the commercial segment, and negative for the industrial segment [41]. For this reason, the analysis of the determinants of the investments and the legal framework has been carried out, proposing possible actions to increase the number of photovoltaic self-consumption facilities at a minimum cost for the electrical system in accordance with the guidelines of good practices of the European Commission on the self-consumption of renewable energy [54].

Thus, given the complexity of the phenomenon and the interplay of many factors, the application of qualitative methodologies of analysis through facilities as a multiple case study is chosen. This methodology allows us to overcome the limitations of the scope of quantitative information and provides a deeper vision for the analysis of innovative environmental investments [55,56], both in the specific aspects of the case studies analyzed [57] and in the definition of theoretical approaches [58,59].

For this purpose, the data of 35 photovoltaic self-consumption installations in Spain, for which ample information about their technical characteristics and economic and financial aspects is available, are compiled and analyzed (Thanks to the collaboration of the company FENÍE ENERGÍA, 35 self-consumption facilities in Spain that were promoted by this company between 2016 and October 2017 could be analyzed).

In light of this, the selected characteristics of the installations that make up this empirical study are detailed in Appendix A Table A2. They include the climate zone, which is a determinant of solar radiation levels; type of installation; installed capacity; consumer profile (residential,

industrial or services); cost of the installation; financing rate; power contracted in the case of installations connected to the grid; and annual electricity production.

It should be highlighted that obtaining information regarding the internal costs and specific operational conditions directly from installed systems is not an easy task, and it means a smaller number of valid observations. Even though the sample was given by a unique company, the analyzed systems are fully identified, and this allows us to integrate all the data for the empirical analysis. In addition, it can be considered a relevant sample of the systems installed in Spain (At present in Spain, approximately 1266 systems are registered in the public register of the Spanish Government. The specific modus operandi of the Company FENÍE ENERGÍA must be considered because it only promotes facilities that are carried out by independent installers. This means that the analyzed sample is heterogeneous with regards to the equipment and operational conditions and can be considered as relevant in the geographical context of the country).

To identify the common features of these installations, a statistical-descriptive analysis has been applied and the results are shown in Section 3.

Once the most important variables in the private investment decisions have been identified, potential influential factors on these variables that could be regulated are apparent and have been described.

However, the impact of these incentives and barriers would not be the same for the different types of self-consumption facilities. To obtain a forecast of the evolution of the self-consumption sector, a model that transfers the influence of the determining factors to the deployment of self-consumption under specific regulatory scenarios has been developed.

3. Results

To figure out the common characteristics of the investments made in self-consumption facilities in Spain, an analysis of a sample of well-documented installations has been carried out.

The installed peak power was lower than 10 kW in 77% of the cases. The cases studied have always been low voltage and with a contracted power of less than 100 kW. Figure 3 shows the size of the installations.
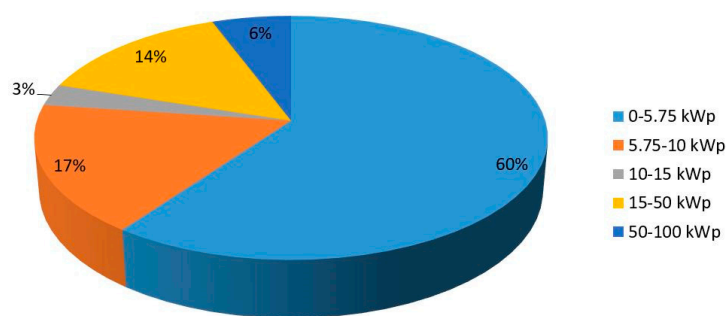

Figure 3. Size distribution of the installations.

By means of a statistical-descriptive analysis, it can be observed that the installations have been mounted in the two climatic zones with the highest solar incidence: 89% in climatic zone IV (from 4.6 to 5 kWh/m^2) and 11% in climatic zone V (more than 5 kWh/m^2).

As shown in Figure 4, the facilities under study were mainly in residential buildings and connected with small and medium companies, although two solar pumps (isolated installations with self-consumption to pump water for later irrigation) were also studied. Installations have been also classified according to consumer profiles: domestic (43%), industrial (20%), and services (37%).
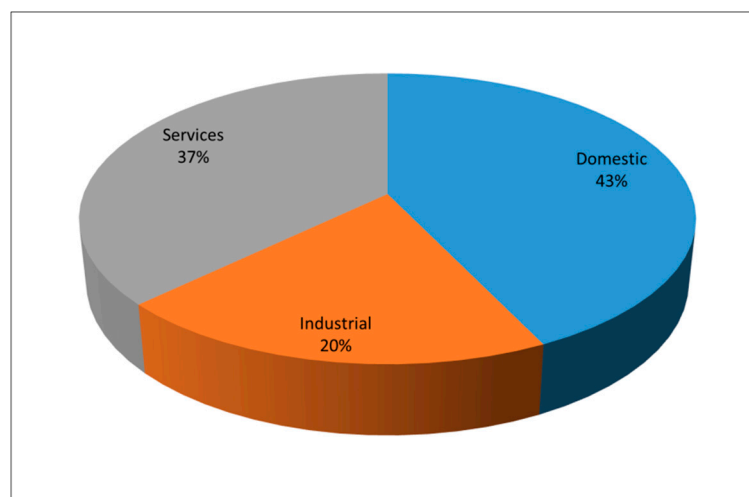
Figure 4. Type of consumer owner of the self-consumption facility.

