EMPOWERING ENERGY COMMUNITIES: THREE METHODS TO DISTRIBUTE SAVINGS IN LOCAL ENERGY MARKETS

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ABSTRACT:

In the current context of energy crisis, the energy sector is undergoing significant transformations towards a sustainable, competitive, and affordable energy landscape. Central to this transformation are Energy Communities (ECs), which have emerged as an ideal vehicle to facilitate the energy transition for small consumers.

This paper evaluates the performance of three alternative methods (i.e. bill-sharing, price-based and surplus-based) to allocate costs and benefits within ECs. Specifically, we compare the distribution of savings generated by energy internal trading under each of the three allocation methods.

The three allocation methods guarantee extracting the maximum economic surplus (i.e. savings) from the internal market, but one of them (bill-sharing) does not guarantee that participating in the internal trading is beneficial for every member. This is a major obstacle for its implementation since, frequently, some agents are worse off due to its participation in the community. The other two methods guarantee that participation is beneficial, but they differ in how savings are distributed. The distribution under price-based methods is influenced by the prices at which different members of the EC can buy and sell energy from the grid, while surplus-based methods distribute savings according to a criterion agreed by the EC members. Here we assume that they do it proportionally to the energy traded in the internal market.

Keywords: ***energy communities, local energy market, allocation method***

RESUMEN:

En el contexto actual de crisis energética, el sector energético está experimentando transformaciones significativas hacia un ecosistema energético sostenible, competitivo y asequible. En el centro de esta transformación se encuentran las Comunidades Energéticas (CEs), las cuales han surgido como un instrumento ideal para facilitar la transición energética de pequeños consumidores.

Este artículo evalúa tres métodos alternativos (bill-sharing, price-based y surplus-based) para asignar costes y beneficios dentro de las CEs. Específicamente, comparamos la distribución de los ahorros generados en el mercado interno bajo cada uno de estos tres métodos de asignación.

Los tres métodos de asignación garantizan obtener el máximo excedente económico (o ahorro) en el mercado interno, aunque uno de ellos (bill-sharing) no garantiza que la participación en el mercado interno sea beneficiosa para todos los miembros. Esto representa un obstáculo importante para su implementación, ya que con frecuencia algunos agentes se verán perjudicados cuando participan en la comunidad. Los otros dos métodos garantizan que la participación es beneficiosa, pero difieren en cómo se distribuyen los ahorros. La distribución bajo métodos de tipo price-based se ve influenciada por los precios a los que diferentes miembros de la CE pueden comprar y vender energía de la red, mientras que los métodos surplus-based distribuyen los ahorros de acuerdo con un criterio acordado por los miembros de la CE. Aquí asumimos que lo hacen de manera proporcional a la energía transferida en el mercado interno.

Keywords: ***comunidades energéticas, mercado local de energía, método de asignación***

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1. – INTRODUCTION: THE ENERGY COMMUNITIES CHALLENGE

For several years now, the energy sector has been going through a unique period characterized by localized shortages, high price volatility, strong dependence on fossil fuels, and disturbing turbulences in the geopolitical landscape. As a result, energy markets and policies have evolved and continue evolving. Nowadays there are strong environmental and economic arguments in favor of affordable, competitive and sustainable energy sources that could guarantee the long-term welfare of citizens [1].

In the energy sector, citizens have traditionally been considered only in their role as consumers and, therefore, they have suffered a weak position in terms of market power. To address this issue, new citizen empowerment policies have been promoted by the European Commission [2], aimed at changing the balance of power in the energy market. Innovative tools that allow taking advantage of the distributed nature of small consumers are emerging, such as self-consumption of locally produced clean energy, demand response management and distributed storage. In particular, Energy Communities (ECs) have proven to be a useful vehicle for the implementation of this type of citizen empowerment tools, and one of the main instruments for the energy transition of households and small consumers.

Consequently, ECs face an ambitious challenge: make European energy policies a reality, while modifying the balance of power in the energy market, starting from a disadvantaged position. To do this, research and innovative technologies are required. The objective is to provide beneficial, simple and understandable tools for citizens, to achieve the critical mass and the multiplier factor necessary for the success of ECs.

2. – POWER FLOWS AND ECONOMIC FLOWS

Research on ECs has grown exponentially in the last 5 years [3]. Note that operating ECs requires dealing with two distinct types of flows: power flows (energy distribution and assets management), and economic flows (business models, costs and savings). Both need to be considered to achieve an optimum operation.

