

Article

A Heuristic Approach to the Decision-Making Process of Energy Prosumers in a Circular Economy

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Abstract: Renewable distributed energy and self-consumption are promising and sustainable solutions in the energy-transition scenario for moving toward a circular economy. In this future scheme, prosumers are expected to play a leading role in the forthcoming sustainable energy market, facing new technical, economic, and financial challenges as energy producers at a small scale. In fact, the adoption of photovoltaic (PV) self-consumption systems requires mobilizing capital for investment and their interaction with the market. In this scenario, the aim of this paper was to explore insights into the decision-making process of prosumers to enhance the understanding of self-consumption deployment and to support effective policymaking. This study contributes to the state of the art by defining and classifying determinants of the energy prosumers' decision-making process and their relevance using a heuristic approach. Potential measuring tools and methods are analyzed through a specific case study of Spanish prosumers.

Keywords: self-consumption; circular economy; environmental management tools; corporate finance; prosumers

1. Introduction

A key principle of the circular economy (CE) is that energy is powered via renewable sources [1], leading to significant reductions in fossil-fuel consumption [2,3] and greenhouse gas (GHG) emissions [4]. Additionally, some authors argued that the CE also shifts toward the use of waste-derived resources in value chains [5], while companies undertaking activities related to the CE introduced the consumption of renewables [6,7].

Haas et al. (2015) indicated that strategies targeting the CE are shifting from fossil fuel to renewable energy sources and translating efficiency gains into a reduction in the overall level of resource consumption [2]. In the same vein, a shift toward a more efficient and distributed energy generation model based on renewables, as is the case for self-consumption, is appearing [8]. Self-consumption deployment increases energy self-sufficiency within an energy-transition period toward a new, more sustainable, and circular model, and it helps maximize the consumption of locally generated electricity. Thus, self-consumption can increase retail competition and support market transformation, promoting the entry of suppliers capable of offering new services in a circular business model, in response to more rooted levels of public and private green purchases [9].

In a circular model, renewable self-consumption helps achieve two objectives in parallel. Firstly, it very concretely empowers consumers while facilitating a bottom-up deployment of renewables. More importantly, the consumers' involvement in the energy market contributes to the achievement of binding national renewable targets by attracting private capital from actors (i.e., consumers) who have

lower expectations in terms of rate of return compared to pure financial investors [10]. In addition, it has to be taken into account that the market for renewable technologies relies on a variety of materials that will evolve in the future depending on their deployment rates and the technology mix, such that the CE has to be considered for recycling and material procurement [11].

In summary, evolution toward a CE depends on structural changes in the management of energy and material flows, especially in a new configuration of economic interactions. Solving technical problems does not guarantee the success of this circular scheme, and economic and social challenges must also be addressed. More recent circularity concepts have shifted the perspective to include consumers that, instead of matching their needs to the product offerings available, would cocreate or coproduce the products and services they actually need; thus, the importance of culture, education, and awareness in achieving circularity has been highlighted [12].

In this scenario, the aim of this study was to explore insights into the decision-making process of energy prosumers to enhance the understanding of self-consumption deployment and to support effective policymaking. This study contributes to the state of the art by defining and classifying determinants of the prosumers' decision-making process and their relevance using a heuristic approach. In particular, a Spanish case study is analyzed to ascertain which factors play a significant role in photovoltaic (PV) self-consumption adoption; these factors are subsequently graded on the basis of the results of a semi-structured interview among a sample of prosumers.

We analyze the results obtained through an explorative study on decision-making in self-consumption facilities, using data collected through semi-structural interviews of prosumers within facilities installed by a Spanish company (please see <https://www.fenienergia.es/> (accessed in August 2020)).

This article is organized as follows: After the introduction, Section 2 provides the theoretical approach to set the basis for the evaluation of the case study, which is described in Section 3, along with an analysis of the results and a discussion. Finally, some recommendations for academics, practitioners, and policymakers are included in Section 4.

2. Background

At present, a reduction in the consumption of nonrenewable resources is especially urgent in the framework of the energy-transition objectives set by the European Union (EU) and for the achievement of the principles of a circular economy (CE) in the territory of the EU [13]. In the context of a CE, if imported energy resources are reduced due to self-consumption, or if the gap between importing and exporting costs is increased, the system would be financially feasible for the average household and it would provide significant benefits in terms of grid balancing [14]. Thus, the circular loops could be closer to investments in small-scale renewables within the framework of a CE [15].

