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A MULTI-OBJECTIVE DECISION-MAKING APPROACH TO SUPPORT THE DESIGN OF SOCIAL INNOVATIONS IN THE ENERGY SECTOR

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ABSTRACT

Social innovations in the energy sector (SIE) are essential for accelerating the transition to clean, renewable, and democratic energy while encouraging citizens' involvement. However, SIE lacks clear boundaries, making it challenging to make design decisions. Clear and effective design decisions can help identify opportunities and constraints that may impact the success of social innovations. To support decision-making in SIE design, this paper proposes a multi-objective decision-support model based on the definition and exploration of the SIE design space. The model integrates various objective functions related to economic, environmental, and social perspectives, to ensure that selected solutions are tailored to the needs of citizens. By exploring the SIE design space, the model allows designers to evaluate the feasibility and effectiveness of different design options and select the most suitable solutions. To illustrate the proposed approach, this paper applies the model to a specific case of SIE: photovoltaic self-consumption. The findings of this paper provide a decision support model to assist SIE designers in making informed design decisions.

Keywords: Decision making, Innovation, Energy, Optimisation, Exploration

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1 INTRODUCTION

Design process involves making decisions for creating a product or system that meets specific objectives or requirements. However, objectives may be conflicting, and achieving one objective may require trade-offs. So, designers must carefully weigh the trade-offs between conflicting and competing objectives to achieve solutions that best satisfy all the requirements. It is the same for the social innovation in the energy sector (SIE) design process. SIE is a novel approach that promotes the transition to clean, sustainable, renewable, and fair energy. It is social by its goal of improving society and by the involvement of citizens/customers in its development (Hoppe and de Vries, 2018; Koukoufikis, 2020; Polman and Slee, 2017). But it is a concept that maintains a polysemic meaning and there are no boundaries defining its characteristics. This vagueness complicates the development of SIE. Moreover, SIE often unsuccessful or resisted by consumers. This can be attributed partially to poor design decisions making and unclear definition of the design space before developing any SIE.

The design space for SIE refers to the range of possible solutions that can be developed to address the social and environmental issues related to energy and sustainable development. A clear definition of the SIE design space is crucial to their success as it helps to identify opportunities and constraints that may impact the success of SIE by evaluating multiple dimensions such as social, economic, and environmental. Moreover, defining the design space for SIE can help identify the most effective solutions to address the SIE challenges. Defining the design space can also help in engaging citizens in the design and implementation of SIE. By involving stakeholders in the process, innovations are more likely to be adopted, and their success is more likely to be sustained over the long term. Thus, a clear and comprehensive definition of the SIE design space is critical to make informed design decisions (Abi Akle et al., 2019) and maximizing the SIE success chances. For example, a social innovation that aims to reduce carbon emissions may face trade-offs between economic growth and environmental sustainability. If the innovation requires significant investment, some stakeholders may resist it. Thus, to achieve feasible and successful solutions, SIE designers must resolve the inherent trade-offs that exist between conflicting objectives. Therefore, design space sizing and modelling are helpful to SIE designers better understand the needs and constraints and identify the different objectives influencing the innovation.

To help SIE designers in making their design decisions, this paper proposes a multi-objective decision model for the design of SIE. The current work presents an approach to define and explore the SIE design space while considering three dimensions: Economic, Social, and Environmental. It includes a case study on photovoltaic self-consumptions to illustrate the proposed approach. There are five objectives in this case study for optimizing the design of photovoltaic self-consumption system. The first is to maximize the share of overproduced PV energy. The second corresponds to maximize the locality related to the used materials and the actors. The third is to maximize the economic profitability through the Net Present Value. The fourth aims to maximize the self-consumption. The last objective is to minimize the energy payback time. Two scenarios were presented in this paper. The first explores the design space of a PV self-consumption system by varying the panels covered area. The second refines the first explored design space by eliminating the undesirable solutions and varying the locality.

