energies

Review

Effect of Sharing Schemes on the Collective Energy Self-Consumption Feasibility

Eva Llera-Sastresa [1,*], José Ángel Gimeno [2], José Luis Osorio-Tejada [3] and Pilar Portillo-Tarragona [4]

1 Department of Mechanical Engineering, CIRCE Research Institute, University of Zaragoza, 50018 Zaragoza, Spain
2 CIRCE Research Institute, University of Zaragoza, 50018 Zaragoza, Spain; joseangel.gimeno@fenieenergia.es
3 School of Engineering, The University of Warwick, Coventry CV4 7AL, UK; jose.osorio-tejada@warwick.ac.uk
4 Department of Accounting and Finance, IEDIS Research Institute, University of Zaragoza, 50009 Zaragoza, Spain; portillo@unizar.es
* Correspondence: ellera@unizar.es; Tel.: +34-976-762951

Abstract: Collective self-consumption is called to be a crucial part of the current energy transition. In addition to the advantages of individual self-consumption, the possibility of improving economic feasibility exists. This paper shows how matching production and consumption loads increase the rate of self-consumption. Still, how the electricity is distributed among a renewable energy community's prosumers would reduce the total costs of self-consumed energy. Possible criteria for the allocation of the generated electricity among shareholders are analysed. The study also evaluates the use of static and dynamic distribution coefficients, observing their results and applicability and sorting them to maximise self-consumption participants' savings. The results are questioned against them and a reference scenario without shared self-consumption installation. As the exploitation of renewable energy for self-consumption is closely linked to the energy market and regulations, the analysis is based on a territorial case study. It is shown that the highest savings occur when electricity is allocated following distribution coefficients that consider the customer's energy consumption better than investment participation or contracted power, even when the compensation of surpluses is added. These criteria can accomplish technical and economic objectives and are introduced in regulations that foster the requested changes in consumers' behaviour and prosumers for sustainability.

Keywords: self-consumption; renewable energy; sharing criteria; resource savings

Citation: Llera-Sastresa, E.; Gimeno, J.Á.; Osorio-Tejada, J.L.; Portillo-Tarragona, P. Effect of Sharing Schemes on the Collective Energy Self-Consumption Feasibility. *Energies* **2023**, *16*, 6564. https://doi.org/10.3390/en16186564

Academic Editor: Manolis Souliotis

Received: 21 July 2023
Revised: 31 August 2023
Accepted: 7 September 2023
Published: 12 September 2023

1. Introduction

Energy security and decarbonisation are the Leif Motive of the current energy transition process. Self-consumption with renewable energies is one of the most feasible strategies in the short term. On the one hand, it responds to supplying reliable energy at affordable prices and low carbon content. On the other hand, it relies on highly developed technologies, such as photovoltaics, with demonstrated success in micro-generation projects [1]. The main contribution of self-consumption to the traditional distributed generation is the possibility of making transactions under specific rules with the electricity produced and not consumed.

The macroeconomic benefits of self-consumption are clear. Properly planned self-consumption with renewables will enable energy self-sufficiency with locally generated electricity, contributing to a more sustainable and circular model. It is also an option to fully integrate renewables in the grid and reduce the energy system's general costs thanks to optimising consumption and reducing the peaks produced by adjusting the loads.

Self-consumption will also attract investments in renewable energy and improve the energy system's efficiency, inducing socioeconomic benefits. Studies identifying barriers and drivers of self-consumption [2–5] agree that regulatory aspects are essential to their deployment.

Self-consumption would contribute to the energy transition mainly with private capital from small investors with lower expectations for their investment than companies. Although there are many aspects of becoming a prosumer [6], the investment return still has importance, but the inherent risk tends to be mitigated through cooperation [7].

Storage systems other than classical batteries to increase the degree of self-consumption and decrease the operating costs of an installation have been scrutinised. For instance, the use of electric vehicle batteries [8,9] or the aggregation of diverse consumers and shared loads [10]. This idea matches the foundations of collective self-consumption.

As [11] showed, residential self-consumption could cover self-consumption ratios between 15% and 56%, typically between 30% and 36%. Collective self-consumption should improve these ratios by effectively replacing other consumers' action measures such as Demand Side Management or individual or collective storage.

Collective self-consumption (CSC) extends the limitation of a single site of electricity production and consumption as in the individual self-consumption to incorporate various prosumers operating under an energy-sharing principle. These projects do not run in a closed circuit, like microgrid islands, but stay connected to the grid. Unlike virtual power plants, CSC arranges that generation and consumption nodes are close.

Applying existing knowledge on individual self-consumption may help address the promotion. Still, specific aspects will require different treatment, such as those relating to the new business models and price systems derived from various stakeholders' participation.

This paper introduces a set of criteria to estimate distribution coefficients and tests their effectiveness in a specific case study. The paper evaluates static and dynamic distribution coefficients for the first time, examining their outcomes and applicability closely. Moreover, the study thoroughly analyses the impact of various allocation models on the economic feasibility of electricity generated under different circumstances. In addition, the paper reviews the anticipated attributes of a collective self-consumption project and suggests that regulations should carefully consider such characteristics. The criteria outlined in the paper effectively address both technical and economic objectives and, therefore, could serve as a valuable tool in regulatory efforts to promote sustainable consumer behaviour and prosumers. The study is based on a territorial case study and, thus, provides valuable and practical insights into the feasibility of collective self-consumption.

The aim is to identify aspects that will be decisive in the decision-making process by susceptible investor groups and analyse several allocation models' effects on the generated electricity on economic feasibility.

Although all these issues need to be strengthened by specific regulations currently under development, studies such as this try to add new visions to the public debate based on the prosumers.

The paper begins by reviewing the expected characteristics of a CSC project and how the regulations should anticipate them. In particular, the issue related to the distribution of self-produced energy is key to savings. Some criteria for estimating distribution coefficients are introduced in Section 3 and tested for a case study in Section 4.

2. Review of Energy Collective Self-Consumption Status in Europe

The most extended CSC projects are based on a single installation collectively operated on a multi-tenancy building [12,13].

Recent regulations have paved the way for projects based on sharing distributed electricity generation installations among domestic consumers, companies, industries and even local authorities and business models with peer-to-peer trades between shareholders.

As part of the Clean Energy Package (CEP), the Renewable Energy Directive (Directive EU 2018/2001) introduced CSC (renewables-based) at the EU level through the definitions of "renewable energy community" (art. 2.16) and "jointly acting renewable self-consumers" (art. 2.15).