Stakeholder engagement in the energy transition has been a theme throughout the literature in the last decade [16]. However, the role of prosumers from a CE perspective is a relatively novel line of inquiry, and the decision-making process with respect to investment in self-consumption is still under study. In fact, the responsibility for effecting change has been increasingly passed down from large-scale renewables, such as government agencies or industries, toward the individual user in concert with the progress of energy transition [17]. Thus, to understand how prosumers behave is a relevant area of research to establish the complex process of influencing the deployment of sustainable energy.

In self-consumption facilities, the consumer is also a producer that faces many additional questions during the decision-making process before installation. On the one hand, these investors are strongly influenced by socioeconomic factors. Some of them are external factors such as the equipment and installation costs, the electricity tariff, local taxes, and incentives, while others are inner or individual factors such as the demand profile, income, and home value. These contextual factors underpin "rational" or "objective" decisions when dealing with investment in the installation. The socioeconomic context, defined by variables such as income level and demographic characteristics, was shown to be determinant in the effectiveness of policies in the adoption of renewable technologies at the user level.

For instance, Zhao et al. (2011) found that potential customers of photovoltaic installations in big cities are less sensitive to economic incentives such as feed-in tariffs or investment tax credits than customers in small cities [18].

If economic criteria win in the final decision, contextual external factors constitute the economic incentives for investment [14]. A transition scenario of zero emissions and renewable energy is not cost-free, and it raises the need for incentive mechanisms, reflected in energy tariffs and payback schemes [19]. The results indicate that, in spite of the numerous financial incentives, the largest barriers are still the high capital costs, the low cost-effectiveness, and the risk of losing money when moving home [20]. The effects of different parameters related to financial resources and the allocation of public subsidies were demonstrated for eco-innovative investments [21]. In addition, from a CE perspective, similar conclusions were achieved by Aranda-Usón et al. (2019) when analyzing the relationship between the financial resources of firms and their circular scope [15]. Thus, it is relevant to analyze the role of economic parameters in the final decision from a theoretical perspective.

In this context, behavioral change theories attempt to make sense of and model this complex issue, but each differs in its focus, although, as explained by Moloney, Horne, and Fien (2010), the key distinction in the examination of these models for low-carbon energy consumers is that which is made between variables that are “located in the physical, social, and discursive environments in which a person lives” and variables that “influence or shape what goes on inside a person’s mind” [22].

Masini and Menichetti (2013) demonstrated that the institutional context does not always affect the technology adoption as long as there are many psychological factors that may have an influence on the prosumers [23]. Following the study of Faiers and Neame (2006), the “value of the installation” is a characteristic of the individual adopter and includes not only monetary but also nonmonetary costs, such as information search costs and uncertainty about future performance, operation and maintenance requirements, and perceptions of quality, sacrifice, and opportunity cost [24]. In addition, environmental beliefs are also a part of this group of attitudinal factors on which the “personal” or “subjective” decision of the investing prosumer relies. All of these attitudinal factors can be modified through dissemination and information campaigns, and it is for this reason that social and communication networks are considered strong determinants in the decision-making of individuals [25].

The complexity of such a predictive model limits its use at the installer level, which was shown as one driver in the promotion of these kinds of installations. In spite of a lower certainty, simpler and more transparent analytical models are desirable for evaluating the sensitivity of strategies to different factors. Furthermore, in the model of a CE, a society is proposed that takes into account environmental criteria, in addition to economic and social ones, which allows predicting a sustainable energy supply in the second half of the 21st century [26]. In this context, some authors used agent-based simulation models (ABMs) to obtain the relationships among factors, showing that it is very complex [27–30].

Table 1 shows a classification of the main factors that could influence on the decision-making process of prosumers using a heuristic approach.

Table 1. Classification of factors that influence the decision-making of prosumers in self-consumption installations.

	Contextual	Attitudinal
Internal	Income level Consumption level Demand profile Demographic characteristics Energy access	Risk acceptance Uncertainty tolerance Environmental beliefs Appreciation of technological innovations
External	Price of the technology Electricity rates Tax incentives Environmental taxes Compensation for electricity surplus	The soundness of related policies

The factors classified in Table 1 are usually combined into several decision criteria in order to establish the main motivations for self-consumption PV installations. A brief review of recent European studies focused on this line of research is summarized in Table 2.