2 STATE OF THE ART ON DESIGN SPACE

During the design process, complex decisions are made, and those decisions have a vital impact on the design solution, the business, and the design process itself (Hansen and Andreasen, 2004). Literature on design research tends to use the term design space quite frequently (see e.g Abi Akle and al., 2017). In the preliminary concept phase, designer must choose one solution among others, with particular design options and values for a design model. The main challenge when designing complex systems lies in resolving the inherent trade-offs that exist between the overall system and subsystems, and between conflicting and competing objectives. It's about decision-making. In the design or decision-making processes, the goal is to select the best choice among several alternatives. Here, the "best" refers to a decision that maximizes or minimizes several criteria simultaneously, which is known as optimization (Stadler, 1988). Multi-criteria decision making (MCDM) refers to decision-making in the presence of multiple, usually conflicting criteria (Zanakis and al., 1998). MCDM problems are commonly categorized as continuous or discrete depending on the type of solution alternatives, whether they are finite (discrete) or infinite (continuously changing features) (Yoon and Hwang, 1995).

Basically, the design space consists of all the decisions to be made about an artifact, as well as all the alternatives that are available to the designer. Therefore, it provides guidance and to enumerate the possible options for each design. It covers all possible solutions to a problem that can be observed by the designer.

Design Space could be represented with three different situations with more or less data:

- Representing the single vector of design parameters featuring the product solution, (X): this refers to the feasible design space,
- Representing the single vector of solution performances for feasible solutions, (Y): this refers to the feasible performance space,
- Representing two sets of design parameters and corresponding performances for feasible solutions (respecting constraints and requirements), $\begin{pmatrix}X\\Y\end{pmatrix}$: this refers to the feasible design and performance space.

A design point (or design candidate) is a solution defined in a design space and can be described by its coordinates in the design space.

Finally, exploring design space is a useful approach to identify feasible solutions as opposed to impractical solutions, as well as those violating engineering constraints or client requirements. Comparing solutions performance can help identify those which provide a good trade-off and select a solution that adequately satisfies preferences. In other words, the design is selected after evaluating the elements present to identify optimal solutions by reducing the design space to an area of performance (Abi Akle and al., 2017, 2019).

While the application of the design space modelization and exploration approach is well known within multiple fields like the manufacturing industry and the architectural, it is under-explored in the social innovation domains. In this paper, we propose a modelization that leads to the exploration of the SIE design space, and we claim the setting up of our design space model as an optimization problem. We illustrate a design space definition and exploration of the photovoltaic self-consumption as a widespread example of social innovation in the energy sector. For this purpose, we determine whether each measure should be treated as an objective or constraint, specify whether the goal is to minimize or maximize the value of the measured objectives, as well as the conditions which would make the design unfeasible according to the measured constraints.

3 PROPOSED APPROACH

The purpose of this paper is to assist designers when designing social innovations in the energy sector. Using the design space, they can explore multiple scenarios by varying the values of several criteria, comparing, and discussing the available options, and identify the best designs. Then, by considering