Regarding the technical execution, as it is shown in Figure 5, the installations studied have been mainly isolated with batteries (43%) and grid-connected without remuneration (40%), with a lower incidence of isolated (14%) or connected with which the surplus electricity is sold to the grid (one installation, 3%).
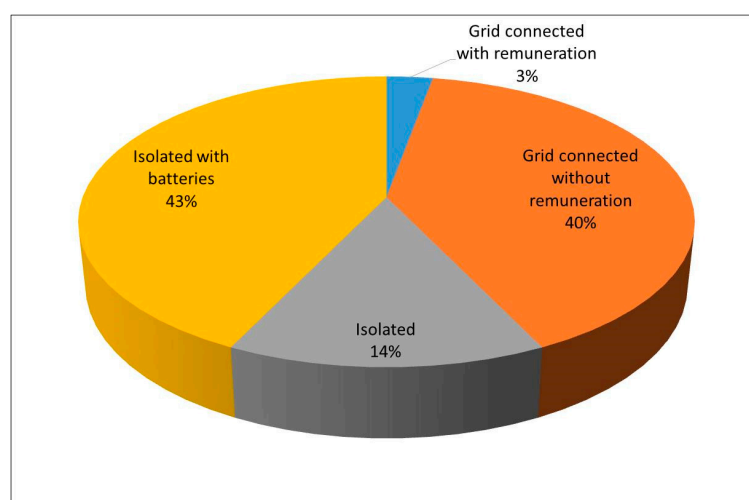

Figure 5. Type of installation.

Installations have had a medium-low investment, from €2200 to €255,000, with an average of €24000. A total of 91% of the installations were financed by the energy company that executed the keys-hand installation, with financing periods between 4, 5 and 8 years.

The profitability of the facilities was evaluated through the calculation of the economic return period of the installation, based on the following data and considerations. The cost of the installation is a known fact of the contract signed between the client and the energy company that carried out the execution of the turnkey project. The total amount includes the cost of materials, equipment, structure, installation, legalization, project or report, financing if applicable, and gross margin of the installation company.

For the characterization, the lifetime of the investment is assumed to be equal to 20 years, although the lifecycle of a PV panel is usually assumed to be 25 years. The inverter of the installation has a useful life of more than 10 years, so it is expected to be replaced, at least once, within the lifetime

of the investment. The cost of the investor accounts for 15–20% of the installation, and experiences a relative cost influenced by the scale factor. The accumulators of energy (batteries) have a useful life of about 8–10 years, so the installations must amortize, if necessary, the batteries at half the life of the installation. The cost of the batteries represents approximately 20% of the cost of the installation depending on the type of batteries installed, and on the depth of discharge in the use of the batteries. The lag between the useful life of the installation and that of its components has been contemplated by incorporating the weighting factors on the initial investment, as summarized in Table 3.

Table 3. Weighting factors on the initial investment due to component replacement.

Installation's Components	Factor
Installations with inverter and without batteries	1.2 €/Wp
Installations with batteries	1.1 €/Wp
Installations with inverter and batteries	× 1.2 × 1.1 €/Wp

The loss of efficiency of the photovoltaic modules is introduced in the study by means of an annual decrease factor of 0.8%. Likewise, an increase in the cost of annual electric energy with a value of 3.5% has been factored in. This energy cost is supported by the increase in electricity prices reflected in the Spanish National Statistical Institute reports of the general consumer price index (CPI) and the energy CPI, despite their short-term volatility. It should be mentioned that the analysis does not include any type of maintenance of the facilities, which usually has a lower impact on the cost of the installation and that, in the types of self-consumption studied, is the responsibility of the owner of the installation.

The execution of the self-consumption facilities studied involves avoiding an equivalent amount of energy demanded from the distribution network or generated by generating sets (in isolated installations), or that of an opportunity cost of consumption not implemented due to the technical or financial difficulty of the interconnection with the distribution network. The cost of this energy in the interconnected installations has been realized by means of a valuation of the cost of said energy at the cost regulated by the voluntary price for the small consumer (PVPC, PVPC tariff is a regulated tariff designed for private consumers), during the year 2016 (middle price) for contracted power supplies equal to or less than 10 kW. For powers greater than 10 kW, the corresponding adjustment has been made by applying the corresponding access tariffs. In summary, the prices applied are detailed in Table 4.

Table 4. Price of the avoided energy by power ranges.

Contracted Power (Kw)	Price of the Avoided Energy (€/kWh)
Pc ≤ 10	0.104393
10 kW ≤ Pc ≤ 15 kW	0.117726
Pc > 15 kW	0.072941

The opportunity cost of not implementing activities that involve electricity consumption, and that can be carried out with the self-consumption installation executed, is valued at most as the cost of using the generator set. These costs are affected by the so-called energy CPI explained above (3.5%) during the 20-year life of the facility. For each installation, this includes the energy expected to be generated in 20 years (in kWh), the total updated cost of the installation considering the entire useful life (€), the unit cost (€/Wp), the cost of electricity not acquired from the network (€), and the return period (in years).

This study does not include charges for variable self-consumption to interconnected plants (77% of the facilities analyzed are 10 kW or less of contracted power and are exempt and do not affect isolated

installations). The analyzed facilities, except for one of them, are self-consumption plants Type 1 and, therefore, are not remunerated for surplus electricity.

In summary, the results show initial costs of the installation between 0.73 and 10.14 €/Wp, with an average cost of 3.3 €/Wp, and return periods between 3 and 22 years and with an average period of 9 years.

In the next figures, considerable differences can be observed depending on the type of installation, as reflected in the following graphs that show the statistical analysis of the data collected for the 35 facilities.

It can also be observed in Figure 6 that the isolated installations have lower return periods than the installations connected to the network, even though their initial installation costs are higher, since they cover electrical consumption that would otherwise have a high cost for generating energy. In the case of self-consumption facilities in grid-connected supplies, the investment costs are between 0.73 and 3.71 €/Wp (with an average of 1.93 €/Wp), which is substantially lower than those of the isolated facilities given the smaller size of the batteries. However, as it is shown in Figure 7, they have return periods of between 4 and 22 years, with an average of 12 years.
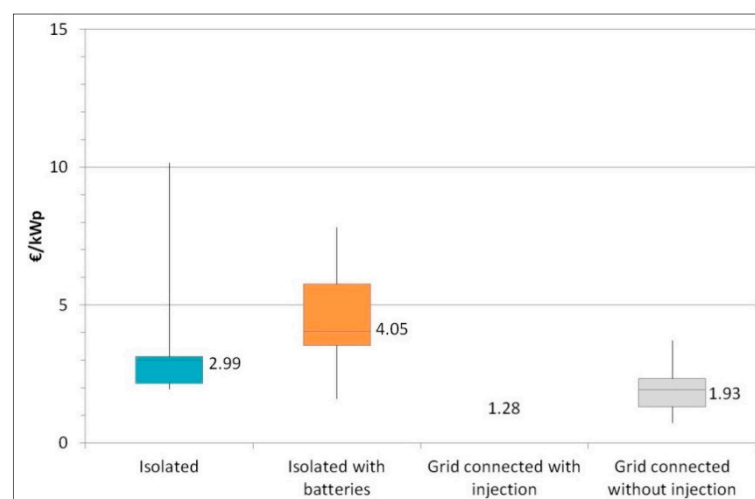