Table 2. Recent studies related to European self-consumption adopters. PV: Photovoltaic.

	SCOPE	Reported Criteria for PV Adoption
Balcombe, Rigby, and Azapagic (2014) [20]	United Kingdom	Saving or making money Increasing energy autonomy Protection against a future increase in energy price
Bouly de Lesdain (2019) [31]	France	Electricity autonomy
Engelken et al. (2018) [32]	Germany	Economic benefits Energy autonomy Environmental awareness Affinity with technology
Gautier et al. (2019) [33]	Belgium	Environmental and financial motivations
Gram-Hanssen, Hansen, and Mechlenborg (2020) [34]	Denmark	Financial arguments that underpin self-sufficiency and emission reductions
Korcaj, Hahnel, and Spada (2015) [35]	Germany	As long as costs were low Social status
Leenheer, de Nooij, and Sheikh (2011) [36]	Denmark	Other investor motivations Economic benefits
Palm (2018) [37]	Sweden	Environmental and financial motivations
Vasseur and Kemp (2015) [38]	The Netherlands	Electricity cost-savings and costs of PV system Self-sufficiency and contribution to a better natural environment

The review was focused in Europe and over a short time period because it was assumed that prosumers will operate in similar socioeconomic and normative scenarios. According to the literature review, the recurring thought in the prosumers’ judgement was saving or making money with a small investment and short recovery period. Thus, the decision to adopt self-consumption photovoltaic systems is based on a cost–benefit analysis, where the internal and external economic factors listed in Table 1 are considered, with an additional interest in minimizing the effect of possible increases in electricity prices. This decision criterion can be based on objective information, as there are easy ways of estimating the return on investment.

Minor motivations include reducing the energy dependence of the electricity network and contributing to a reduction in environmental impact. In the case of isolated installations, autonomy is a clear and real motivation. However, in connected installations, the subjective perception of risk has an interesting role, and the feeling of insecurity can be reduced if energy storage systems are allowed. Due to difficulties faced in their proper estimation and allocation before installation, environmental benefits can be considered halfway between objective and subjective.

In summary, the encompassing concept of PV self-consumption adoption is energy security, as set out by the International Energy Agency (IEA), applied to particular spheres [39]. This is not new, as experiences in developing countries show a similar motivation, while it is to be expected that the criteria of energy availability, affordability, and environmental sustainability have different effects on the result. In addition, according to the comprehensive study of Amala Devi (2018) in India, “consumer confusion over procedures and delays in approvals due to institutional inconsistencies and lack of coordination” restrains these installations [40].

From an analysis of the literature, we consider it necessary to study the determinants of the decision-making process experimented by prosumers using a heuristic approach, since previous studies offered a fragmented analysis of this line of inquiry. As one of the contributions raised, the role of prosumers in a CE scheme was included in this study because it has been scarcely analyzed to date. In addition, we recognize two gaps in the literature. First, there is a general need of detailed analysis of the motivations that move consumers to become prosumers. Second, the majority of previous studies did not offer a specific analysis of determinants of investments in small-scale PV self-consumption

facilities and their influence on the decision-making process of prosumers for the deployment of renewables in a circular model.

On the basis of the previous considerations, the following research questions arise:

- RQ1. What are the most widespread self-consumption-related reasons for an energy consumer deciding to become a prosumer?
- RQ2. What are the determinants of the decision-making process and how do they influence the prosumers' investments?

In summary, the aim of this paper is to present a simple and transparent procedure to identify how energy consumers become prosumers, as well as a method of classification and measurement of factors influencing the decision-making process. After establishing a heuristic framework for the adoption process, the target is to ascertain the vectors that, in a hypothetical hierarchical decision tree, would transfer the significance of particular factors to the final decision. To this end, we analyze the decision process of a sample of Spanish self-consumption PV adopters as a European case study.

3. Case Study and Method

3.1. Methodology

The research design hinges on a new dataset built through a semi-structured interview of companies and individual users who have already adopted PV self-consumption. Access to the population for the purpose of this study was achieved through a company that installs self-consumption facilities, and semi-structured interviews were conducted with Spanish PV self-consumption owners. A total of 16 out of 35 owners whose installations were commissioned from 2016 to April 2019 by the company agreed to participate in the interview.