Research on power flows focuses on issues such as the optimal design of renewable energy systems and batteries, power balancing, smart grid design, etc. [4][5]. Research on economic flows deals with issues such as returns on investment and the distribution of costs and benefits among the members of the EC [6]. Generally, ECs operate renewable energy resources that, through self-consumption and internal trading, can generate significant savings [7]. These savings can be greater if the community operates collectively than if each of its participants acts independently [8]. Consequently, managing an EC implies having to distribute costs and benefits among its members.

To obtain maximal savings, many authors highlight the need for a central entity (community manager) that should operate a local energy market based on peer-to-peer (P2P) energy trading [9]. This implies some additional complexity to achieve efficiency. Moreover, to apply research results at the citizen level, we must operate in the pursuit of simplicity and flexibility to meet the challenge of ensuring participants engagement and facilitating their adaptation to the latest information and communication technologies [10].

Recent research focuses on an emerging trend: the design of business models for ECs that can include market power mitigation tools [11]. Here, ex-post mechanisms, such as cost allocation methods, can be used to solve imbalances due to the different position that agents may have on the energy value chain. In this area, in [3] we define a set of desirable properties (i.e. beneficial participation, efficiency, fairness, smoothness and environmental friendliness) and we study which of these properties are satisfied by different cost allocation methods. Our contribution here is a comparative analysis of three allocation methods for ECs along different dimensions, using real-world scenarios.

3. – METHODOLOGY

3.1.- DESCRIPTION OF A TYPE OF ENERGY COMMUNITY

We analyze the savings obtained by a community of prosumers who operate a facility that generates electricity from a renewable energy source (REF - Renewable Energy Facility) and are allowed to trade energy internally. Let A denote the community. The energy generated by the REF facility at time slot t (often, an hour) is denoted by E_t^g.

To explain the operating of this community step by step, we use Fig.1, which shows (left) a simple situation where there is no energy-generating facility, (middle) a situation where there is a REF facility but no internal trading, and (right) the situation where there is a REF facility and internal trading, which is the case we analyze in this paper. We use letter a to denote a particular member of the community (or agent). Every variable we use refers to a particular time slot t, so they all should be indexed in t, but for the sake of notational clarity we dispense with this index from now on.

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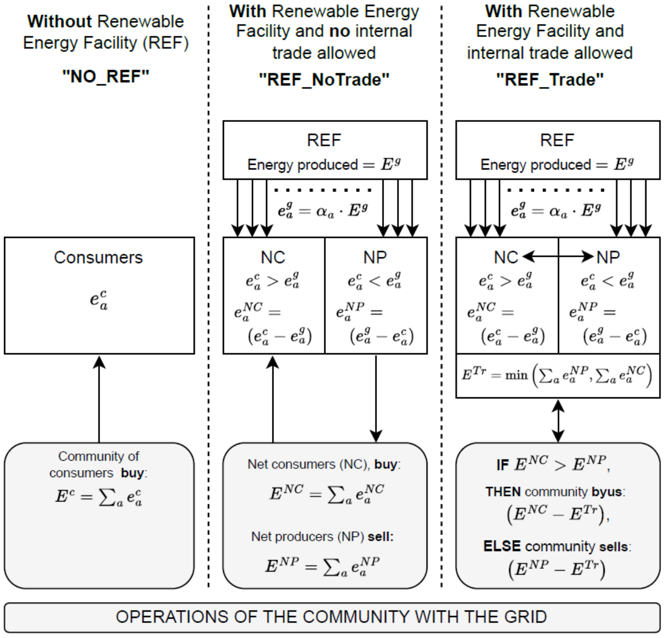

Fig. 1. Three different types of communities. Left: a community of consumers without any energy-generating facility. Middle: a community of prosumers who share a REF but cannot trade energy internally. Right: a community that shares a REF and whose members can trade energy internally.

The situation where there is no facility is simple (Fig. 1, left). Using e_a^c to denote the energy consumed by agent $a \in A$, the community needs to buy a total energy of $E^c = \sum_{a \in A} e_a^c$ from the grid.