- 'Renewable energy community' means a legal entity, which, following the applicable national law, is based on open and voluntary participation, is autonomous and is effectively controlled by shareholders. These community members are located in the proximity of the renewable energy projects that are owned and developed by that legal entity.

- 'Jointly acting renewables self-consumers' means a group of at least two renewables self-consumers located in the same building or multi-apartment block.

The differences between energy communities and collective self-consumption are threefold. First, the communities have increased empowerment concerning the scope of generation and distribution facilities and infrastructure; second, with the predominant aim of maximising the local interest and environmental and social sustainability of the energy communities in the face of the fundamentally economic self-consumption and social impacts [14]; and third, on a more restrictive applicability perimeter in collective self-consumption, mainly limited supplies in the same building, condominium or located in nearby locations.

In contrast to renewable energy cooperatives [15], CSC is an activity rather than a different agent. The adaptation of the CSC activity in the energy system is going to raise new challenges. As with individual self-consumption, the main determinants in collective self-consumption are related to normative, technical and economic issues that are frequently interrelated. Innovations linked to the sharing economy and information and communication technologies are facilitating platforms for sharing the use of resources [16].

Regulation has to clarify the roles, duties, responsibilities and restrictions of the CSC stakeholders (namely, the CSC entity, distribution system operator and national regulatory authority). Concretely, it should regard the sharing and trading of self-consumed electricity and how they should manage communication about energy data.

In contrast, regulation will not offer a stable and secure financial landscape for self-consumption that will attract private investments and interest in the renewable industry that could become a financial partner [17].

From the CEP release, national and regional regulations are evolving to address the collective self-consumption sharing principle [18,19]. Despite the wide-ranging degree of implementation reported by [20], regulations generally focus on delimiting CSC operations' scope and finding appropriate schemes for its deployment.

Unlike individual self-consumption, collective self-consumption has yet to be regulated or has generally been incomplete in most European countries. Table 1 summarises collective self-consumption legal status in the leading European economies (Germany, United Kingdom, France, Italy and Spain). Portugal has also been incorporated for its favourable location for deploying such facilities.

Regulations usually impose technical standards and rules that a CSC project must accomplish. In addition to the technical limitation by which shareholders must be connected to the same low-voltage sub-station, a maximum perimeter is sometimes set to ensure that the production facility is close to consumption points, restricting any possibility of retailing. Under the same idea, installed power can also be limited.

The question of the organisational and legal form also arises. As a collective prosumer can be both owner and user, applying the business models for the sharing economy identified by [21] can be inspirational but not straightforward.

After analysing the same examples of consumer (co-)ownership reported by [22], it can be set that three figures can appear in shared self-consumption: The operator of the installation, its owner and the associated self-consumers. The three agents may be different, which facilitates several combinations: For example, a third party and investor can install the self-consumption on the roof of the property from which the neighbours in their house can take advantage, as well as the same community of neighbours by electrically feeding the common areas, making the community, in turn, owner of the installation.

Table 1. Regulations of collective self-consumption.

	Portugal	Spain	Italy	France	Germany	UK
Specific regulation? [1]	Yes	Yes	Yes	Yes	Yes	No
Installations	From 100 kW, approval of the network operator is required	Indoor or nearby installation via a network (less than 500 m, connected to the same transformer station or same cadastral reference)	In the same building and condominiums Limited up to 200 kW. Restricted to homes or supplies with no predominant commercial or industrial use	Within the same low voltage network, with power and distance limitations. Need for an individual meter to control shared energy	In the same multi-apartment building. Annual production and maximum installed renewable power must be met	The use of the public network for feeding collective self-consumers is prohibited.
Legal setup	Not mandatory	Not mandatory	Through a private legal contract.	A legal entity that groups consumers and producers		
Energy distribution	Distribution coefficients	Distribution coefficients		The contract between DSO (distribution system operator) and legal entity that groups consumers and producers of CSC	By agreement provided by consumers	There are neither barriers nor legislation to support it
Possibility of selling surplus	Yes	Yes	Yes	Yes	Yes	Yes
Incentives	No	No	It contemplates a premium to shared energy paid by the DSO		They receive the same sales incentives as individual self-consumers. On the contrary, they must pay 40% of the toll to sustain RES.	No

[1] Sources: Portugal: DL 162/2019, 25 de outubro 2019. Decreto-Lei do autoconsumo coletivo e comunidades de energia aprovado em Conselho de Ministros. Spain: Real Decreto 244/2019, de 5 de abril. Italy: Real Decreto 318/2020/R/eel delibera 4 agosto 2020. France: Code de l'énergie, art. 315-1 a 31.5-8. Germany: Erneuerbare-Energien-Geset, 2017. UK: Electricity Act of 1989, y FIT regulations (Feed-in Tariffs Order, 2012; No. 2782). https://www.enea-consulting.com/wp-content/uploads/2020/07/ENEA_CollectiveSelfConsumption-web.pdf (accessed on 1 July 2023).

According to European regulations, the installation operator registers the installation and will receive financial compensation for unused surpluses discharged to the network. For this reason, CSC shareholders must be organised in a legal representative entity (company, association, etc.) and sign contracts that support and define everything possible between the parties. This legal entity will be the single point of contact with the network operator and must take care of electricity and cash flows.

In that regard, the accessibility to energy consumption and production data is critical, and the accurate tracking of electricity exchanges among prosumers and with the national grid is essential. Sometimes, existing smart meters cannot manage the complexity of a CSC project, and the installation of extra hardware could also be a financial barrier for the consumer. Also, poor communications or low data granularity are real barriers to deploying CSC.

Barone et al. [23] showed the feasibility of the proposed solution. They demonstrated the effectiveness of combining smart metering and smart charging to increase the daily synchronous self-consumption of the community.

According to the review by [24], "prosumer-based energy management and sharing (PEMS) has enormous potential for cost savings, energy conservation and peak load balancing". However, they ask for some incentives and new protocols for success. Independently from its architecture, an energy management system (EMS) requires an optimisation method to reach its objective (decrease in energy costs, load shifting), and the recent development of blockchain comes with some promising applications in the field of energy, especially for collective self-consumption [4,25].

The economic viability of the CSC model is still crucial for its deployment. As with individual self-consumption, it can be reached with low costs of self-consumed energy and high self-consumption rates. On the one hand, the installation's optimal size would be that all the electricity generated was consumed instantly if its energy level cost, LCOE, is lower than the grid's electricity price. Storage can propel CSC's added value by reducing peak demand and network and generation costs.