The main goal of the interview questionnaire developed by the authors was to understand the owners' decision-making process when adopting solar energy, as well as the experience in selecting and installing a PV self-consumption system. PV adoption is a multicriteria decision process where the different economic, social, and environmental criteria have to be considered. Thus, the interviews, which were carried out in Spain from May to June 2019, included specific questions closely related to these three criteria.

Prosumers were asked to participate in a semi-structured interview composed of four parts. Part A concerned the general information of the prosumer for stratification. In the case of a company, questions were related to the identification of the firm (business name, address, ID number), as well as the number of employees (size), location, and sector. In the case of persons, the focus was on household characteristics. Part B determined the technical and financial aspects of the installations. Parts C (pre installation) and D (post installation) included closed and open questions related to the decision-making process and to the subsequent experience of the prosumer with respect to the installation. The methodological technique adopted in this study involved a nonprobabilistic sample, given that the number of complete interviews was 16.

The profile of the respondents encompasses 37.5% (6 out of 16) of the companies and 62.5% (10 out of 16) of the individual users. The size of the PV systems installed by the companies ranged from 1.56 to 41.6 kW, while the size of the PV systems installed by the individual users ranged from 0.52 to 9.9 kW.

3.2. Main Results and Discussion

Regarding the decision-making process itself, we asked how important the following factors were in the decision to install the PV system:

- C1.1 General interest in energy self-generation;
- C1.2 Improving value of the company/house;
- C1.3 Obtaining savings in energy bill;

- C1.4 Avoiding electricity network dependency;
 C1.5 Reducing environmental impact using renewables.

For closed questions, answers were structured according to the following Likert scale: 1 “not relevant”, 2 “rarely relevant”, 3 “relevant”, 4 “very relevant”, and 5 “totally relevant”.

Considering pre-installation (Part C of the questionnaire), respondents considered the five factors as “relevant” (3) at the very least, although some differences were noticeable, as shown in Figure 1, which includes the average values (all above 4 “very relevant”) and dispersion.

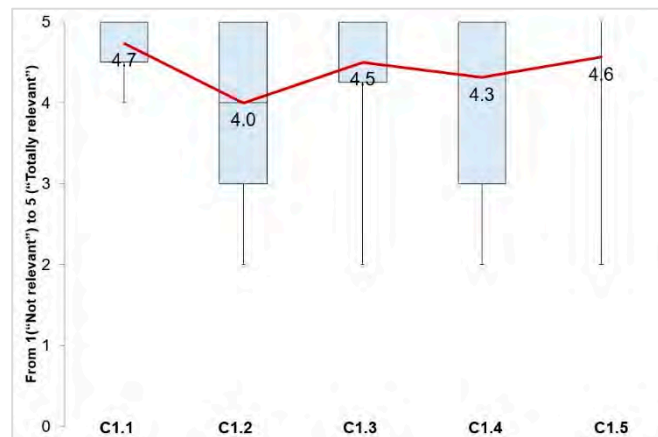


Figure 1. Relevance level (average and range) of global factors in the pre-installation phase.

Using box plots, we could identify the median of all the answer values and graphically illustrate the interval in which the most common and, therefore, most representative values fell. The mean is also included in these figures. Vertical lines show the rank of the obtained answers, and colored boxes allow seeing the dispersion of answers. Colored bars show the 25th and 75th percentiles as a function of the median, i.e., each bar covers the central 50% of data. A larger colored box denotes greater dispersion of the answers. An inexistent colored box means that the values were barely dispersed, although the median could have differed from the average value due to atypical values.

Responses to an open-ended question related to the motivations when installing PV systems revealed that responders considered energy security and energy independence as part of the economic benefits, as they felt that they were “less vulnerable to changes in the electricity tariff”. On the other hand, “influence of others in the neighborhood with PV systems” and “influence of a close acquaintance not from the neighborhood” were not considered relevant factors in the decision to install PV systems. This is mainly because the spatial distribution of these systems was sparse; the responders were largely “innovative” adopters.

Finally, at the end of the interview (Part D in the questionnaire), responders were asked to rate the performance, operation, maintenance, and financial attractiveness of their systems post installation. The same set of questions as in Part C1 (see Figure 1) was used in order to compare the obtained results. This approach was expected to eliminate the subjectivity seen in pre-installation answers from the average values and data dispersion.

By comparing the average answers shown in Figures 1 and 2, the following conclusions can be drawn:

- Regarding the level of general interest in energy self-generation (C1.1 vs. D1) or environmental concern (C1.5 vs. D5), we can say that internal attitudinal factors were unchanged on average, but dispersion increased in the answers related to the second issue.