Figure 6. Unit cost of the installation (€/kWp) according to its connection to the network.
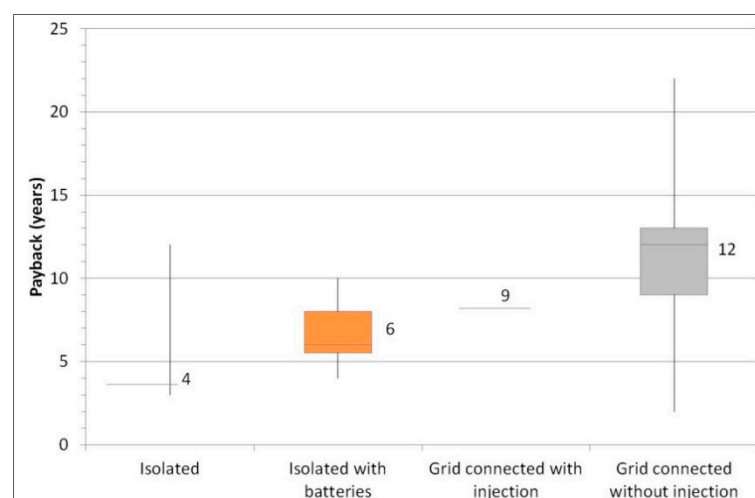

Figure 7. Payback of the facilities according to their connection to the grid.

Additionally, as expected, isolated installations with accumulators have higher return periods and initial investment costs than isolated plants that do not have energy storage elements. The only exception is the case of solar pumping with a return period of 12 years due to the high cost of the installation, which is heavily influenced by the costs of the auxiliary pumping equipment for storage in the tank and subsequent impulsion for irrigation.

As a general result, it can be affirmed that the cost of the avoided electrical energy is of key importance in the economic return of the investment for the considered installations. The profitability is particularly favorable (faster economic return) for those customers who pay for electricity at a higher price (domestic customer or electricity produced in a generator set) and worsens for customers with more power contracted and with an average price of lower electricity.

In short, the improvement of the profitability of self-consumption facilities is related to the possibility of increasing the difference between the levelized cost of the produced electricity (LCOE) and the grid electricity price. In a scenario with stable grid electricity prices and according to the LCOE definition [60], this increase can be achieved by reducing the investment (mainly reducing the cost of batteries), reducing operating costs (basically, decreasing the power contracted or reducing taxes), or by increasing revenues from economic returns through the injection of electricity into the grid, even at wholesale market prices (The producer under the self-consumption modality receives the corresponding financial compensation according to the regulations in force, according to article 14th of Royal Decree 900/2015, which regulates the conditions of self-consumption in Spain. From Decree Law 9/2013, of July 12, and Royal Decree 413/2014, of June 6, no specific remuneration is applied in Spain to the discharge of electric power to the net, so the producer only receives the hourly price wholesale market income. OMIE manages the wholesale electricity market on the Iberian Peninsula and reports the intra-daily market prices at http://m.omie.es/reports/index.php?m=yes&report_id=121&lang=en#).

After identifying that cost-related variables are the most important in the investment decision, potential influential factors on these variables that could be regulated must be pointed out.

To illustrate how a small change in the incentives and barriers related to the above economic variables would encourage self-consumption, the same methodology used for the analysis of the comparative legal framework has been applied. Economic savings and incomes could be favored with policies related to Driver 1 and 2 and would mean a higher score for them. Reducing the cost of batteries would be possible with incentives for the incorporation of energy storage systems, which would mean higher scores for Driver_4 and Barrier_1. Finally, policies aimed to reduce economic obligations related to the transport and distribution network would improve the scores for Barrier_3 and 4. Only one level of improvement (one scoring point) has been considered for Drivers_1, 2 and 4 and Barrier_1, and three levels of improvement have been considered for Barrier_3 and 4.

Ultimately, in this favorable scenario incentives and barriers would take the values shown in Table 5, leading to a better position in the matrix of incentives and barriers as shown in Figure 8.

Table 5. Impact of regulations on the incentives and barriers to self-consumption in current and the favorable scenarios.

| Incentives and Barriers		Current Scenario	Favorable Scenario
Driver_1	Other income	0	1
Driver_2	Injection income	0	1
Driver_3	Third party right extend	−1	−1
Driver_4	Geographic compensation	0	0
Driver_5a	Framework duration (short term)	0	0
Driver_5b	Framework duration (long term)	3	3
Driver_6	Other drivers	0	1
Barrier_1	Particular limits	−1	0
Barrier_2	Aggregated limits	1	1
Barrier_3	T&D charges	−3	0
Barrier_4	Additional costs and restricted codes	−3	0
Barrier_5	Others	−1	−1
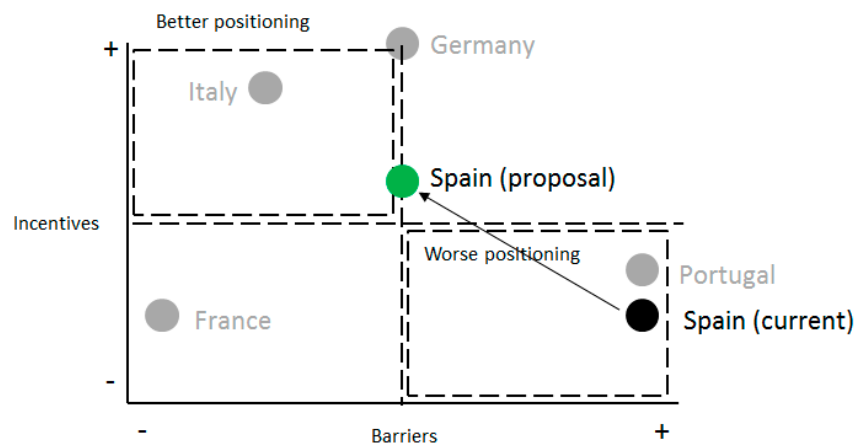
Figure 8. Favorable positioning for the development of self-consumption systems (own elaboration).