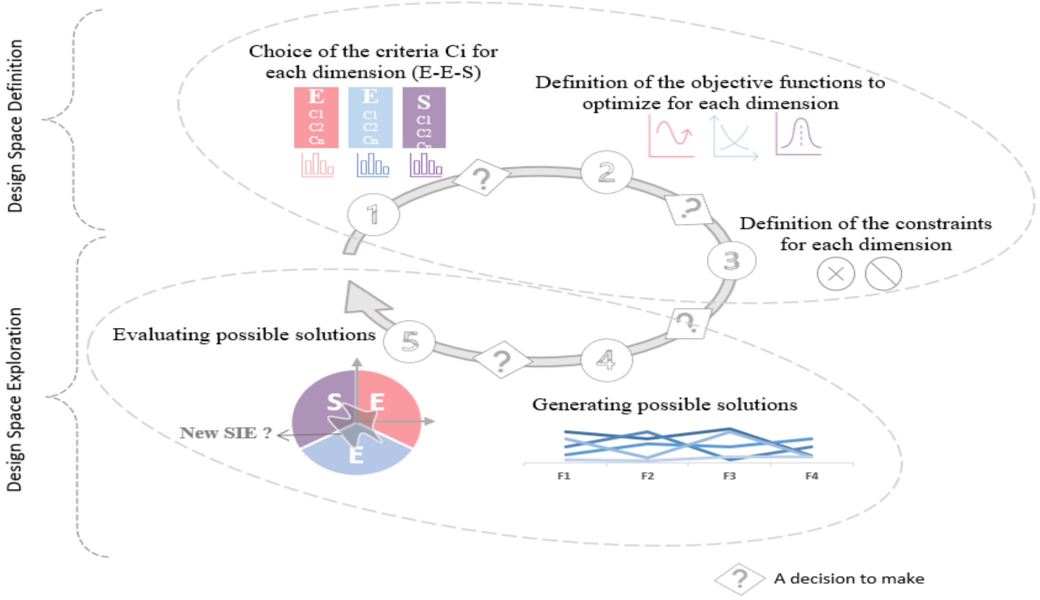

Figure 1. SIE design decision making approach

the myriad options, new ideas may be identified. The general proposed approach to help SIE designers is illustrated in the figure 1.

The first step of this approach is to define the dimensions to be considered and the criteria related to each dimension. It is arguable which dimensions are significant enough to be explicitly considered in the SIE design space. Obviously, additional dimensions could be added, and others removed as appropriate. Social innovations in the energy sector aim to promote sustainability, which means finding sustainable solutions for energy production and consumption. Sustainability is often broken down into three key dimensions: (i) environmental sustainability, (ii) social sustainability, and (iii) economic sustainability (Bouzguenda and al., 2019). Social sustainability for SIE aims to ensure equity and inclusion by ensuring that all citizens should have access to reliable and affordable sources of energy. Environmental sustainability aims to minimize the environmental impact of energy production and use, by promoting the use of renewable energy sources and reducing greenhouse gas emissions. Social innovations in this area include the development of clean energy technologies, improving the energy efficiency of buildings, and promoting sustainable modes of transportation. Economic sustainability aims to ensure the financial viability and efficiency of energy systems, by encouraging sustainable economic growth and reducing energy costs for consumers. Social innovations include the establishment of innovative economic models for renewable energy projects, such as energy cooperatives, as well as improving the efficiency of energy networks to reduce costs. Thus, we consider reasonable to model the SIE design space basing on these three dimensions: Environmental, Economic, and Social.

The second step is to define the objective functions related to the environmental, economic, and social dimensions that describe SIE design space and specify what is to maximize and minimize. There are major objectives for optimizing the design of any social innovation in the energy sector, such as maximizing energy efficiency, reducing greenhouse gas emissions, minimizing costs, and maximizing reliability. However, it is also important to consider case-specific objectives because each SIE is unique and may present different needs. For example, if a rural community wants to develop an autonomous energy system, it might be important to maximize local energy production and minimize installation and maintenance costs. The objective functions of maximizing energy sharing, locality, economic benefits, reduction of greenhouse gas emissions, and minimization of the Energy Payback Time are all important considerations when designing SIE. Maximizing energy sharing helps to ensure that renewable energy sources are utilized efficiently, and excess energy can be distributed to areas that need it, reducing energy waste and ensuring energy is used more effectively. Maximizing the locality of both materials and actors is important to consider when designing SIE. The use of local materials in the construction of energy systems can reduce transportation costs and emissions and promote local economic development. Similarly, involving local actors in the design, implementation, and maintenance of energy systems can increase community ownership and engagement. Maximizing economic benefits from energy systems is important to ensure that they are financially sustainable. It is possible to make energy systems more affordable and accessible for communities by optimizing their design to maximize economic benefits. The reduction of greenhouse gas emissions is crucial in addressing climate change and promoting environmental sustainability. By designing energy systems that minimize emissions, we can contribute to reducing the negative impacts of climate change on communities and the planet. Lastly, minimizing the Energy Payback Time is essential in creating more sustainable energy systems with a lower environmental impact. By reducing the time required for an energy system to generate as much energy as was used in its manufacture and installation, we can promote the development of energy systems that contribute to the reduction of greenhouse gas emissions and environmental degradation.