- Economic concern was displaced from savings (C1.3 and D3) to home value (C1.2 and D2). After installation, prosumers identified the possibility of improving the value of their home. However, owners did not perceive a reduction in their total electricity consumption post installation of PV systems, and the independence of the grid was not as high as expected.
- Regarding avoiding electricity network dependency (C1.4 vs. D4), the reduction seen in the range of answers could have been due to the fact that any perceptions were now evidenced.

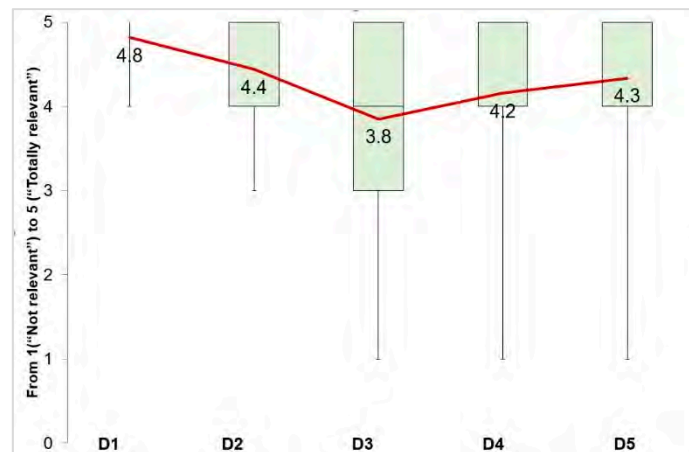


Figure 2. Relevance level (average and range) of global factors in the post-installation phase.

Economic and financial aspects are expected determinants in the adoption of PV self-consumption; thus, Part C.2 was intended to gather the interviewee’s thoughts with regard to the relevance of price (C2.1), access to financing (C2.2), payback (C2.3), operation and maintenance costs (C2.4), and regulations (C2.5) in their final decision. Answers are shown in Figure 3.

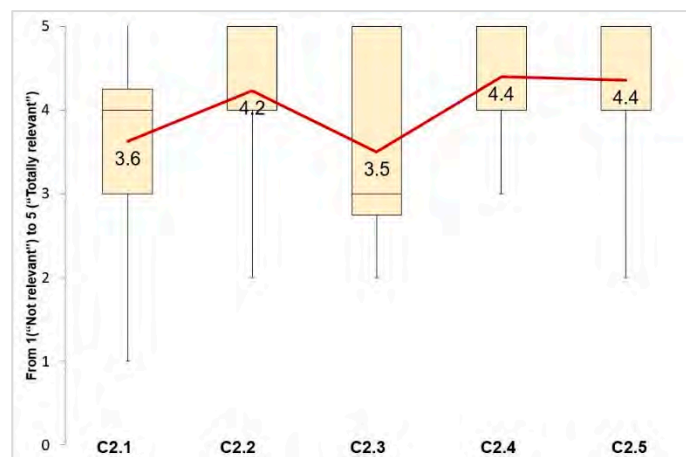


Figure 3. Relevance level (average and range) of economic and financial factors.

Prosumers were asked to select the tool used to establish the economic viability of their installation (internal rate of return, net present value, etc.), revealing that a cost–benefit analysis was implemented by all respondents.

As they were all assisted by installers when calculating financial attractiveness, price (C2.1) and payback (C2.3) displayed the same level of relevance, but the latter featured a wide range of responses. Access to financing (C2.2) appeared more important than the investment level. Moreover, operation and maintenance costs (C2.4) and regulations (C2.5) had a higher weight in the final decision.

Answers to the open-ended questions suggested that the unknown performance of the PV installation and the little trust in future regulations had a high weight in the final decision. As these were noncontrollable variables, their judgement was consequently subjective.

Finally, the degree of relevance in the PV adoption decision with respect to general access to information (C3.1) and other aspects such as maintenance of the installation (C3.2) (notice that this question is a control question which was already included as C2.4), simplicity of the installation (C3.3), employment generation (C3.4), and role of the installer (C3.5) was requested. Answers are shown in Figure 4.