In general, it is assumed that the installation has to be paid among all the shareholders themselves; it depends on the business model that applies to the commercial exploitation of the plant. The person who finances the installation will be an individual, a group or a company, which will receive income depending on the yield given to the production generated by the plant.

As in the first stage of energy efficiency technologies, the total cost of self-consumed energy can be reduced through financial incentives, taxes or new tariffs that improve the remuneration of excess electricity injected into the grid. However, considering that surpluses have economic stimulus (FiT, premiums) or incentives such as the net balance could give some financial risks.

Tenders or feed-in tariffs are more controllable and minimise potential windfall effects. On the other hand, self-consumption rates can be increased by matching production and consumption loads, which is straightforward with a CSC project that allows adding participants with different demand and production curves.

However, a critical aspect of allocating production to each shareholder and compensating for a collective self-consumption installation arises. Dehler et al. advise that self-consumption solutions could lead to unfair distribution of network charges, taxes and levies [26], which should be fixed. Determining the sharing scheme among prosumers is critical to collective self-consumption deployment [18]. Distribution coefficients are critical to the contractual part among shareholders because of their impact on the CSC facility's economic behaviour.

Distributed storage will play a crucial role in developing energy communities, bringing economic benefits to market participants, including arbitrageurs, renewable producers, consumers and prosumers and enhancing energy communities' efficiency, resiliency and profitability [27].

It enables the integration of distributed–connected renewable plants and helps in the optimal scheduling of energy flows within the community [28]. Adding storage devices to electricity distribution networks increases the self-consumption of renewable energy. It can enhance the profitability of projects, especially when deployed to provide stacked services across the electricity supply chain [29].

However, incorporating self-consumption demand in prosumers' economic dispatch scheduling policy with energy storage and distributed energy sources presents modelling challenges. Analysing the two scenarios separately and finding the optimal storage scheduling strategy based on the sub-ranges of the feasible state of charge range of storage can provide multistage decision-making guidance for prosumers [30]. Transactive control frameworks for energy communities equipped with independent service-oriented energy storage systems are needed.

These frameworks aim to optimise the scheduling of energy flows within the community, making the energy supply more efficient for prosumers while creating a sustainable and profitable business model for storage providers [31], as is the case of recharging electric vehicles (EVs) using the energy storage capabilities of long-term parked nonresident EVs [32]. In the context of transactive energy systems, these frameworks enable the coordination and oversight required for intra-community trading and the utilisation of renewable generation potentials [32,33]. They also address the challenges posed by the intermittence of renewable energy sources and the mismatch with demand profiles, ensuring the operation and resiliency of the electrical grid [34]. Additionally, control technology is necessary to establish the relationship between the energy community and the dispatch centre of the distribution system operator. There are proposals for real-time decentralised demand-side management systems that adjust the real-time residential load to follow a preplanned day-ahead energy generation by the microgrid based on predicted customers' aggregate load. This helps balance the planned electricity generation and its real-time use [35].

Several studies [36,37] have shown that the performance of innovative control frameworks for energy communities equipped with independent service-oriented energy storage systems does not alter fairness at the community level, and no participant strongly benefits from changing its strategy while compromising others' welfare.

By incorporating control frameworks, energy communities can effectively manage and leverage the flexibility of controllable energy resources, such as energy storage, to achieve increased renewable self-consumption and reduced electricity costs.

This paper shows how matching production and consumption loads is vital to increasing self-consumption. Still, how the electricity is distributed among a renewable energy community's prosumers would reduce the total costs of self-consumed energy.

The analysis shows the results of applying various coefficient allocation criteria, sorting them to maximise self-consumption participants' savings. In contrast to other studies, the influence of individual electricity consumption behaviour and consumer preferences on the individual benefit of a self-consumption system is considered.

The study does not include the hypothesis of using any storage, such as batteries, to accumulate electricity not consumed instantly because of its current cost, above which it would allow it to be monetised before the end of its useful life.

3. Review of Sharing Criteria

Table 1 shows that the distribution of energy generated among shareholders is considered in regulations as a necessary step for its final implementation. This allocation should be established by the entity holding the asset or a pact after the legal company's start-up and before the entry into operation. For instance, an agreement that includes weighting the distribution (through coefficients) of the electricity generated is compulsory in Spain and Portugal.

Likewise, the selection of optimal distribution criteria that ensure a high on-site use of the energy generated or more significant economic savings is also an analysis necessary to improve the development of shared self-consumption by producing an improvement in investment indicators.

In the case of a collective installation, the distribution of the produced energy among consumers is established by the distribution coefficients (the sum of which must be 1), which allocate the energy measured by the generation meter among the participants in the self-consumption project. In other words, distribution coefficients specify the proportion of the energy generated at the shared installation that each consumer will receive:

$$G(i,t) = \mu(i) \cdot G(t) \quad (1)$$

where:

- $G(i,t)$ is the generated energy allocated to the consumer i at time t.
- $G(t)$ is the total generated energy at time t.
- $\mu(i,t)$ sharing coefficient of energy generated for the consumer i at time t.

Sharing coefficients can be dynamic, that is, they change over time $\mu(i,t)$, or static if they do not change $\mu(i)$.

It should be noted that this allocation is instead a physical distribution. Until management systems are not implemented, the energy generated will feed each consumer's electricity demand without meeting any restrictions. Subsequently, the reading agent will apply that distribution in the corresponding measurements.

Several rational types of coefficients for the distribution of generated electricity among shareholders can be considered:

A. Proportional to the individual investments in the CSC installation.
B. Proportional to individual contracted power.
C. Proportional to the individual percentages of the total energy consumed by the CSC project during a year.
D. Proportional to the individual percentages on the total energy consumed by the CSC project during periods with energy generation.
E. Proportional to the individual percentages on the costs of the energy consumed during periods with energy generation.

It is expected that the criteria not indexed with energy consumption (criterion A and partly criterion B) will not be a driver to find the energy and economic optimal of the installation. The annual variability of the criteria based on the consumptions (C, D and E) does not guarantee futures. Criterion D would prioritise the distribution to the consumer of higher consumption during generation hours. Criterion E, indexed to electricity prices, could overestimate lower rate customers (lower contracted power) since tolls and system costs are higher at low voltage rates than high and lower power than higher. In addition, this analysis involves a subjective element: The price of each customer's electricity. That depends on each customer's capacity and interest to obtain a more or less competitive price and the time the contract was negotiated. The latter factor is significant because the duration of the supply contracts is annual. Consequently, in the case of non-alignment on the start and end dates of the contract of all self-consumers, it determines that the analysis carried out at the initial time is valid only for that time and unless all contracts are renewed on the same dates.