The third step is to determine the constraint functions that describe the feasibility of different solutions in the SIE design space. Then, the last two steps are to generate the possible solutions and evaluate them by focusing on the design candidates that optimize the values of the objectives as far as possible. A detailed design space modelization and exploration of a particular case of SIE is presented in the following section.

4 ILLUSTRATIVE EXAMPLE

4.1 Photovoltaic self-consumption design space definition

Renewable sources such as solar are valuable avenues to produce clean and affordable electricity through technological advances and increase environmental awareness, then fostering the clean energy transition (Nguyen and Kakinaka, 2019). As a motivating example of SIE' multidisciplinary project, we consider modelling the design space of solar photovoltaic self-consumption system which consists in consuming locally a part of the produced PV energy. The design space modelling of PV self-consumption systems is an optimization problem that must balance multiple competing objectives through different properties. According to the literature, most of the studies in the PV photovoltaic self-consumption design optimization field have been carried out basing on economic dimensions, environmental dimensions, or both. For example, economic optimization for rooftop PV systems in industrial halls by (Lee and al., 2012), technical and economic optimization for residential PV installations by (Li and al., 2018), economic optimization for photovoltaic irrigation systems by (Campana and al., 2015), and economic and environmental optimization of PV self-consumption in commercial buildings by (Allouhi, 2020).These studies focus on several factors of energy efficiency and solar energy potential as well as on economic factors. However, to our knowledge, social factors such as maximizing the share of overproduced PV energy with neighbours and increasing locality aspects, have never been considered when developing new photovoltaic self-consumption systems. Nevertheless, as it was shown in several studies and confirmed by our research work, social factors are crucial when designing social innovations. Hence, according to the SIE design decision making proposed approach, a multi-objective design space modelling with two novel objective functions related to social dimension is proposed to optimize photovoltaic self-consumption systems designing not only economically and environmentally but also socially.

4.1.1 Social dimension

One of the main purposes of SIE is to increase energy autonomy by decentralizing energy production and thus enabling each region to cover its own energy needs. In addition, SIE are an important lever to empowering citizens as pilot actors for a fair and sustainable energy transition. When it comes to PV self-consumption, this can be translated by the fact that citizens are themselves energy producers and able to share their surplus production with their neighbours. There are, however, two logics that can be outlined, the first is to implement only the panels that cover its needs, so optimizing just its personal self-consumption. The second logic is to cover not only his own needs but also share the surplus energy with neighbours, so to implement for a greater number of panels, it is therefore a collective optimization. In the context of SIE, we opt for the second logic which aims to increase the share of the produced PV energy. To achieve this goal, an objective function is introduced, in our model, to maximize the PV energy production by covering as much available surface as possible (roofs and façades). Thus, the first objective function related to social dimension is defined as (eq.1):

$$\text{Max (OA)} \quad (1) \qquad\qquad OA = \frac{Area\ that\ can\ be\ covered\ by\ panels}{Available\ area} \quad (2)$$

OA is the rate of the area occupation. For the calculation of this rate, the areas considered are those that are well exposed to the sun, meet all PV panel implementation requirements, and are available to be covered by panels. However, this objective contradicts the environmental objectives related to self-consumption, in which production should be close to consumption. As well as economic objectives regarding investment. Thus, the system might not be optimally designed in terms of self-consumption and economic perspective, but it is optimal from social perspective.