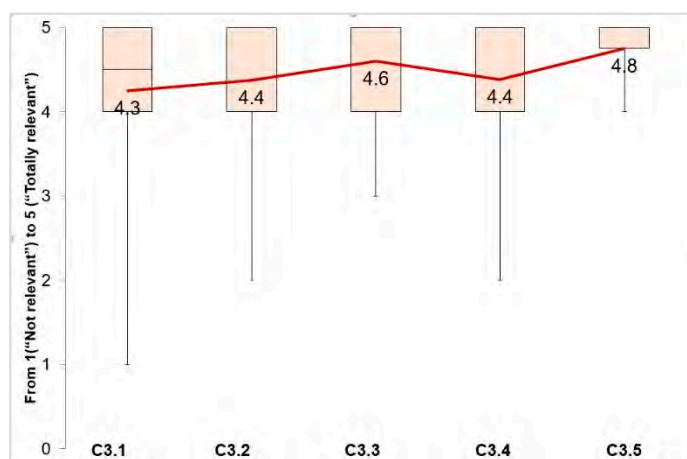


Figure 4. Relevance level (average and range) of information-related factors.

A majority of the responding PV owners considered the five factors to be “very relevant” (4) or “totally relevant” (5), leading to the conclusion that investments in these facilities are highly sensitive to the existence of clear and accessible information that reduces uncertainty in the final decision. In other words, information networks play a significant role in reducing the subjective or attitudinal factors.

As the average values in Figure 1 were not conclusive enough to establish any sort of predominance among the economic, autonomy, and environmental criteria, interviews were examined individually.

For each of the 16 interviews, factors C1.3, C1.4, and C1.5 were ranked to analyze their relevance (Table 3). The relative weight of each factor assigned by the respondents was expressed as a percentage, thereby identifying C1.5 as the factor considered most relevant by most prosumers.

Table 3. Ranking of the relevance of the three factors provided by the prosumers.

Case.	C1.3	C1.4	C1.5
1	33%	33%	33%
2	22%	33%	44%
3	29%	36%	36%
4	33%	33%	33%
5	33%	33%	33%
6	42%	42%	17%
7	38%	38%	25%
8	33%	25%	42%
9	33%	33%	33%
10	42%	17%	42%
11	23%	38%	38%
12	33%	33%	33%
13	38%	23%	38%
14	33%	33%	33%
15	33%	33%	33%
16	23%	38%	38%

In summary, all three factors were taken into account during the decision-making process, with slightly greater relevance afforded to environmental motivation.

Figure 5 shows the factors classified using the heuristic approach outlined in Table 1. The relevance level reported on average by interviewees is also included for consideration. In addition, factors were also grouped according to their natural influence in terms of the three global criteria involved in the final decision.

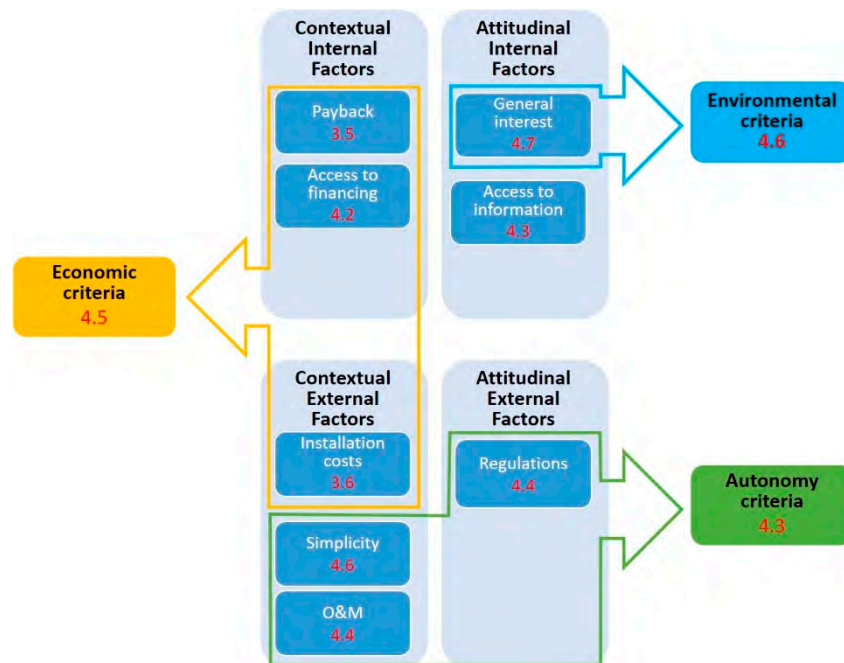


Figure 5. Factors classified using the heuristic approach with respect to the decision criteria.