The main concern is how distribution coefficients affect the installation's economic profitability. Thus, the research questions (RQ) are defined as follows:

- RQ1: What is the criterion that produces the highest savings?
- RQ2: Would savings improve with dynamic coefficients rather than static ones?
- RQ3: Is there a more equitable criterion?
- RQ4: By what criteria does the worst result get?

In order to find the most suitable distribution coefficients for the economic profitability of a CSC project, a cost study is accomplished. The idea is to estimate the electricity's annual cost as purchased electricity from the grid. A group of prosumers will assume several allocation schemes for the generated electricity in the CSC installation in line with previous studies [3,38].

As a first approach, the method does not consider the storage of the electricity not consumed instantly and assumes that there are no restrictions or preconditions for the distribution of energy taken into account or foreseen as frequent in the future.

For this purpose, the electricity production from a solar installation allocated to each shareholder $G(i,t)$ is compared to the actual consumption data of each shareholder $D(i,t)$ on a temporal basis.

When the individual demand $D(i,t)$ is higher than the allocated generated electricity $G(i,t)$, the cost of the electricity from the grid is calculated considering the instant price for each consumer $PP(i,t)$:

$$[D(i,t) - \mu(i,t) \cdot G(t)] \cdot PP(i,t) \quad (2)$$

In periods without generation production $G(t) = 0$, all the electricity demand must be covered by the grid, and the cost of the electricity for each participant will be estimated as $D(i,t) \cdot PP(i,t)$

If the installation is producing electricity $G(t) \neq 0$, self-consumed electricity SC can be estimated as:

$$SC\ (i,t) = min[G(i,t), D(i,t)] \quad (3)$$

Moreover, savings can be estimated from the purchase price $PP(i,t)$, providing that it could vary among consumers and periods:

$$Sav(i,t) = SC(i,t) \cdot PP(i,t) \quad (4)$$

If the individual demand $D(i,t)$ is lower than the allocated generated electricity $G(i,t)$, there will be a surplus of generated electricity not consumed by the shareholders. The so-called under-generated electricity (UG) can be estimated as follows:

$$UG(i,t) = \mu(i,t) \cdot G(t) - D(i,t) \quad (5)$$

In an optimised self-consumption installation, the total produced energy must be consumed locally, reducing surpluses and exports to the grid. The latter means that the installed power must be adjusted to the consumers' needs, and the produced electricity must be adequately distributed to obtain the minimum value for $UG(i,t)$. Searching the minimum value for $UG(i,t)$ could also be considered an optimisation criterion.

If this surplus could be sold or compensated at an agreed price, $SP(i,t)$

$$UG(i,t) \cdot SP(i,t)$$

the total savings for each shareholder at any time would increase:

$$Sav(i,t) = SC\ (i,t) \cdot PP(i,t) + UG(i,t) \cdot SP(i,t) \quad (6)$$

The above amounts can be integrated for all the self-consumption community members and the whole year to obtain the following indicators for the CSC project:

- Total annual savings:

$$Annual\ savings = \sum_t \sum_i SC\ (i,t) \cdot PP(i,t) + UG(i,t) \cdot SP(i,t) \quad (7)$$

- The ratio of self-consumption:

$$SCR = \frac{\sum_t \sum_i SC(i,t)}{\sum_t G(t)} \quad (8)$$

- Ratio of self-sufficiency:

$$SSR = \frac{\sum_t \sum_i SC(i,t)}{\sum_t \sum_i D(i,t)} \tag{9}$$

- Payback:

$$PB = \frac{Installation\ cost}{Annual\ savings} \tag{10}$$

Table 2 summarises the equations to calculate the distribution coefficients according to this model.

Table 2. Distribution criteria for generated electricity in a collective self-consumption project.

Criterion	Distribution Coefficient
A. Proportional to the individual investments	$\mu(i) = \frac{Inv(i)}{\sum_i Inv(i)}$
B. Proportional to individual contracted power (CP)	$\mu(i) = \frac{CP(i)}{\sum_i CP(i)}$
C. Proportional to the total consumed energy	$\mu(i) = \frac{\sum_t D(i,t)}{\sum_i \sum_t D(i,t)}$
D. Proportional to the energy consumed in periods with energy generation	$\mu(i) = \frac{\sum_t D(i,t) - SC(i,t)}{\sum_i \sum_t D(i,t) - SC(i,t)}$
E. Proportional to energy costs in periods with energy generation	$\mu(i) = \frac{\sum_t [D(i,t) - SC(i,t)] \cdot PP(i,t)}{\sum_i \sum_t [D(i,t) - SC(i,t)] \cdot PP(i,t)}$

4. Case Study

Since the exploitation of renewable energy for self-consumption is closely linked to the local energy market, Spain has been selected as a case study.

Spain was among the first movers to partially implement Article 21 of RED II with the Royal Decree RD244/2019, published last April. It allows the CSC where more than one consumer is associated with the same production facility. Moreover, the connection between the production facility and the point of consumption must be either an internal network or a direct line, a low-voltage network derived from the same substation in a perimeter under 500 m.

In collective renewable self-consumption projects under RD244/2019, the production of one single installation is shared among the associated consumers according to their allocation criteria and communicated to the distribution company in charge of the energy readings through the marketer with which each prosumer has signed the supply contract.

The distribution company reads the electricity produced by the self-consumption installation on an hourly basis, allocates this production to each shareholder and makes the hourly balance between consumption and production.

According to the resolution published by the Government (https://www.boe.es/diario_boe/txt.php?id=BOE-A-2019-5089 (accessed on 1 July 2023)), Spanish prosumers may be compensated by their electricity providers for the surpluses they inject into the network.

The ratio definition is up to the self-consumption collective users. If such communication did not occur, the energy allocation would be proportional to each participant's contracted power against the total contracted power.

Currently, the Spanish regulations only allow static coefficients (fixed as a minimum for a monthly tariff period) but open the door to dynamic coefficients able to be adapted to hour, days, months or annual periods.

To illustrate the impact of the distribution coefficients on the economic feasibility of a CSC installation, a shared self-consumption photovoltaic facility located in Zaragoza (Spain) feeds connected supplies through a nearby network is used. The connection is that no tolls or surcharges should be added to use the self-consuming power distribution network.

(a) Design of the facility

A typical PV installation (crystalline silicon, due South) of 15 kW of installed power has been modelled through PVGIS SARAH in an hourly resolution. The facility is located in Zaragoza (41°39′00″ N 0°53′00″ O) with a performance ratio of 25%, generating 1535 kWh per year.