The second goal from a social standpoint is to enhance the locality which is based on two factors. The first factor is the locality of materials LM. This paper is interested in the European setting therefore materials of European origin are preferred. Thus, a local material is defined as one that has at least been assembled in France. The second factor is the locality of actors LA. A local actor is one who is located within 100 kilometres of the PV system installation site. We identify three types of actors in a PV self-consumption project: installers, financiers, and maintenance agents. A greater weight is given to the installers when calculating the locality. Thus, the second objective function regarding to social dimension is (eq.3):

$$\text{Max (L)} \quad (3) \qquad\qquad \text{L} = \frac{L_M + L_A}{2} \quad (4)$$

$$\text{LM} = \frac{Total\ weight\ of\ local\ materials}{Total\ weight\ of\ used\ materials} \quad (5) \qquad\qquad \text{LA} = \frac{A_F + 2\times A_I + A_M}{4} \quad (6)$$

AF, AI, and AM respectively represent financial agent, installer, and maintenance agent. They are binary variables which value of 1 if the actor is located less than 100 kilometres away, and 0 otherwise.

The social dimension is constrained by the requirement of a maximum distance of 2 km between two participants (the producer and the receiver).

4.1.2 Economic dimension

From an economic perspective, the objective is to maximize economic benefits of PV self-consumption systems. Numerous metrics are available to quantify these benefits. In the literature, the most commonly used is the Net Present Value (López Prol and Steininger, 2017; Roberts and al., 2019; Sommerfeldt and Madani, 2017; Thebault and Gaillard, 2021). In general, the NPV is defined as (Sommerfeldt and Madani, 2017) by Eq. (8)

Max (NPV) (7) $NPV = \sum_{t=1}^{L} B_t - C_t$ (8)

L = 30 years is the lifetime of the system. Bt and Ct are respectively the benefits and the costs of the system. They are calculated as (Sommerfeldt and Madani, 2017) by Eq. (9) and eq. (10)

$$B_t = S_0 + \sum_{t=1}^{L} \frac{E_{sc}\,\mathrm{P}_r + E_{pve}\mathrm{P}_w}{(1+d)^t} \quad (9)$$

Benefits consist of the subsidies S0 and two operational components: Cost savings as a result of deferring grid electricity purchases EscPr (Esc is the self-consumed energy, Pr is the retail price), and the sales of excess energy produced Epve sold to neighbours at the wholesale price Pw.

$$C_t = I_0 + \sum_{t=1}^{L} \frac{OM_t + T_t}{(1+d)^t} \quad (10)$$

In terms of costs, there are one-time and recurring costs. One-time costs are the initial investment to install the PV system I0. Recurring costs include maintenance costs at year t OMt and taxes on overproduction sales Tt.

In order to justify economically the deployment of PV systems, the benefits must exceed the investment costs (Lee and al., 2012).

4.1.3 Environmental dimension

Regarding environmental dimension, the rate of self-consumption is a classical, commonly used, metric for the evaluation of PV self-consumption optimization (see e.g. Luthander and al., 2015). The first objective is, then, to maximize the self-consumption (eq.11):

Max (SC) (11) $SC = \frac{\text{Self consumed Energy}}{\text{Self produced Energy}}$ (12)

This objective may seem contrary to the social objective of maximizing the area occupancy rate. However, it may be viewed in another way as minimizing the energy demand and increasing the efficient consumption of the energy. Another key question presents regarding environmental aspect is whether the photovoltaic system can generate sufficient energy output in comparison to the energy invested in their production. Thus, the second optimization objective consists in minimizing the Energy Payback Time (EPBT). It's a widely used indicator to evaluate the environmental impacts of a photovoltaic installations (Bhandari and al., 2015; Blanc, 2015; Celik and al., 2018; Semassou and al., 2012). The EPBT is expressed as the ratio between the total energy consumed to build the system and its annual production. According to (Celik and al., 2018), it can be calculated as (eq.14):