The following conclusions arise after evaluating the typologies of the factors under study:

- The economic criteria are only based on contextual factors that are known, accessible, and usually accurate, such as installation costs or energy consumption data for the calculation of payback. However, access to financing seemed to be the main economic concern as its relevance level was comparable to the overall economic criteria.
- The autonomy criteria are linked to external factors for which reliability is key for the final decision. The user-friendly operation of installations, particularly the existence of regulatory and institutional frameworks that ensure the sustainability and economic viability of these investments, is very important. In fact, the very useful role of installers was appreciated.
- The environmental criteria depend only on the awareness of the adopter, as attitudinal factors are impacted by information campaigns.

Figure 6 schematically summarizes the factors taken into account by the prosumers throughout the decision process, and it also shows the relevance assigned by interviewees to each factor. As can be observed, longer-term factors that may be influenced by events after the start-up of installation, over which the prosumers lack control, are generally more relevant in decision-making.

Data inherent to the financing of the facilities were obtained through Part B of the interview, which revealed that investment received cofinancing of public funds (40%) in only one case. It was found that three installations were financed entirely by personal resources, while financing provided by retail energy companies was the main source of resources (11 cases). It is worth mentioning that prosumers employed more than one source in many cases, but the role of the retail energy company promoting the facilities was prevalent. Thus, these results did not demonstrate a high relevance of public funds in the decision-making process of prosumers, in line with the results of

Scarpellini et al. (2018) for eco-innovation [21]; furthermore, access to financing seemed to be the main economic concern of these investors. Lastly, we assessed other factors such as demographic and psychological aspects deemed important by prosumers, in line with Hahnel et al. (2020) [41].

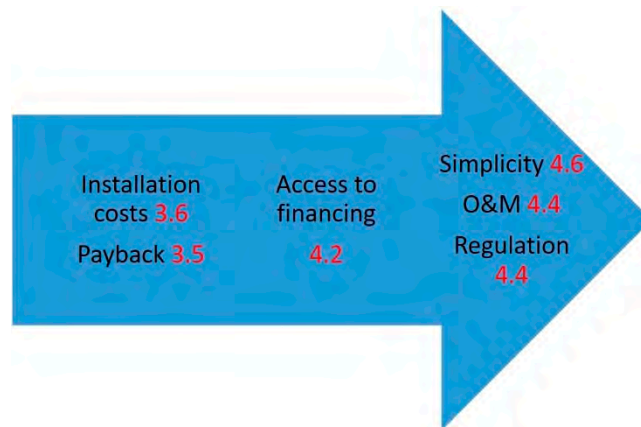


Figure 6. Hypothetical timeline from the beginning to the end of the decision process.

4. Conclusions

Through a qualitative study of the decision-making process of prosumers in Spain, this article provided a heuristic analysis of the influence of economic, environmental, and social criteria for investors. The obtained data allowed a novel analysis of the self-consumption decision process in a circular-economy scenario, which is complementary to prior studies.

As the main consideration, contextual factors influencing the final decisions were mainly related to the investment return and the future performance of the installation in both economic and technical aspects. Initiatives aimed at guaranteeing the reliability of information or access to financing could motivate new adopters. In addition, it was observed that public funds were not essential for the deployment of self-consumption. Attitudinal factors were also found to play a role in the final decision, and dissemination activities such as awareness campaigns and success stories could increase the general interest, by shedding light on environmental concerns and boosting confidence in innovation. In this same vein, installers are expected to play a leading role going forward.

These results partially fill a gap in the literature by providing a heuristic analysis of investment decision-making related to sustainable energy at a small scale, which will involve an increasing number of investors in the short and medium terms. On the one hand, exploring actual insights into the decision-making process of energy prosumers seems to be highly relevant for an understanding of the limitations of self-consumption deployment and for effective policymaking. On the other hand, the acquired knowledge and findings can be extrapolated to similar consumer decisions within the sphere of a circular economy. Policy and industry stakeholders aiming at identifying target groups for self-consumption investment can use these findings.

The main limitations of this study are mainly associated with the territoriality of the analysis and the number of interviewed prosumers. New lines of future research could characterize different factors that influence the decision-making process of prosumers in other regions, applied to different sustainable energy solutions in the framework of a circular economy.

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