(b) Shareholder typologies

The CSC project under study joins three prosumers with tariff and consumption profiles according to Type A, B and C, respectively, as defined by the Spanish system operator REE. Type A and B are domestic consumers with different tariffs (without and with time discrimination), and Type C is commercial.

The hourly consumption profile is assumed to be the same as those established by the Spanish system operator Red Eléctrica de España.

Table 3 summarises three customer types with pricing, power and consumption data.

Table 3. Consumption profiles of the prosumers in the case study.

Prosumer	Contracted Power (kW)	Annual Consumption kWh (Year 2021)	Consumption Profile	Tariff
Type A	4.4	3487	IDAE: Consumos del sector residencial en España Consumos del sector residencial en España: https://www.idae.es/uploads/documentos/documentos_Documentacion_Basica_Residencial_Unido_c93da537.pdf (accessed on 1 July 2023).	2.0A
Type B	6.9	5629	IDAE: Consumos del sector residencial en España Consumos del sector residencial en España: https://www.idae.es/uploads/documentos/documentos_Documentacion_Basica_Residencial_Unido_c93da537.pdf (accessed on 1 July 2023).	2.0DHA
Type C	15	47,790	Boletín de indicadores eléctricos. CNMC. Enero 2020: https://www.cnmc.es/sites/default/files/2820313_11.pdf (accessed on 1 July 2023).	3.0A

(c) Electricity prices:

The electricity prices used are competitive one by rate and period according to the comparator of the National Commission on Markets and Competition, CNMC. These prices do not include a power surcharge against regulated tolls to assure that the trading company's entire commercial margin is applied in terms of energy. Consequently, the savings can be better analysed after the installation of self-consumption. The prices used in the study are in Table 4.

Table 4. Electricity prices for the prosumers in the case study.

Prosumer	Tariffs	Period	€/kWh
Type A	2.0A	P1	0.1229
Type B	2.0DHA	P1	0.145166
	2.0DHA	P2	0.07398
Type C	3.0A	P1	0.101459
	3.0A	P2	0.08794
	3.0A	P3	0.064602

Concerning surpluses, Spanish regulation allows collective self-consumption with or without surpluses. There are two surplus valuation mechanisms: By simplified compensation in the invoice or by selling the excess production. Even with the possibility of receiving income from the total surplus energy, this latter case is less likely for the case analysed by the corporate, and tax obligations it requires. Consequently, customer-generated surpluses are assumed to be repaid on the invoice using the simplified compensation mechanism.

The present analysis has considered a competitive price for non-self-consumption surpluses of 0.049 €/kWh.

(d) Installation cost

The installation cost has been extrapolated from the experience acquired by an energy company whose services are the execution of individual self-consumption turnkey projects since 2015.

The cost of the considered installations is 16,500 €. It is supposed that this investment is shared among the prosumers in percentages of 20%, 20% and 60%, respectively.

(e) Distribution coefficients:

Table 5 summarises the most relevant data, and Table 6 shows the calculated variables to estimate the distribution coefficients.

Table 5. Data for the calculation of the distribution coefficients.

Prosumer	Annual Demand (kWh)	Annual Consumption from the Public Grid in P1 (kWh)	Annual Consumption from the Public Grid in P2 (kWh)	Annual Consumption from the Public Grid in P3 (kWh)
Type A	3487	1978	0	0
Type B	5629	1208	1300	0
Type C	47,790	6453	19,129	2958
TOTAL	56,906			

Table 6. Data for the calculation of the investments.

Prosumer (i)	% Investment $Inv(i)$	Contracted Power (kW) $CP(i)$	Annual Demand (kWh) $\sum_t D(i,t)$	Electricity from the Grid (kWh) $\sum_t D(i,t) - G(i,t)$	Cost of the Electricity from the Grid (€) $\sum_t [D(i,t) - G(i,t)] \cdot PP(i,t)$
Type A	20	4.6	3487	1978	243
Type B	20	6.9	5629	2508	271
Type C	60	15	47,790	28,540	2518
TOTAL	100	26.5	56,906	33,026	3042

After applying the equations in Table 2, distribution coefficients for the criteria A to E are shown in Table 7. A reference scenario (Criterion 0) includes no self-consumption installation for comparison. Criterion F, resulting from the arithmetic mean of criteria A to E, is also included.

Table 7. Distribution coefficients regarding studied criteria under a fixed annual coefficient scenario.

Criterion	Criteria for Distribution Coefficients	$\mu(A)$	$\mu(B)$	$\mu(C)$
Criterion 0	Without self-consumption	N/A	N/A	N/A
Criterion A	Proportional to the individual investments	0.2	0.2	0.6
Criterion B	Proportional to individual contracted power (CP)	0.17	0.26	0.57
Criterion C	Proportional to the total consumed energy	0.06	0.10	0.84
Criterion D	Proportional to the energy consumed in periods with energy generation	0.06	0.08	0.86
Criterion E	Proportional to energy costs in periods with energy generation	0.08	0.09	0.83
Criterion F	Average of coefficients A–E	0.11	0.15	0.74

According to the Spanish regulation, without notification of the distribution coefficients' agreement, the distributor will calculate them, depending on the contracted power.

5. Results

Table 8 shows each shareholder's annual electricity cost and the aggregate value under a fixed yearly coefficient scenario.

Table 8. Annual costs of electricity under a fixed yearly coefficient scenario without compensation.

Prosumer	Criterion 0	Criterion A	Criterion B	Criterion C	Criterion D	Criterion E	Criterion F
Type A	428.49	219.32	222.85	271.29	273.25	252.08	255.48
Type B	580.22	361.23	354.78	392.59	413.21	399.97	394.13
Type C	4048.40	2800.29	2856.02	2418.73	2389.79	2429.60	3005.81
Total Cost	5057.11	3380.85	3433.64	3082.61	3076.25	3081.65	3655.43

They are the costs of buying grid electricity once the individual hourly demand is covered by electricity generated in the self-consumption facility (free of charge) and allocated according to the distribution criteria of Table 5.

Table 9 shows the economic savings in percentage with respect to the electricity consumed cost without self-consumption (criterion 0).

Table 9. Percentage of savings under a fixed annual coefficient scenario.