However, the impact of these incentives and barriers would not be the same for the four types of facilities identified.

A model that transfers the influence of the determining factors to the deployment of self-consumption under specific regulatory scenarios has been developed and applied to the case of Spain.

Three scenarios (most likely scenario, best-case scenario, and worst-case scenario) have been considered. They incorporate hypotheses regarding the evolution of the variables of influence with respect to a theoretical static scenario, in which there were neither positive nor negative changes—also called "business as usual" (BaU)—that would be the equivalent to the current. Considered factors because of their relevancy are those shown in Table 5: Driver_1, Driver_2, Driver_6, Barrier_1, Barrier_3, and Barrier_4.

Table 6 shows the influence level (low, medium, or high) that each incentive or barrier has on the profitability of each of the considered types of self-consumption facilities:

Table 6. Weight matrix (own elaboration).

Type of Installation	Driver_1	Driver_2	Driver_6	Barrier_1	Barrier_3	Barrier_4
Isolated	Low	Low	Low	Low	Low	Low
Isolated with batteries	Low	Low	High	Low	Low	Low
Grid-connected without injection	Low	Medium	High	High	High	High
Grid-connected with injection	High	High	Medium	High	High	High

Table 7 summarizes the assumptions regarding the evolution occurring in each of the three proposed scenarios. Again, three levels of trend or estimated variation for each variable (incentive or barrier) have been chosen in each of the scenarios. An increase ("+") means a positive evolution, a decrease ("−") implies a negative evolution, and a stagnation ("=") indicates absence of significant variation of the variable with respect to the current situation.

The best scenario for the promotion of self-consumption therefore requires that all the variables evolve positively ("+"), while the worst case will be given by a worsening or stagnation ("−"). As stated above, the "business as usual" scenario is a hypothetical case in which there is no change to the current situation.

The evolution of the influential variables in each scenario will have a greater impact on self-consumption depending on the importance that these variables have for the profitability of the facilities of each type.

Table 7. Definition of scenarios for self-consumption (own elaboration).

Incentives and Barriers	Best Case	Most Likely	Worst Case	Business as Usual	Explanation
Driver_1	+	=	−	=	Positive evolution means rising grid electricity prices
Driver_2	+	=	−	=	Positive evolution means rising prices for injected electricity
Driver_6	+	+	−	=	Positive evolution means reduction in battery costs
Barrier_1	+	+	−	=	Positive evolution means reduction in installation costs
Barrier_3	+	=	−	=	Positive evolution means reduction in T&D charges
Barrier_4	+	=	−	=	Positive evolution means lessening limitations

Assigning values 1, 2 and 3 for the selected resolution level and combining the weight matrix with the evolution matrix for each scenario, a number from 1 to 9 will be obtained regarding the positive or negative influence of each of the variables in each of the subsectors for each scenario, with 9 being the maximum positive influence (greater impulse to self-consumption) and 1 the maximum negative influence (less impulse to self-consumption). From the average values for each variable in the three scenarios, the most probable percentage of relative variation with respect to the static scenario is calculated.

4. Discussion

The present analysis has allowed definition of the variables for the characterization of 35 self-consumption facilities of low voltage supplies with power less than 100 kW in Spain. There are few samples of this type in the studies published to date, which have mainly been prepared from case studies or aggregated data. Given that particular facilities have been identified, this study provides an interesting advance in empirical knowledge because of the geographical scope, the type of investor, the number of facilities, and the scope of the data analyzed—both that which is inherent to the technical characteristics, as well as the economic and financial aspects.

As a general result, it can be affirmed that the cost of the avoided electrical energy is of key importance in the economic return of the investment for the considered installations. This is in line with the results obtained by other authors, thus providing a response to the research question posed (R1).

With regards to the installation costs and return periods obtained, the results can be explained by the separate analysis of two types of configurations: isolated and grid-connected installations. Both types have different implementation and maintenance costs, which are higher for the isolated installations due to the batteries, as well as very different savings. This has a bearing on the payback period and the lowest values were found for the isolated installations in the sample under study.

It is also worth noting the self-consumption facilities carried out in low-power homes (less than 10 kW) or other customers in other sectors with access to the network and therefore, with easy access to the power extension or total coverage of their needs through the distribution network.

Likewise, the presence of isolated installations demonstrates that self-consumption allows the resolution of situations with a lack of access to electricity, even with long periods of return on investment. In this sense, solving a basic need such as the access to electricity can be a priority over the economic cost.

However, it should be noted that the low return periods for isolated installations are linked to the high cost of generating electricity through the generator sets that are the most common equipment for this type of supply (maximum cost is also assigned to the opportunity cost for those customers who, even if they do not make such an investment, do not implement a possible solution with connection to the network). It is reasonable to think that these high generation costs can be avoided in some cases.

In this case, an estimated 12-years payback period for the interconnected facilities seems to be more realistic and similar to results obtained by Chiaroni et al. [49] and could be a more representative value for both types of installations. These long periods of return could justify the low level of implementation of this type of facility, except when other motivations such as the need for electricity, innovation, or environmental sensitivity influence decision-making in terms of investing in these types of self-consumption facilities.

Among the general observations of this study, it can be claimed that the fact of having reached network parity in Spain does not seem to be enough for citizens and companies to decide to become prosumers. This is in line with the report of the IEA Photovoltaic Power System Programme [61], where it is said that the price of photovoltaic electricity would have to fall well below the grid parity, so the assumed financial risk and inertia is overcome. The final price of photovoltaic electricity could be reduced through measures such as net-billing or net-metering.

The case study has made it possible to define the determinants of self-consumption investments, advancing knowledge in this area for its promotion and facilitating the decision-making process where economic profitability is one of the factors with the greatest impact on the deployment of these facilities.