Let us now assume that the community operates an energy-generating facility that produces a total energy of E^g (Fig. 1, middle). Each individual agent $a \in A$ is assigned a fraction α_a of this total energy. The energy obtained by agent a from the facility is denoted $e_a^g = \alpha_a \cdot E^g$, and we use $p_{buy}^{Facility}$ to denote the marginal cost of one unit of energy obtained from the facility. We assume that $p_{buy}^{Facility}$ is lower than any price at which agents can buy or sell energy to the grid, so agents are always happy to obtain their allocated energy e_a^g from the facility.

We can now define the set of net consumers $NC = \{a \mid e_a^c > e_a^g\}$ and the set of net producers $NP = \{a \mid e_a^c < e_a^g\}$ in a certain time slot t. For a net consumer $a \in NC$, let $e_a^{NC} = (e_a^c - e_a^g)$ denote the part of her consumption that is not satisfied by the energy obtained from the facility. For a net producer $a \in NP$, let $e_a^{NP} = (e_a^g - e_a^c)$ denote her excess energy. If internal trading is not allowed, net consumers and net producers interact separately with the grid. We allow for agents to have different buying ($p_{buy,a}^{Grid}$) and selling ($p_{sell,a}^{Grid}$) prices for their operations with the grid.

Finally, we consider the case where members are allowed to trade energy internally (Fig. 1, right). This is the situation we focus on. We assume that, at every time slot, agents pay a greater price for buying energy from the grid than the price they obtain for selling energy to the grid, i.e. $\min_a p_{buy,a}^{Grid} > \max_a p_{sell,a}^{Grid}$. Thus, if NPs transfer their excess energy to NCs, the community as a whole can save money. Let $E^{NC} = \sum_{a \in NC} e_a^{NC}$ and $E^{NP} = \sum_{a \in NP} e_a^{NP}$. To maximize savings, the amount of energy that should be transferred internally is $E^{Tr} = \min(E^{NC}, E^{NP})$ and, by doing this, the community can save the differences between $p_{buy,a \in NC}^{Grid}$ and $p_{sell,a \in NP}^{Grid}$ for the transferred units of energy (see Fig. 2).

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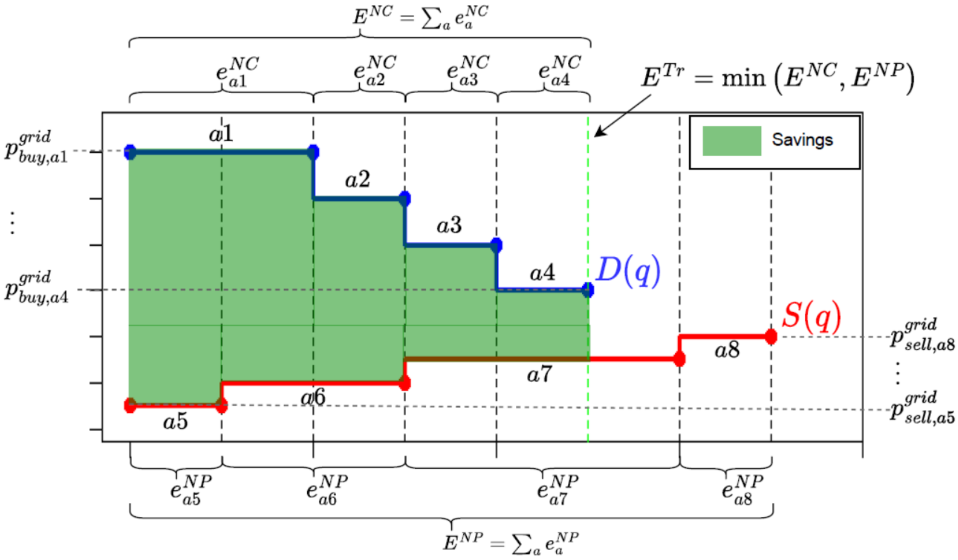

Fig. 2. Example of how internal trading can provide savings. The energy demand function D(q) is shown in blue, and the energy supply function S(q) is shown in red. The maximum total savings that can be achieved is the green area in the figure.