Prosumer	Criterion 0	Criterion A	Criterion B	Criterion C	Criterion D	Criterion E	Criterion F
Type A	0%	−49%	−48%	−37%	−36%	−41%	−40%
Type B	0%	−38%	−39%	−32%	−29%	−31%	−32%
Type C	0%	−31%	−29%	−40%	−41%	−40%	−26%
Total Reduction	0%	−33.1%	−32.1%	−39.0%	−39.2%	−39.1%	−27.7%

As is expected, as shown in Table 10, the higher the self-consumption ratio, the better the return on investment.

Table 10. Payback analysis.

	Criterion A	Criterion B	Criterion C	Criterion D	Criterion E	Criterion F
Self-consumption ratio (%)	76	74	93	94	93	88
Payback (years)	8.3	8.4	7.8	7.8	7.8	7.9

If the valorisation of surpluses is allowed and the compensation option is applied, costs are slightly reduced, as shown in Table 11.

Table 11. Annual costs of electricity under a fixed yearly coefficient scenario with compensation.

Prosumer	Criterion 0	Criterion A	Criterion B	Criterion C	Criterion D	Criterion E	Criterion F
Type A	428.49	82.86	116.13	264.86	267.66	232.28	183.51
Type B	580.22	234.92	163.54	365.62	403.48	380.63	302.77
Type C	4048.40	2790.35	2849.56	2345.34	2304.45	2360.25	2518.52
Total Cost	5057.11	3108.13	3129.23	2975.82	2975.59	2973.16	3004.81

By applying fixed yearly coefficients, the best economic scenario is obtained if generated electricity is proportionally allocated to the energy consumed in periods with energy generation and, only if compensation is allowed, to energy costs.

Spanish regulation also offers the possibility of varying the distribution coefficients each month. Table 12 shows the coefficients calculated as proportional to each self-consumer's monthly energy consumed in periods with generation.

Table 12. Distribution coefficients regarding studied criteria under a fixed annual coefficient scenario.

	January	February	March	April	May	June	July	August	September	October	November	December
Prosumer Type A	184	165	163	157	158	169	192	191	148	141	152	158
Prosumer Type B	243	223	211	194	195	201	235	239	183	180	196	209
Prosumer Type C	2309	2206	2219	2207	2403	2781	2987	2768	2394	2180	2082	2005
Total	2736	2594	2593	2558	2755	3151	3414	3198	2726	2501	2429	2372
Coef A	0.07	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.07
Coef B	0.09	0.09	0.08	0.08	0.07	0.06	0.07	0.07	0.07	0.07	0.08	0.09
Coef C	0.84	0.85	0.86	0.86	0.87	0.88	0.87	0.87	0.88	0.87	0.86	0.85

After applying the above monthly fixed distribution coefficients, the results obtained are included in Table 13 under criterion G.

Table 13. Electricity costs after several criteria for the distribution coefficients.

Prosumer	Criterion D	Criterion E	Criterion G	Criterion H
Type A	267.66	232.28	267.36	265.45
Type B	403.48	380.63	402.44	405.41
Type C	2304.45	2360.25	2303.60	2301.49
Total Annual Cost	2975.59	2973.16	2973.39	2972.35

The potential incorporation of dynamic distribution coefficients has also been analysed. In this case, hourly coefficients proportional to the energy consumed each hour by each self-consumer are estimated. In this case, electricity costs are included in Table 12 under the epigraph Criterion H.

Table 13 summarises the electricity costs in the best results for static coefficients (D and E for yearly and G for monthly coefficients) and those for dynamic coefficients (H).

Based on the results obtained in the study, it is possible to establish a hierarchy proposal in the criteria for distribution coefficients according to the raised savings, as shown in Table 14.

Table 14. Hierarchy proposal in criteria for the distribution coefficients.

Criterion	Criteria for Distribution Coefficients
Criterion E	Proportional to energy costs in periods with energy generation
Criterion D	Proportional to the energy consumed in periods with energy generation
Criterion C	Proportional to the total consumed energy
Criterion F	Average of coefficients A-E
Criterion A	Proportional to the individual investments
Criterion B	Proportional to individual contracted power (CP)
Criterion 0	Without self-consumption

6. Conclusions

With the current Spanish regulatory development, the highest savings occur when electricity is allocated following distribution coefficients that consider the customer's energy consumption, even when the compensation of surpluses is added. Among them is the one that contemplates self-consumers' consumption when there is a distributed generation. Applying criteria that consider energy consumption allows one to obtain overall savings higher than 4% compared to not having them (an approach that considers energy consumption).

The study is based on a territorial case study in Spain, which may limit the generalizability to other regions or countries with different energy markets and regulations. However, findings can be applied to specific regulations currently under development to be further strengthened to address the issues related to the energy distribution and allocation models.

As stated, the paper does not consider using storage systems, such as batteries, to accumulate and monetise unused electricity, which could impact collective self-consumption systems' feasibility and economic benefits. Future studies can consider the storage of electricity not consumed instantly and the potential restrictions or preconditions for the distribution of energy, which may be frequent in the future.

The analysis makes it possible to conclude that applying variable coefficients (monthly and time) yields the most significant difference in overall savings between the best criteria by better adapting to overall consumption and improving the current situations' criteria. Consequently, regulations that will enhance the dynamism and flexibility in using such coefficients will improve the techno-economic performance of the CSC installations.

Under a justice criterion, the scenario in which the distribution coefficients are constant and proportional to the investment made by each client is the most equitable. It allows the client to benefit from the investment made proportionately by shifting consumption to generation hours as an equity approach.

Although objective and clear to customers, the contracted power selection criterion provides the worst savings. The contracted power does not respond to optimal technical and economical, which pushes the worst selection of coefficients and, consequently, the worst operating scenario. It should be noted that this is the criterion for allocating subsidiary coefficients in the current legislation in the absence of further communication.

The selection criteria differ depending on a global approach (the final result of the installation), savings or individualised. Significantly, the best outcome for the type A prosumer occurs when the highest distribution coefficient corresponds to the investment proportional coefficient criterion (when recovering savings with simplified sur-plus compensation), even if that criterion does not determine the optimal scenario in a global approach. As a result, the criteria that provide the highest total savings only benefit some self-consumers. There are criteria whose application determines more self-consumers with more significant savings than they receive in the case of greater overall savings.

Even though other factors such as grid constraints, technical limitations and maximum installed power are not considered in this approach, from the point of view of the allocation of electricity based on distribution coefficients, the above criteria can accomplish technical and economic objectives and are suited to be introduced in regulations fostering the requested changes in consumers' behaviour and prosumers for sustainability.

While it is out of the scope of this paper, further research can be conducted to provide a comprehensive analysis of the impact of individual electricity consumption behaviour and consumer preferences on the benefits of self-consumption systems and strengthen the identified aspects that are decisive in the decision-making process by susceptible investor groups.