Min (EPBT**)** (13) $EPBT = \frac{E_{in}}{E_{out}}$ (14)

where Ein is the primary energy demand (or embedded energy) of the PV module, and Eout is the annual energy generated by the systems. According to (Philipps and al., 2022) the EPBT worth 1.05 if the panels are produced in EU and 1.18 if they are produce in China. Added to that, one of the main environmental issues of renewable energy projects is the reduction of CO2 emissions compared to conventional energy resources. We describe this attribute as the carbon emission reduction volume of the invested project, which ranges from 150 tons, representing a microgrid project (such as rooftop solar panels) to 12,000 tons, representing a large-scale energy project (such as a large solar panel farm). In reality, the level of carbon emission reduction is proportional to the size of the project (Wu and al., 2022), which corresponds to the area covered by the photovoltaic panels. Thus, for this study, the attributes "carbon emission reduction volume" and "the rate of the area occupation" (presented in the section4.1.1) are perfectly correlated and are therefore considered as a single attribute “the rate of the area occupation”.

As shown above, the proposed model is based on a multi-objective optimization. Through this model, the design space of a PV self-consumption system is represented based on different objectives which were characterized through three dimensions: economic, environmental, and social. The first and second objectives are related to the social dimension and correspond to a maximization of the share of overproduced PV energy and a maximization of the locality. The third is related to economic dimension and aims to maximize the Net Present Value (NPV). The two last objectives are environmental and correspond to maximize the self-consumption and minimize the energy payback time.

4.2 Photovoltaic self-consumption design space exploration

To illustrate how the design space can support the design decision making process, a design problem of a photovoltaic self-consumption system of a house in Basque country is presented. The total available area of the house is 45 m^2. In this section two scenario are presented.

- The first scenario: Variation of the area covered by PV panels (Spv)

For the first scenario, the area covered by panels (Spv) is varied from 5 to 45 m^2. This variation influences the number of panels (from 4 to 30) as well as the power produced (from 1.44 to 10.8 Kw).

To evaluate the social dimension, the first indicator is the occupation rate OA.The second parameter is the locality that consists of two components. For this first scenario, we assume that all used materials are not of European origin and that only the installers are local. Thus, the locality of materials Lm is 0, and the locality of actors La is 0.5. This way, the locality L is 0.25.

For the economic dimension, the price of electricity in France is 0.18 €/kwh in 2022. The initial investment I0 varies from 3.75 M€ (Spv=5m^2) to 28.12 M€ (Spv=5m^2), the maintenance cost is fixed to 150 € and the tax of overproduction is 0.12 €/kwh. The annual production of the system depends on the number of panels and goes from 1584 Kw/year to 11880 Kw/year. The self-consumed energy is fixed to 1155 Kw/year. We suppose that all the overproduced energy is sold to neighbours. Thus, the shared energy varies from 429 (Spv=5m^2) to 10725 Kw/year (Spv=45m^2). This is proportionally related to the tax of overproduction to pay which attend 1287 €/year (Spv=45m^2). For the benefits, the buy-back price of one kwh is 0.18 €/kwh. and the subsidies are determined in €/kWp depending on the PV capacity (See table 1 in the appendix). We assume the same annual costs and benefits throughout the lifespan of the system (30 years). Therefore, the total benefits and the total costs are respectively calculated through the eq. (9) and (10). The Net Present Value is, thus calculated depending on these two last measures.

Regarding the environmental dimension, the rate of self-consumption is calculated as the eq. (12). And the energy payback time of the system is 1.18 because panels are not produced in the EU. For this studied example, the variation of the PV covered area (Spv) has result on the exploration presented on Figure 2.