Figure 2 shows an example of how internal trading can provide savings. The figure refers to a specific time slot, in which there are four net consumers $(a1, a2, a3, a4)$ and four net producers $(a5, a6, a7, a8)$. Note that the set of net consumers and net producers will generally be different in different time slots, depending on energy production and consumption patterns. The energy demand function *D(q)*, shown in blue in Fig. 2, is formed by the energy requirements of net consumers $(e_{a\in NC}^{NC})$, considering the maximum price they would be willing to pay for the energy they require $(p_{buy,a\in NC}^{Grid})$. The energy supply function *S(q)*, in red, is formed by the excess energy of the net producers in the time slot $(e_{a\in NP}^{NP})$, considering the minimum price they would be willing to accept for their excess energy $(p_{sell,a\in NP}^{Grid})$. The amount of trading that maximizes the savings for the whole community is $E^{Tr} = \min(E^{NC}, E^{NP})$, and the maximum total savings that can be achieved is the green area in the figure.

3.2.- COSTS AND SAVINGS OBTAINED BY THE ENERGY COMMUNITY

The cost incurred by a community that has no energy-generating facility (Fig.1, left) is:

$$Cost^{NO\_REF} = \sum\nolimits_{a\in A} p_{buy,a}^{Grid} \cdot e_a^c$$

Now, let us compute the savings achieved by a community due strictly to operating a REF, i.e., assuming that internal trading is not allowed. Later, we will also compute the additional savings due to the possibility of internal trading (see Fig. 3).

The savings achieved for operating the facility (without internal energy trade) would be:

$$\begin{aligned} Savings^{REF\_NoTrade} = & \sum\nolimits_{a\in NC} \left(p_{buy,a}^{Grid} - p_{buy}^{Facility}\right) \cdot e_a^g \\ & + \sum\nolimits_{a\in NP} \left(p_{buy,a}^{Grid} - p_{buy}^{Facility}\right) \cdot e_a^c + \sum\nolimits_{a\in NP} \left(p_{sell,a}^{Grid} - p_{buy}^{Facility}\right) \cdot e_a^{NP} \end{aligned}$$

The first term represents the savings achieved by NCs, who use up all their allocated energy e_a^g. The two other terms represent the savings achieved by NPs, who use a fraction of their allocated energy produced by the facility to satisfy their whole energy consumption e_a^c (second term), and have some excess energy $e_a^{NP} = \left(e_a^g - e_a^c\right)$ left which they can sell to the grid (third term).

If agents are allowed to trade energy internally, they can achieve even greater savings (see Figs. 2 and 3). The reason is that net consumers pay a greater price to buy energy from the grid than the price that net producers obtain by selling it to the grid $(\min_a p_{buy,a}^{Grid} > \max_a p_{sell,a}^{Grid})$. Thus, if they trade internally, they can save this price spread for each unit they trade internally. The maximum savings that can be achieved by the community for operating an internal market are:

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$$MaxSavings^{Trading} = \int_0^{E^{Tr}} (D(q) - S(q))\, dq$$

where $D(q)$ and $S(q)$ are, respectively, the (inverse) demand and the (inverse) supply function of energy in the internal market. These maximum savings equal the economic surplus obtained in the internal market if it is cleared efficiently, i.e. if energy is traded preferentially between the NCs with the highest prices and the NPs with the lowest prices (see Fig. 2). In the following section we discuss different methods that can be used to allocate these maximum savings among the members of the community.

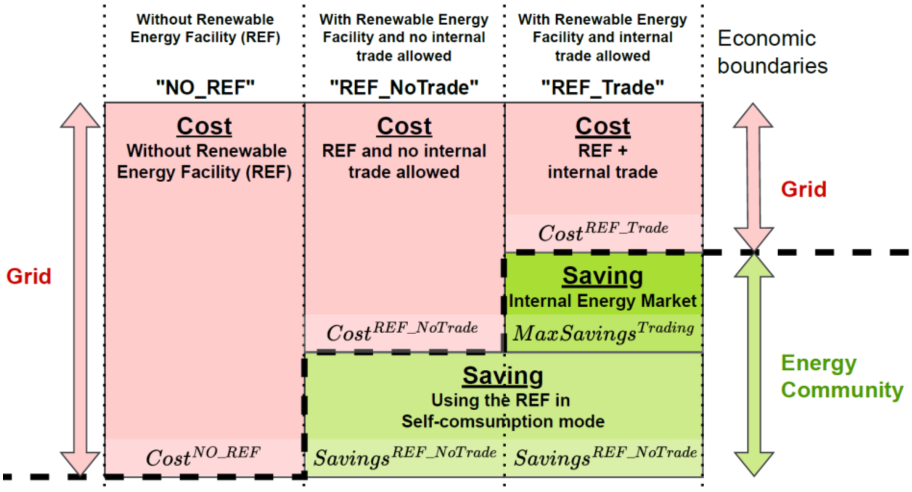

Fig. 3. Economic boundaries that reflect our approach in terms of consumer empowerment through a proper market clearing and allocation mechanism within energy communities.