In addition, the potential challenges and limitations associated with the organisational and legal forms of collective self-consumption projects could be further addressed, such as the complexities of implementing sharing economy business models and the roles of different stakeholders.

It can be noticed that the implementation of collective self-consumption projects will impact the energy market, and regulations must be investigated from several perspectives to understand their potential for promoting sustainability and changes in consumer behaviour.

Author Contributions: Conceptualisation, E.L.-S., J.L.O.-T., J.Á.G. and P.P.-T.; formal analysis, E.L.-S., J.L.O.-T., J.Á.G. and P.P.-T.; Investigation, E.L.-S., J.L.O.-T., J.Á.G. and P.P.-T.; methodology, E.L.-S., J.L.O.-T., J.Á.G. and P.P.-T.; writing—review and editing, E.L.-S., J.L.O.-T., J.Á.G. and P.P.-T. All authors participated equally in the research design, development of the theoretical framework, methodological choices and analysis. All authors wrote and revised the paper. All authors have read and agreed to the published version of the manuscript.

Funding: This study has been partially financed as part of the TED2021-130000B-I00 and TED2021-131397B-I00 R&D projects, both funded by MCIN/AEI/10.13039/501100011033/ and by the "European Union NextGenerationEU/PRTR". The co-financing provided by the Regional Government of Aragon in the framework of Research Groups T46_23R and S33_23R is also gratefully acknowledged.

Data Availability Statement: Not applicable.

Acknowledgments: We thank the collaboration with FENIE ENERGIA, S.A., for the empirical study.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the study's design; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Abbreviations

CSC: collective self-consumption; CEP: Clean Energy Package; DSO: distribution system operator; RES: renewable energy sources; PEMS: prosumer-based energy management and sharing; EMS: energy management system; LCOE: Levelized Cost of Energy; FiT: Feed-in-tariff; EV: electric vehicle.

References

1. 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]
2. Gfk Belgium Consortium. Study on "Residential Prosumers in the European Energy Union". JUST/2015/CONS/FW/C006/0127. Framework Contract EAHC/2013/CP/04. 2017. Available online: https://commission.europa.eu/system/files/2017-11/study-residential-prosumers-energy-union_en.pdf (accessed on 1 July 2023).
3. Gimeno, J.Á.; Llera, E.; Scarpellini, S. Investment Determinants in Self-Consumption Facilities: Characterisation and Qualitative Analysis in Spain. *Energies* **2018**, *11*, 2178. [CrossRef]
4. Stephant, M.; Hassam-Ouari, K.; Abbes, D.; Labrunie, A.; Robyns, B. A Survey on Energy Management and Blockchain for Collective Self-Consumption. In Proceedings of the 2018 7th International Conference on Systems and Control (ICSC), Valencia, Spain, 24–26 October 2018; pp. 237–243. [CrossRef]
5. Tayal, D.; Rauland, V.; Moezzi, M.; Ingle, A.; Lutzenhiser, L.; Sigrin, B.; Bhalla, T.; Macgrogan, A.; Miller, E.; Tosi, N.; et al. Barriers to the Adoption of Photovoltaic Systems: The State of the Art. *Renew. Sustain. Energy Rev.* **2015**, *49*, 60–66. [CrossRef]
6. Gimeno, J.Á.; Llera-Sastresa, E.; Scarpellini, S. A Heuristic Approach to the Decision-Making Process of Energy Prosumers in a Circular Economy. *Appl. Sci.* **2020**, *10*, 6869. [CrossRef]
7. Scarpellini, S.; Portillo-Tarragona, P.; Marín-Vinuesa, L.M.; Moneva, J.M. Green Patents in the Manufacturing Sector: The Influence of Businesses' Resources and Capabilities. *Universia Bus. Rev.* **2017**, *2017*, 18–35. [CrossRef]