Bearing in mind that some authors consider that energy prices and network access charges should reflect the real costs of supply in order to not distort the consumer incentives when choosing between a photovoltaic installation and the supply of the network, it is of interest to propose a transition framework for a zero emission and renewable environmental energy scenario, even if it is not free of costs. Thus, aligned with Aragonés et al. [39], the convenience of incentives for the deployment of self-consumption may be considered opportune, which in turn requires energy prices and network tariffs that provide the right economic signals.

Table 7 summarizes the response to the second research question (R2), showing the influence level that each driver or barrier has on the profitability of each of the considered types of self-consumption facilities.

Graphically, as it is shown in Figure 9, the variables with the greatest influence are the incentives that reduce the cost of batteries and the barriers related to the monetary and non-monetary costs of the installation, while the typologies with the highest expectations of growth are the installations connected to the grid according results in Figure 10.
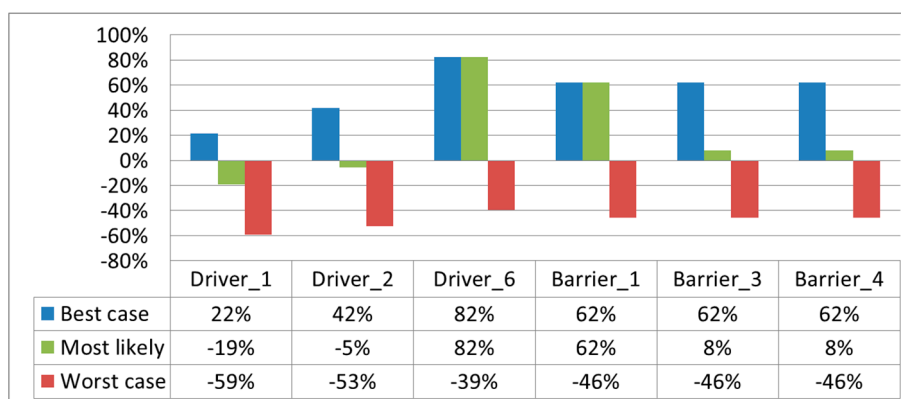

	Driver_1	Driver_2	Driver_6	Barrier_1	Barrier_3	Barrier_4
■ Best case	22%	42%	82%	62%	62%	62%
■ Most likely	-19%	-5%	82%	62%	8%	8%
■ Worst case	-59%	-53%	-39%	-46%	-46%	-46%

Figure 9. Most likely percentage of relative variation of self-consumption potential in Spain by variable and scenario with respect to static (own elaboration).
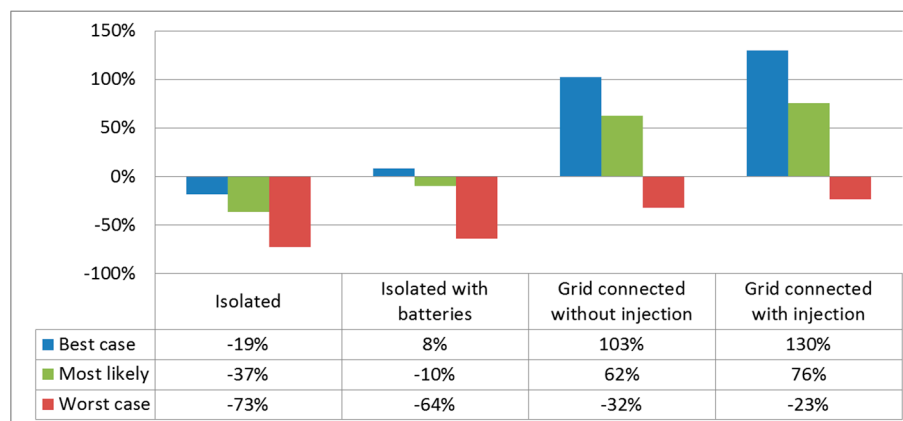
	Isolated	Isolated with batteries	Grid connected without injection	Grid connected with injection
■ Best case	-19%	8%	103%	130%
■ Most likely	-37%	-10%	62%	76%
■ Worst case	-73%	-64%	-32%	-23%

Figure 10. Most likely percentage of relative variation of self-consumption potential in Spain by type and scenario with respect to static (own elaboration).

Among the contributions of interest provided by this study, it is worth highlighting the detailed study of the determinants of self-consumption investments, and the elaboration of scenarios based on the analysis of the country's legal framework and the corresponding barriers and incentives.

However, this study has some limitations inherent to the number of installations analyzed and the number of variables. Through a more in-depth study, the influence of the charges associated with the system costs on the return period, or the decision-making process for each type of investor, could be investigated.

As a general reflection, it is worth mentioning that to increase the adoption of this kind of technology and encourage consumers to make private investments, policies for renewable energy must consider self-consumption and microgeneration as the main axis, by increasing the availability of energy when necessary. For instance, the promotion of energy storage from these kinds of facilities could receive priority treatment, as well as the rewarding of energy self-sufficiency in the interests of security of supply in a period of energy transition towards a new, more sustainable model. Incentive schemes, aids to compensate the additional costs resulting from the battery storage or easing of restrictions in terms of contracted power would foreseeably increase the rates of adoption of the technology, favoring its faster development in terms of R&D and product innovation.

Appendix

Table A1. Regulatory frameworks in the selected European countries (adapted from [61]) Acronyms: FiT: feed-in-tariff, FiP: feed-in-premium, SSP: Scambio Sul Posto (acronym in Italian, meaning Exchange on Site), ToU: time of use tariff, SeU: Sistema Efficiente di Utenza (acronym in Italian, meaning User Efficiency Systems), EEG: Erneuerbare-Energien-Gesetz (acronym in German, meaning Renewable Energy Act).