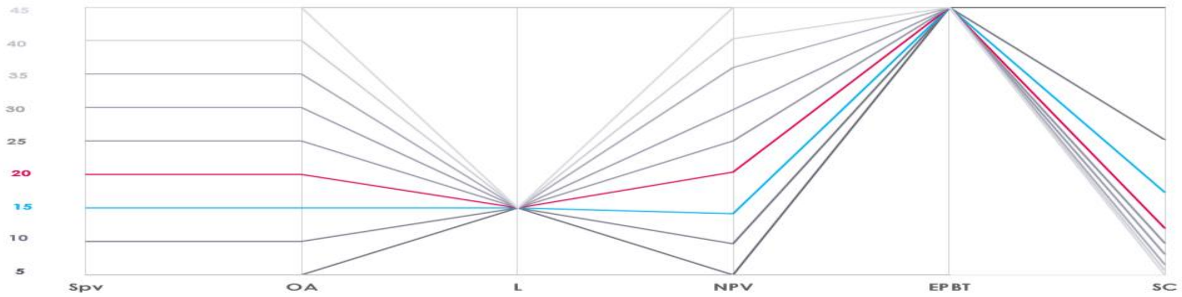

Figure 2. Explored solutions through the variation of the Spv

First, as result of this exploration, it appears that various strategies, can lead to different configuration of the system, and so, different values of the objectives.

If we consider only the first two objectives of the problem *OA* and *L*, we can imagine that the optimal solution is that with (Spv=45m^2) that consists in a coverage of all the roof of the house with PV panels. Indeed, this solution aims to maximize the share of overproduction PV energy (OA). This solution is also optimal from an economic perspective, it maximizes the net present value of the system (NPV). However, this scenario is not optimal from the self-consumption perspective of. If we consider all the objectives, we could observe that the design candidates of Spv=15m^2 and Spv=20m^2

seem to be the best trade-offs. Which consist in covering a part of the available area, self-consuming the energetic needs, and share the overproduction. Nevertheless, the main issue here is how to choose between these two candidates or even between the other solutions which vary between them. For further refinement, a second scenario on the interval of Spv= [15 m², 20 m²] is proposed to eliminate the less satisfactory solutions.

- The second scenario: Variation of the locality (L)

For the second scenario, only the solutions where the (Spv) varies from 15 to 20 m² are considered. With the same constant parameters as the first scenario, we vary the locality (L). To calculate (Lm), we consider only the weight of the panel (12 Kg/m²) and the weight of the inverter (17 Kg). For this scenario, the installers and the maintenance agent are considered locals. Thus, the locality of actors (La) is fixed to 0.75. While the locality of materials (Lm) varied based on three propositions. First, all materials used are not from European origin, so Lm =0. Second, only panels are produced in Europe, in this case, the value of Lm depends on the number of panels and inverters employed. The last, consists of using only materials from European origin, the locality (Lm) in this case is maximum and worth 1.
Through the exploration of the second scenario (Figure 3), it can be seen that the maximization of the locality (L) and the minimization of the Energy Payback Time (EPBT) are proportional. The EPBT has lower value when panels are from European origin. The best trad-offs, according to the second objective about maximizing the locality (L) are the configurations with a locality L=0.82 and L=0.83. These configurations consist in the use of panels made in Europe, with a covered area respectively Spv=18 m² and Spv = 19 m². The net present value (NPV) of these configurations is respectively 8520.35 M€ and 9232.21 M€. The Energy Payback Time (EPBT), for both configurations, presents the lowest value (1.05). And the rate of self-consumption (SC) worth respectively 0.24 and 0.22. As a result of exploring the second scenario, we have refined our design space, which helped us to make better design decisions by taking all the objectives into account.