3.3.- THREE METHODS TO SHARE ENERGY AND ALLOCATE COSTS AND BENEFITS

Savings from the internal market are shared between NPs and NCs. There can also be trading with the grid, which may provide costs or benefits. All these costs and benefits must be allocated to the different members of the community. In Table 1 we consider three allocation methods. In all three cases, any unsatisfied demand or remaining supply after internal trading is sorted out with the grid by the EC members individually.

Allocation method	Internal energy trading	Distribution of savings from internal trading	Comment
Bill sharing (BS) [12]	The EC acts as a single unit. If $E^{NC} > E^{NP}$, then all E^{NP} is given for free to NCs, in decreasing order of $p^{Grid}_{buy,a}$. If $E^{NC} < E^{NP}$, then NPs give their energy to NCs for free, in increasing order of $p^{Grid}_{sell,a}$.	NCs get the energy from NPs for free. Thus, NCs obtain savings even greater than the surplus obtained in the internal market. NPs, on the other hand, lose the income they would get if they sold their excess energy to the grid.	It can be interpreted as a special case of a price-based method where $p_{Tr} = 0$.
Price-based (PB) [3]	Clear the internal market by setting a common transfer price p_{Tr} for the energy traded internally (Fig.2) such that: $\min_a p^{Grid}_{buy,a} > p_{Tr} > \max_a p^{Grid}_{sell,a}$	Each unit of energy traded internally provides $(p^{Grid}_{buy,buyer} - p^{Grid}_{sell,seller})$ in savings. In each traded unit, the buyer gets $(p^{Grid}_{buy,buyer} - p_{Tr})$ and the seller gets $(p_{Tr} - p^{Grid}_{sell,seller})$.	Distribution of savings depends on how p_{Tr} is set, and on the elasticity of the demand and the supply. Here we set p_{Tr} to the average of the buying and selling prices of the last unit traded.

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Surplus-based (SB) [3]	Same market clearing mechanism as price-based method.	Surplus obtained in the internal market is distributed according to a criterion agreed among EC members.	Here we distribute savings proportional to the energy traded in the internal market.

Table 1. Three cost allocation methods considered in this paper.

The choice of a cost-benefit allocation method can have a significant impact both on the performance of an EC and on participants' perceptions in terms of fairness and transparency. The aim is to achieve an efficient operation of the EC, while providing greater transparency and understanding of how costs and revenues are distributed. An allocation of benefits that is clear and is perceived as fair is key for the success of the EC.

3.4.- SIMULATIONS BASED ON REAL DATA

The goal of the simulations is to compare the three allocation methods under different scenarios based on real data. To that end, we simulate a community of 50 agents during a year, using hourly time slots and the following datasets:

- Consumption profiles were taken from the dataset in [13].
- Buying and selling prices were taken from the Spanish electricity market in 2021 [14].
- The profile of generated energy was taken from a solar photovoltaic facility at a specific location in Spain [15]. We assume that every agent gets the same fraction of energy from the facility ($\alpha_a = 1/50\ \forall a$). The size of this facility was chosen to highlight the differences between the methods. These differences are most noticeable when savings generated in the internal market are large, and savings are greatest if there are both NCs and NPs within the same time slot, with significant energy demands and energy excesses, respectively. This tends to occur when the energy generated within the community is moderate [3]. Thus, we chose the size of the facility so the total generated energy was about 50% of the total energy consumed by the community.