Title	Spain	France	Germany	Italy	Portugal
Revenues from self-consumed PV	Savings on the electricity bill	Savings on the electricity bill	Savings on the electricity bill	Savings on the electricity bill	Savings on the electricity bill and right to guarantee of origin from renewable sources
Charges to finance T&D	Yes ("solar tax")	None	None	Yes, above 20 kW	Yes, above 1.5 kW for 10 years
Revenues from excess electricity	None//Wholesale market price minus taxes	FiT	FiT or FiP	SSP, net-billing based on energy and services; market price for selling	<1.5 kW Wholesale market price minus 10%>1.5 kW Reference tariff, established annually by the government
Maximum timeframe for compensation	Real-time	Real-time	Real-time	Self-consumption, real time; SSP, advance payment twice per year	Real-time
Geographical compensation	None	On-site only	On-site only	On-site (meter aggregation is allowed for some specific SSP cases)	None
Regulatory scheme duration	Unlimited	20 years (FiT)	20 years (FiT)	Unlimited	15 years
Third party ownership accepted	None//Yes ("solar tax")	None	All	Yes, with conditions for SSP	Yes, with conditions
Grid codes and additional taxes/fees	Above 10 kW//Yes	Possible move towards a higher share of fixed grid costs	Grid codes compliance and partial EEG-surcharge	None	Register costs, metering costs, and Grid codes compliance, civil liability insurance taking out
Other enablers of self-consumption	None	ToU Tariffs	Battery storage incentives	None	None
PV system size limitation	100 kW but below or equal to capacity contracted//Below or equal to capacity contracted	None	Minimum 10% of self-consumption	Self-consumption, none (below 20 MW for SeU); SSP, up to 500 kW	Self-consumption power below or equal to contracted power. Different requirements up to 1.5 kW, between 1.5 and 250 kW, and more than 250 kW
Electricity system limitations	Distributor's license	None	52 GW of PV installations	None	In all self-consumption below 20 MW on an annual basis
Additional features	Taxes on batteries	Projects to increase the fixed part of grid costs	EEG levy must be paid anyway by the prosumer (above 10 kW)	None	None

Table A2. Main characteristics of the self-consumption installations under study.

Title	Type of Installation	Location	Power(kWp)	Contracted Power (Kw)	kWh per Year	Installation Cost (€)	Financing Rate (%)
1	Isolated with batteries	Apartment block	0.7	N/A	1185	5466	96
2	Grid-connected without remuneration	SME	1.56	4.4	2641	1907	96
3	Isolated with batteries	SME	9.36	N/A	15,847	52,092	96
4	Grid-connected without remuneration	SME	6.76	6.9	12,248	4966	0
5	Grid-connected without remuneration	SME	37.44	41.6	67,837	43,772	0
6	Isolated with batteries	Dwelling	2.25	N/A	3809	7552	96
7	Isolated with batteries	Dwelling	0.9	N/A	1524	4873	0
8	Grid-connected without remuneration	SME	5.1	51	8570	12,044	96
9	Isolated with batteries	SME	6.24	N/A	10,564	10,803	96
10	Isolated with batteries	Dwelling	1.02	N/A	1727	4134	48
11	Isolated with batteries	Dwelling	4.68	N/A	7923	13,163	96
12	Isolated with batteries	Poultry farm	5.76	N/A	9752	9144	96
13	Grid-connected without remuneration	Dwelling	3.64	5.196	6427	8213	96
14	Grid-connected without remuneration	Camping	26	100	48,797	48,924	96
15	Isolated	SME	6.36	N/A	10,768	12,371	96
16	Grid-connected without remuneration	SME	5.3	29.58	9354	13,664	96
17	Grid-connected without remuneration	Funeral parlor	5.2	29.7	9084	10,482	96
18	Grid-connected without remuneration	SME	15.9	92	27,549	31,418	96
19	Grid-connected without remuneration	Catering	18.02	19.8	34,250	30,821	96
20	Isolated with batteries	Dwelling	1.53	N/A	2590	6459	60
21	Grid-connected with remuneration	Catering	50.88	110	94,060	65,189	96
22	Isolated with batteries	Dwelling	3.3	N/A	5587	12,263	96
23	Isolated with batteries	Dwelling	3.18	N/A	5384	20,925	96
24	Isolated with batteries	SME	11.13	N/A	18,843	43,455	96
25	Grid-connected without remuneration	Dwelling	1.06	3.3	2930	3934	96
26	Isolated with batteries	Dwelling	0.52	N/A	880	3645	96
27	Grid-connected without remuneration	SME	2.16	6 928	3068	7391	96
28	Isolated with batteries	Dwelling	1.02	N/A	1727	6078	36
29	Isolated	Dwelling	99.2	N/A	167,946	212,569	96
30	Isolated	Solar pumping	0.4	N/A	677	4057	96
31	Isolated	Dwelling	2.55	N/A	4317	7958	96
32	Isolated	Solar pumping	2.55	N/A	4317	7622	96
33	Grid-connected without remuneration	Dwelling	2.7	6.9	2085	2842	96
34	Isolated with batteries	Dwelling	5.355	N/A	9066	20,172	96
35	Grid-connected without remuneration	SME	35.25	170	38,430	55,686	96

References

1. Grin, J.; Rotmans, J.; Schot, J.; Geels, F.; Loorbach, D. *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*; Routledge: New York, NY, USA, 2010. [CrossRef]
2. Geels, F.W. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Res. Policy* **2010**, *39*, 495–510. [CrossRef]
3. *Renewable Energy: A Major Player in the European Energy Market. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*; European Commission: Brussels, Belgium, 2012; Volume 271, p. 2.
4. *Making the Internal Energy Market Work. Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions. Progress towards Completing the Internal Energy Market*; European Commission: Brussels, Belgium, 2014; Volume 15.
5. *Solar Power Europe Renewable Self—Consumption: Cheap and Clean Power at Your Doorstep*; SolarPower Europe: Brussels, Belgium, 2015.
6. Pötzinger, C.; Preißinger, M.; Brüggemann, D. Influence of Hydrogen-Based Storage Systems on Self-Consumption and Self-Sufficiency of Residential Photovoltaic Systems. *Energies* **2015**, *8*, 8887–8907. [CrossRef]
7. Palmer, J.; Sorda, G.; Madlener, R. Modeling the diffusion of residential photovoltaic systems in Italy: An agent-based simulation. *Technol. Forecast. Soc. Chang.* **2015**, *99*, 106–131. [CrossRef]
8. Balcombe, P.; Rigby, D.; Azapagic, A. Investigating the importance of motivations and barriers related to microgeneration uptake in the UK. *Appl. Energy* **2014**, *130*, 403–418. [CrossRef]
9. Masini, A.; Menichetti, E. Investment decisions in the renewable energy sector: An analysis of non-financial drivers. *Technol. Forecast. Soc. Chang.* **2013**, *80*, 510–524. [CrossRef]