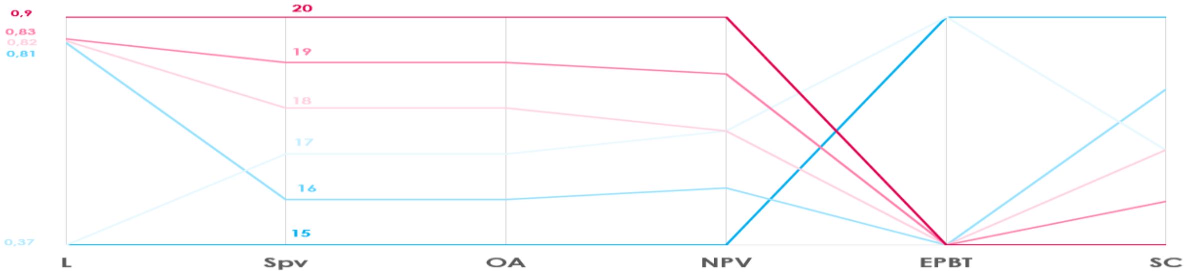

Figure 3. Explored solutions through the variation of the locality

Finally, to optimize the design of PV self-consumption system, three dimensions were considered: economic, environmental, and social perspective with the optimization of five objective functions. The first objective aims to maximize the share of overproduced PV energy by maximizing the occupation area of PV panels (OA). The second, aims to maximize the locality (L). The third corresponds to maximize the Net Present Value (NPV). The fourth aims to maximize the self-consumption (Sc). The last objective corresponds to minimize the energy payback time (EPBT). It appears that the second and the fifth objective are proportionally related. In fact, the maximization of the locality means that the material used are from EU origin, which result in a low value of the EPBT. Indeed, the maximization of the coverage area of PV panels, increase considerably the benefits of the overproduced PV energy sales which increase the NPV. Thus, the first objective is proportionally related to the fourth objective and the economic parameters depends on the total covered PV area. Nevertheless, the first objective is inversely proportional to the fourth objective about the maximization of the self-consumption rate (Sc). It may be concluded that the maximization of the PV overproduction energy appears as not economically beneficial for a house of 45 m². However, this could be most profitable considering big buildings. It is also advantageous for hospitals, municipalities, and other public institutions.

5 DISCUSSION AND CONCLUSION

This study aims to help SIE designers to make better decisions via the definition and exploration of the SIE design space. Indeed, a clear exploration of the design space can help designers to identify all possible design solutions. This can give them a broader perspective and help them avoid being limited to narrow design options. Thus, they can compare the performance of different options and choose the best designs based on their requirements, preferences, and constraints. We assume that a better definition of the SIE design space is a key step for SIE design space exploration. This involves identifying and specifying the performances and parameters that describe the SIE, as well as the ranges of values for each of these variables.

Based on a concrete example of SIE design, a modelization of a photovoltaic self-consumptions system and two scenarios, it is investigated how the exploration of the design space and the variation of the design parameters values, can support the design decisions of future PV self-consumption systems, especially by comparing and discussing the explored design alternatives.

According to our proposed approach, designers can better understand the design problem, and easily compare the different design options. This was demonstrated through the PV case study design space exploration. Indeed, bad solutions were eliminated narrowing down towards solutions that best meet the needs of the project and leading to an informed decision. Design space exploration is not a unique way to make design decision and often the "intuition" of the designers plays a significant role in choosing the best designs because experiences are reliable for decision making (Badke-Schaub and Eris, 2014; Salas and al., 2010). By using design space exploration, it is possible to leverage intuition while also minimizing its potential drawbacks and biases. An in-depth design space exploration to identify a wider range of potential solutions will therefore be implemented through the algorithm MOGA II (Multi-Objective Genetic Algorithm II) in a simulation software.

The proposed approach offers advantages to SIE design decision makers by assisting and guiding them to make effective decisions through the exploration of the SIE design space. The novelty of this approach is that it considers social factors as design parameters. This is important because these factors can play a significant role in the adoption and success of new SIE. However, social factors need to be evaluated carefully because their optimization could be very expensive.

To enhance the current work, we identify two main perspectives. Firstly, in the proposed decision-making model, all three dimensions are equally weighted. It is recommended to assign a weight for each dimension to place more emphasis on environmental and social factors. Secondly, three dimensions (social, economic, and environmental) were considered to model the SIE design space. Three other dimensions (participative, technological, and innovative) are also valuable to consider in the development of SIE and will be added to our model. As result the five parameters mentioned in this work are not the only parameters to consider. Therefore, a six-dimension model will be proposed with more parameters related to the innovative, technological, and participative dimensions This can help SIE designers to better understanding the design problem and make more informed decisions.

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APPENDIX

Table 1. Subsidies for self-consumption in France in 2022

PV capacity (kWp)	< 3	]3-9]	]9-36]	]36-100]
S0 in e/kWp	430	320	180	90