Another factor that affects the savings generated in the internal market is the difference between NCs' buying prices and NPs' selling prices (see Fig. 2). The wider the spread between buying and selling prices, the greater the savings. Given the importance of this factor, we consider two scenarios:

- "Equal prices". In each hour, all members have the same buying price and the same selling price. This is a common case when consumers are within the same geographical area or in cooperative-like EC archetypes [7].
- "Different prices". All members have different prices within the same time slot. This scenario can occur in more liberal EC archetypes, with a heterogeneous origin of participants. Typically, they may use external trading platforms for the economic management of the community. To make the price spread consistent with the real data, we have established a $\pm 50\%$ spread; specifically, we have multiplied the individual prices considered on the "Equal prices" scenario by a vector of 50 elements where the i-th element is $0.5 + \frac{i-1}{50-1}$, with $i\ \in [1{,}50]$, thus creating a vector of N different prices that we assign to the participants. We assign better prices to agents with greater consumption, as is often the case in the real world. In this way, we have introduced heterogeneity in prices, while respecting the magnitude of real energy prices to a large extent. We also checked that condition $\min_a p_{buy,a}^{Grid} > \max_a p_{sell,a}^{Grid}$ is met at every time slot.

Finally, to facilitate a neat comparison between the allocation methods, we do not include the use of batteries or any other ancillary assets in our simulations.

4. - RESULTS AND DISCUSSION

The savings obtained in each scenario under the three allocation methods are summarized in Table 2. These savings are shown as a percentage of the total cost that the EC would bear if it did not generate any energy ("NO_REF" in Fig.1 and Fig.3). We can see that savings strictly due to self-consumption (i.e., without internal trading) are 33.24% in the "Equal Price" scenario and slightly greater (36.83%) in the "Different prices" scenario. Savings due to internal trading are slightly greater than 3% in all cases. These savings are distributed equally (or almost equally) between NCs and NPs under the *price-based* and the *surplus-based* methods, but very unequally under the *bill-sharing* method. Under this method, NPs would be better off if internal trading was not allowed.

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Method	Savings in scenario "Equal prices"			Savings in scenario "Different prices"		
	Self-consumption "REF_NoTrade"	Internal trading "REF_Trade"	NC / NP Share of internal trading savings	Self-consumption "REF_NoTrade"	Internal trading "REF_Trade"	NC / NP Share of internal trading savings
[BS] Bill-sharing	33.24%	3.58%	260.44% / -160.44%	36.83%	3.26%	258.36% / -158.36%
[PB] Price-based	33.24%	3.58%	50.00% / 50.00%	36.83%	3.26%	50.36% / 49.64%
[SB] Surplus-based	33.24%	3.58%	50.00% / 50.00%	36.83%	3.26%	50.00% / 50.00%

Table 2. Percentage summary of the contribution to the overall savings for each allocation method compared to the total cost without renewable energy generation facility ("NO_REF" scenario).

More detailed simulation results are depicted in figures 4 and 5 respectively. These figures have been created as 5x3 matrices, where each column corresponds to one of the three allocation methods, and each row represents different evaluation aspects of the EC performance (see Table 3).

Graph	X axis	Y axis
A	1 datum for each of the 50 members, ordered from lower to greater savings in the internal market	• Primary (left): Cost curves (k€) for the three possible situations: "NO_REF", "REF_NoTrade" and "REF_Trade" (See Fig.3) • Secondary (right): Savings (k€) provided by the internal market
B		Ratio (%) of energy transferred in the internal market for NPs (red) and NCs (blue)
C		Percentile ranking of buying/selling prices with the grid expressed in increasing order (from P0 to P100), where the size of each point is proportional to the energy transferred (Graph "B" ratio)
D		Is participation in the internal market beneficial? Yes (green) / No (red)
E	1 datum per hour in 1 year (8760 h)	Distribution of savings generated by the internal market between NP and NC

Table 3. Explanation of graphs in figures 4 and 5.