10. Kreifels, N.; Killinger, S.; Fischer, D.; Wille-Haussmann, B. Uncertainty and error analysis of calculation procedures for PV self-consumption and its significance to investment decisions. In Proceedings of the 13th International Conference on the European Energy Market (EEM), Porto, Portugal, 6–9 June 2016. [CrossRef]

11. Juntunen, J.K.; Hyysalo, S. Renewable micro-generation of heat and electricity—Review on common and missing socio-technical configurations. *Renew. Sustain. Energy Rev.* **2015**, *49*, 857–870. [CrossRef]

12. Shah, V.; Booream-Phelps, J. Deutsche Bank, Markets Research, Industry Solar. Solar Grid Parity in a Low Oil Price Era. 2015. Available online: https://www.db.com/cr/en/docs/solar_report_full_length.pdf (accessed on 12 August 2018).

13. Wittenberg, I.; Matthies, E. Solar policy and practice in Germany: How do residential households with solar panels use electricity? *Energy Res. Soc. Sci.* **2016**, *21*, 199–211. [CrossRef]

14. Carreño-Ortega, A.; Galdeano-Gómez, E.; Pérez-Mesa, J.; Galera-Quiles, M. Policy and Environmental Implications of Photovoltaic Systems in Farming in Southeast Spain: Can Greenhouses Reduce the Greenhouse Effect? *Energies* **2017**, *10*, 761. [CrossRef]

15. Witjes, S.; Lozano, R. Towards a more Circular Economy: Proposing a framework linking sustainable public procurement and sustainable business models. *Resour. Conserv. Recycl.* **2016**, *112*, 37–44. [CrossRef]

16. Scarpellini, S.; Valero-Gil, J.; Portillo-Tarragona, P. The "economic-finance interface" for eco-innovation projects. *Int. J. Proj. Manag.* **2016**, *34*, 1012–1025. [CrossRef]

17. Rogers, E.M. *Diffusion of Innovations*, 5th ed.; Simon & Schuster: New York, NY, USA, 2003; ISBN 0743258231.

18. Meade, N.; Islam, T. Modelling and forecasting the diffusion of innovation—A 25-year review. *Int. J. Forecast.* **2006**, *22*, 519–545. [CrossRef]

19. Suchman, M.C. Managing Legitimacy: Strategic and institucional Approaches. *Acad. Manag. Rev.* **1995**, *20*, 571–610. [CrossRef]

20. Faiers, A.; Neame, C. Consumer attitudes towards domestic solar power systems. *Energy Policy* **2006**, *34*, 1797–1806. [CrossRef]

21. Foxon, T.J.; Gross, R.; Chase, A.; Howes, J.; Arnall, A.; Anderson, D. UK innovation systems for new and renewable energy technologies: Drivers, barriers and systems failures. *Energy Policy* **2005**, *33*, 2123–2137. [CrossRef]

22. Delmas, M.A.; Montes-Sancho, M.J. U.S. state policies for renewable energy: Context and effectiveness. *Energy Policy* **2011**, *39*, 2273–2288. [CrossRef]

23. Daddi, T.; Testa, F.; Frey, M.; Iraldo, F. Exploring the link between institutional pressures and environmental management systems effectiveness: An empirical study. *J. Environ. Manag.* **2016**, *183*. [CrossRef] [PubMed]

24. Zhao, J.; Mazhari, E.; Celik, N.; Son, Y.-J. Hybrid agent-based simulation for policy evaluation of solar power generation systems. *Simul. Model. Pract. Theory* **2011**, *19*, 2189–2205. [CrossRef]

25. Johansson, P.O. On lessons from energy and environmental cost–benefit analysis. *Technol. Forecast. Soc.* **2016**, *112*, 20–25. [CrossRef]

26. Cheng, Y.S.; Cao, K.H.; Woo, C.K.; Yatchew, A. Residential willingness to pay for deep decarbonization of electricity supply: Contingent valuation evidence from Hong Kong. *Energy Policy* **2017**, *109*, 218–227. [CrossRef]

27. Korcaj, L.; Hahnel, U.J.J.; Spada, H. Intentions to adopt photovoltaic systems depend on homeowners' expected personal gains and behavior of peers. *Renew. Energy* **2015**, *75*, 407–415. [CrossRef]

28. Engelken, M.; Römer, B.; Drescher, M.; Welpe, I. Why homeowners strive for energy self-supply and how policy makers can influence them. *Energy Policy* **2018**, *117*, 423–433. [CrossRef]

29. Leenheer, J.; De Nooij, M.; Sheikh, O. Own power: Motives of having electricity without the energy company. *Energy Policy* **2011**, *39*, 5621–5629. [CrossRef]

30. Jager, W. Stimulating the diffusion of photovoltaic systems: A behavioural perspective. *Energy Policy* **2006**, *34*, 1935–1943. [CrossRef]

31. Palm, J.; Eriksson, E. Residential solar electricity adoption: How households in Sweden search for and use information. *Energy. Sustain. Soc.* **2018**, *8*, 14. [CrossRef]

32. Cucchiella, F.; D'Adamo, I.; Gastaldi, M. Photovoltaic energy systems with battery storage for residential areas: An economic analysis. *J. Clean. Prod.* **2016**, *131*, 460–474. [CrossRef]

33. Michaels, L.; Parag, Y. Motivations and barriers to integrating "prosuming" services into the future decentralized electricity grid: Findings from Israel. *Energy Res. Soc. Sci.* **2016**, *21*, 70–83. [CrossRef]

34. Palm, A. Local factors driving the diffusion of solar photovoltaics in Sweden: A case study of five municipalities in an early market. *Energy Res. Soc. Sci.* **2016**, *14*, 1–12. [CrossRef]