8. Fachrizal, R.; Munkhammar, J. Improved Photovoltaic Self-Consumption in Residential Buildings with Distributed and Centralized Smart Charging of Electric Vehicles. *Energies* **2020**, *13*, 1153. [CrossRef]
9. Gudmunds, D.; Nyholm, E.; Taljegard, M.; Odenberger, M. Self-Consumption and Self-Sufficiency for Household Solar Producers When Introducing an Electric Vehicle. *Renew. Energy* **2020**, *148*, 1200–1215. [CrossRef]
10. Roberts, M.B.; Bruce, A.; MacGill, I. A Comparison of Arrangements for Increasing Self-Consumption and Maximising the Value of Distributed Photovoltaics on Apartment Buildings. *Sol. Energy* **2019**, *193*, 372–386. [CrossRef]
11. Luthander, R.; Widén, J.; Munkhammar, J.; Lingfors, D. Self-Consumption Enhancement and Peak Shaving of Residential Photovoltaics Using Storage and Curtailment. *Energy* **2016**, *112*, 221–231. [CrossRef]
12. Pappalardo, M.; Debizet, G. Understanding the Governance of Innovative Energy Sharing in Multi-Dwelling Buildings through a Spatial Analysis of Consumption Practices. *Glob. Transit.* **2020**, *2*, 221–229. [CrossRef]
13. Syed, M.M.; Hansen, P.; Morrison, G.M. Performance of a Shared Solar and Battery Storage System in an Australian Apartment Building. *Energy Build.* **2020**, *225*, 110321. [CrossRef]
14. Scarpellini, S. Social Impacts of a Circular Business Model: An Approach from a Sustainability Accounting and Reporting Perspective. *Corp. Soc. Responsib. Environ. Manag.* **2022**, *29*, 646–656. [CrossRef]
15. Wierling, A.; Schwanitz, V.J.; Zeiß, J.P.; Bout, C.; Candelise, C.; Gilcrease, W.; Gregg, J.S. Statistical Evidence on the Role of Energy Cooperatives for the Energy Transition in European Countries. *Sustainability* **2018**, *10*, 3339. [CrossRef]
16. Portillo-Tarragona, P.; Scarpellini, S.; Marín-Vinuesa, L.M. 'Circular Patents' and Dynamic Capabilities: New Insights for Patenting in a Circular Economy. *Technol. Anal. Strateg. Manag.* **2022**, 1–16. [CrossRef]
17. Scarpellini, S.; Gimeno, J.Á.; Portillo-Tarragona, P.; Llera-Sastresa, E. Financial Resources for the Investments in Renewable Self-Consumption in a Circular Economy Framework. *Sustainability* **2021**, *13*, 6838. [CrossRef]
18. Frieden, D.; Roberts, J.; Gubina, A.F. *Collective Self-Consumption and Energy Communities: Overview of Emerging Regulatory Approaches in Europe*; IEEE: Piscataway, NJ, USA, 2019.
19. Inês, C.; Guilherme, P.L.; Esther, M.G.; Swantje, G.; Stephen, H.; Lars, H. Regulatory Challenges and Opportunities for Collective Renewable Energy Prosumers in the EU. *Energy Policy* **2020**, *138*, 111212. [CrossRef]
20. Frieden, D.; Tuerk, A.; Neumann, C.; D'Herbemont, S.; Roberts, J. *Collective Self-Consumption and Energy Communities: Trends and Challenges in the Transposition of the EU Framework*; COMPILE: Graz, Austria, 2020. [CrossRef]
21. Acquier, A.; Carbone, V.; Massé, D. Technology Innovation Management Review How to Create Value(s) in the Sharing Economy: Business Models, Scalability, and Sustainability. *TIM Rev.* **2019**, *9*, 5–24. [CrossRef]
22. Lowitzsch, J.; Hoicka, C.E.; van Tulder, F.J. Renewable Energy Communities under the 2019 European Clean Energy Package—Governance Model for the Energy Clusters of the Future? *Renew. Sustain. Energy Rev.* **2020**, *122*, 109489. [CrossRef]
23. Barone, G.; Brusco, G.; Menniti, D.; Pinnarelli, A.; Polizzi, G.; Sorrentino, N.; Vizza, P.; Burgio, A. How Smart Metering and Smart Charging May Help a Local Energy Community in Collective Self-Consumption in Presence of Electric Vehicles. *Energies* **2020**, *13*, 4163. [CrossRef]
24. Zafar, R.; Mahmood, A.; Razzaq, S.; Ali, W.; Naeem, U.; Shehzad, K. Prosumer Based Energy Management and Sharing in Smart Grid. *Renew. Sustain. Energy Rev.* **2018**, *82*, 1675–1684. [CrossRef]
25. Menniti, D.; Sorrentino, N.; Pinnarelli, A.; Mendicino, S.; Vizza, P.; Polizzi, G. A Blockchain Based Incentive Mechanism for Increasing Collective Self-Consumption in a Nonsumer Community. In Proceedings of the 2020 17th International Conference on the European Energy Market (EEM), Stockholm, Sweden, 16–18 September 2020. [CrossRef]
26. Dehler, J.; Keles, D.; Telsnig, T.; Fleischer, B.; Baumann, M.; Fraboulet, D.; Faure-Schuyer, A.; Fichtner, W. Self-Consumption of Electricity from Renewable Sources. In *Europe's Energy Transition: Insights for Policy Making*; Academic Press: Cambridge, MA, USA, 2017; pp. 225–236. [CrossRef]
27. Ademulegun, O.O.; Keatley, P.; Mustafa, M.B.; Hewitt, N.J. Energy Storage on a Distribution Network for Self-Consumption of Wind Energy and Market Value. *Energies* **2020**, *13*, 2688. [CrossRef]
28. De Juan-Vela, P.; Alic, A.; Trovato, V. Impact of Policy Options on Battery Storage in Renewable Energy Communities. In Proceedings of the 19th International Conference on the European Energy Market (EEM), Lappeenranta, Finland, 6–8 June 2023; pp. 1–5. [CrossRef]
29. Albouys-Perrois, J.; Sabouret, N.; Haradji, Y.; Schumann, M.; Charrier, B.; Reynaud, Q.; Sempé, F.; Inard, C. Multi-Agent Simulation of Collective Self-Consumption: Impacts of Storage Systems and Large-Scale Energy Exchanges. *Energy Build.* **2022**, *254*, 111543. [CrossRef]
30. Liu, J.; Dai, Z.; Bo, R.; Meng, F.; Ou, M. Optimal Economic Dispatch Policy for Prosumer with Energy Storage Considering Self-Consumption Demand. *Comput. Ind. Eng.* **2023**, *176*, 108853. [CrossRef]
31. Mignoni, N.; Scarabaggio, P.; Carli, R.; Dotoli, M. Game Theoretical Control Frameworks for Multiple Energy Storage Services in Energy Communities. In Proceedings of the 8th International Conference on Control, Decision and Information Technologies (CoDIT), Istanbul, Turkey, 17–20 May 2022; Volume 1, pp. 1580–1585. [CrossRef]
32. Moura, P.; Sriram, U.; Mohammadi, J. Sharing Mobile and Stationary Energy Storage Resources in Transactive Energy Communities. In Proceedings of the 2021 IEEE Madrid PowerTech, Madrid, Spain, 28 June–2 July 2021; pp. 1–6. [CrossRef]
33. Haddad, R.; Morva, G.; Bencsik, J.; Kadar, P. Energy Management System for Energy Communities. In Proceedings of the IEEE 5th International Conference and Workshop Óbuda on Electrical and Power Engineering (CANDO-EPE), Budapest, Hungary, 21–22 November 2022; pp. 199–204. [CrossRef]

34. Marques, L.; Uturbey, W.; Heleno, M. An Integer Non-Cooperative Game Approach for the Transactive Control of Thermal Appliances in Energy Communities. *Energies* **2021**, *14*, 6971. [CrossRef]
35. Tushar, M.H.K.; Zeineddine, A.W.; Assi, C. Demand-Side Management by Regulating Charging and Discharging of the EV, ESS, and Utilising Renewable Energy. *IEEE Trans. Ind. Inform.* **2018**, *14*, 117–126. [CrossRef]
36. Mignoni, N.; Scarabaggio, P.; Carli, R.; Dotoli, M. Control Frameworks for Transactive Energy Storage Services in Energy Communities. *Control Eng. Pract.* **2023**, *130*, 105364. [CrossRef]
37. Mignoni, N.; Carli, R.; Dotoli, M. Distributed Noncooperative MPC for Energy Scheduling OfCharging and Trading Electric Vehicles in Energy CommunitiesCharging and Trading Electric Vehicles in Energy Communitie. *IEEE Trans. Control Syst. Technol.* **2023**, *31*, 2159–2172. [CrossRef]
38. Gimeno, J.Á.; Llera-Sastresa, E.; Scarpellini, S. Determinants and Barriers of PV Self-Consumption in Spain from the Perception of the Installers for the Promotion of Distributed Energy Systems. *Econ. Policy Energy Environ.* **2020**, *11*, 153–169. [CrossRef]