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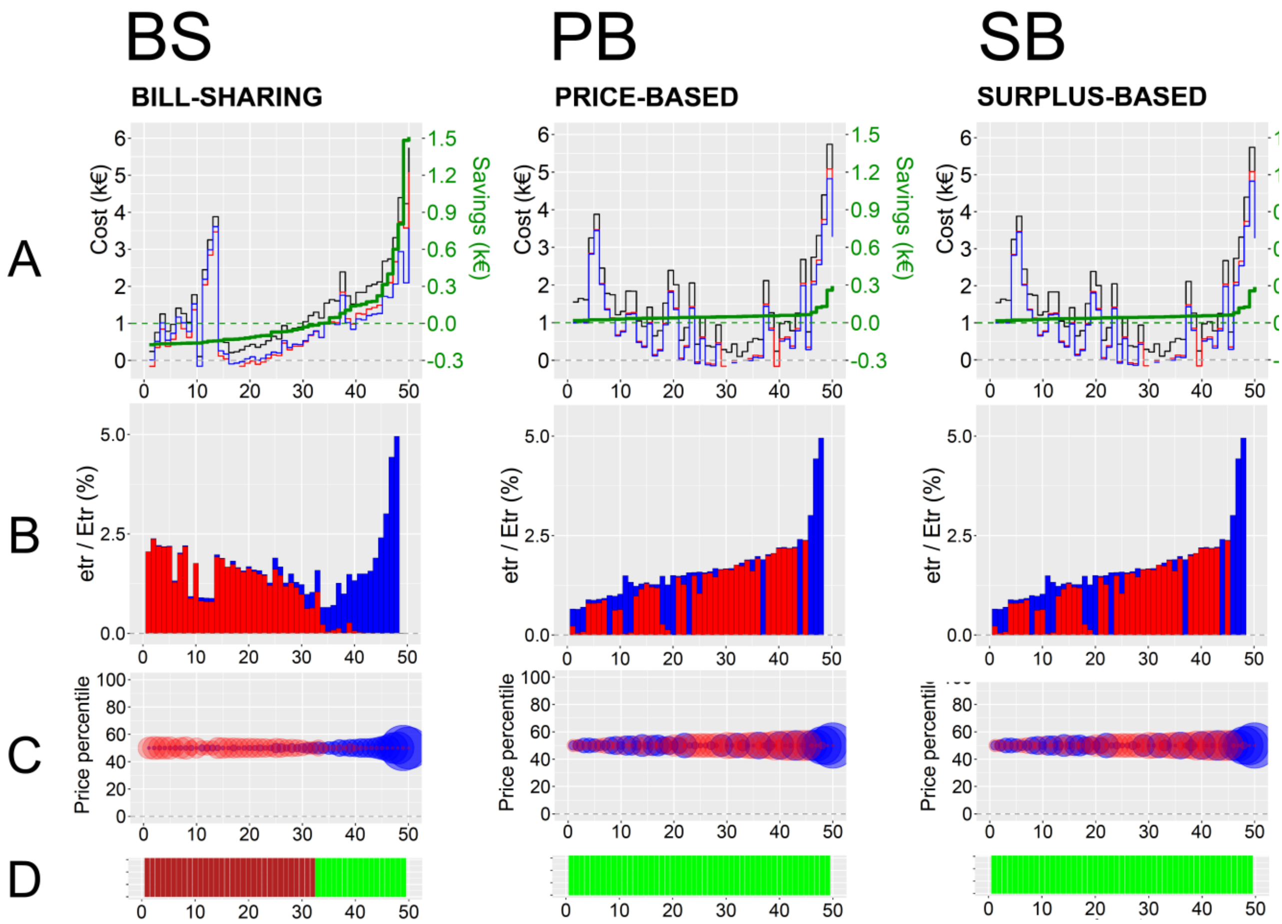

Fig. 4. Simulation of EC dynamics for 3 allocation methods under the "Equal prices" scenario. The numbering of agents corresponds to their position in increasing order according to the magnitude of their savings.

In the "Equal prices" scenario (see Fig.4), participation in the EC under the *bill-sharing* method is not beneficial for NPs [3] (see Table 2). This can also be appreciated in Fig.4.BS-A, where the cost *after trading* for agents 1 to 32 (Cost_REF_Trade), who are mainly NPs (Fig.4.BS-B), is higher than the *no trading* cost (Cost_REF_NoTrade), leading to negative savings due to internal trading (Savings) for them (see also Fig.4 BS-D). With this method, NCs obtain higher savings than with the other two methods, but they do so at the expense of NPs (who are effectively giving their excess energy to NCs for free). On the other hand, under the *price-based* and the *surplus-based* methods, all agents participating in the internal market benefit (Fig.4.PB-D and SB-D).

When prices are the same for all agents, the *price-based* and the *surplus-based* methods are identical [3]. They both distribute savings proportionally to the energy traded in the internal market, regardless of the nature of the agent (NC or NP) or its total consumption. Thus, in the "Equal prices" scenario, the distributions of savings under *price-based* and *surplus-based* methods are the same, and equitable between consumers and producers (Fig.4.PB-E and SB-E).