35. Reeves, D.C.; Rai, V.; Margolis, R. Evolution of consumer information preferences with market maturity in solar PV adoption. *Environ. Res. Lett.* **2017**, *12*, 74011. [CrossRef]

36. Palm, J. Household installation of solar panels—Motives and barriers in a 10-year perspective. *Energy Policy* **2018**, *113*, 1–8. [CrossRef]

37. Faiers, A.; Neame, C.; Cook, M. The adoption of domestic solar-power systems: Do consumers assess product attributes in a stepwise process? *Energy Policy* **2007**, *35*, 3418–3423. [CrossRef]

38. Rai, V.; Reeves, D.C.; Margolis, R. Overcoming barriers and uncertainties in the adoption of residential solar PV. *Renew. Energy* **2016**, *89*. [CrossRef]

39. Aragonés, V.; Barquín, J.; Alba, J. The New Spanish Self-consumption Regulation. *Energy Procedia* **2016**, *106*, 245–257. [CrossRef]

40. Villar, C.H.; Neves, D.; Silva, C.A. Solar PV self-consumption: An analysis of influencing indicators in the Portuguese context. *Energy Strateg. Rev.* **2017**, *18*, 224–234. [CrossRef]

41. López Prol, J. Regulation, profitability and diffusion of photovoltaic grid-connected systems: A comparative analysis of Germany and Spain. *Renew. Sustain. Energy Rev.* **2018**, *91*, 1170–1181. [CrossRef]

42. Ministerio de Industria Energía y Turismo de España Real Decreto 900/2015, de 9 de octubre, por el que se regulan las condiciones administrativas, técnicas y económicas de las modalidades de suministro de energía eléctrica con autoconsumo y de producción con autoconsumo. *BOE—Boletín Of del Estado* **2015**, 27548–27562.

43. Colmenar-Santos, A.; Campíñez-Romero, S.; Pérez-Molina, C.; Castro-Gil, M. Profitability analysis of grid-connected photovoltaic facilities for household electricity self-sufficiency. *Energy Policy* **2012**, *51*, 749–764. [CrossRef]

44. Talavera, D.L.; De La Casa, J.; Muñoz-Cerón, E.; Almonacid, G. Grid parity and self-consumption with photovoltaic systems under the present regulatory framework in Spain: The case of the University of Jaén Campus. *Renew. Sustain. Energy Rev.* **2014**, *33*, 752–771. [CrossRef]

45. Sarasa-Maestro, C.; Dufo-López, R.; Bernal-Agustín, J. Analysis of Photovoltaic Self-Consumption Systems. *Energies* **2016**, *9*, 681. [CrossRef]

46. Dufo-López, R.; Cristóbal-Monreal, I.R.; Yusta, J.M. Optimisation of PV-wind-diesel-battery stand-alone systems to minimise cost and maximise human development index and job creation. *Renew. Energy* **2016**, *94*, 280–293. [CrossRef]

47. Girard, A.; Gago, E.J.; Ordoñez, J.; Muneer, T. Spain's energy outlook: A review of PV potential and energy export. *Renew. Energy* **2016**, *86*, 703–715. [CrossRef]

48. Mir-Artigues, P.; Cerdá, E.; Del Río, P. Analyzing the impact of cost-containment mechanisms on the profitability of solar PV plants in Spain. *Renew. Sustain. Energy Rev.* **2015**, *46*, 166–177. [CrossRef]

49. Chiaroni, D.; Chiesa, V.; Colasanti, L.; Cucchiella, F.; D'Adamo, I.; Frattini, F. Evaluating solar energy profitability: A focus on the role of self-consumption. *Energy Convers. Manag.* **2014**, *88*, 317–331. [CrossRef]

50. Orioli, A.; Di Gangi, A. The recent change in the Italian policies for photovoltaics: Effects on the payback period and levelized cost of electricity of grid-connected photovoltaic systems installed in urban contexts. *Energy* **2015**, *93*, 1989–2005. [CrossRef]

51. 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]

52. López Prol, J.; Steininger, K.W. Photovoltaic self-consumption regulation in Spain: Profitability analysis and alternative regulation schemes. *Energy Policy* **2017**, *108*, 742–754. [CrossRef]

53. Balcombe, P.; Rigby, D.; Azapagic, A. Energy self-sufficiency, grid demand variability and consumer costs: Integrating solar PV, Stirling engine CHP and battery storage. *Appl. Energy* **2015**, *155*, 393–408. [CrossRef]

54. *Best Practices on Renewable Energy Self-Consumption—Accompanying the Document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Delivering a New Deal for Energy Consumers*; European Comission: Brussels, Belgium, 2015.

55. Carrillo-Hermosilla, J.; Del Río, P.; Könnölä, T. Diversity of eco-innovations: Reflections from selected case studies. *J. Clean. Prod.* **2010**, *18*, 1073–1083. [CrossRef]

56. Chanal, V. Innovation management and organizational learning: A discursive approach. *Eur. J. Innov. Manag.* **2004**, *7*, 56–64. [CrossRef]

57. Halila, F.; Rundquist, J. The development and market success of eco-innovations. *Eur. J. Innov. Manag.* **2011**, *14*, 278–302. [CrossRef]

58. Lichtenstein, B.B.; Uhl-Bien, M.; Marion, R.; Seers, A.; Orton, J.D.; Schreiber, C. Complexity leadership theory: An interactive perspective on leading in complex adaptive systems. *ECO Emerg. Complex. Organ.* **2006**, *8*, 2–12. [CrossRef]

59. Eisenhardt, K.M.; Graebner, M.E. Theory Building from Cases: Oppurtinities and Challanges. *Acad. Manag. J.* **2007**, *50*, 25–32. [CrossRef]

60. Branker, K.; Pathak, M.; Pearce, J. A Review of Solar Photovoltaic Levelized Cost of Electricity. *Renew. Sustain. Energy Rev.* **2011**, *15*, 4470–4482. [CrossRef]

61. Masson, G.; Briano, J.I.; Baez, M.J. *Review and Analysis of PV Self-Consumption Policies*; IEA Photovoltaic Power Systems Programme (PVPS): Ursen, Switzerland, 2016.