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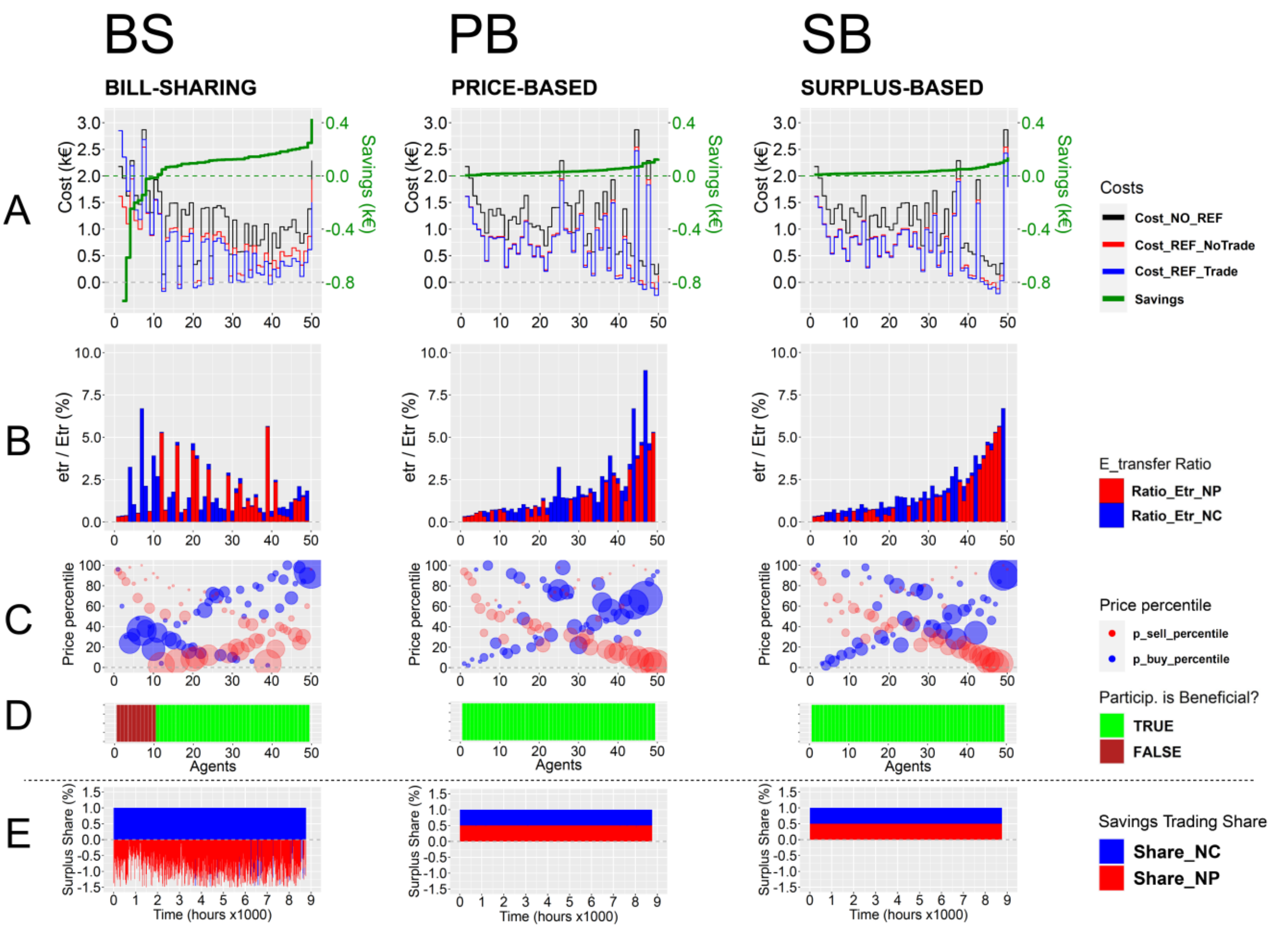

Fig. 5. Simulation of EC dynamics for 3 allocation methods under the "Different prices" scenario. The numbering of agents corresponds to their position in increasing order according to the magnitude of their savings.

In the "Different prices" scenario, the dynamics of the community are more complex, since there are agents with different buying/selling prices in the same time slot (see Fig.5).

Interestingly, in this scenario the *bill-sharing* method harms not only NPs, but also NCs who trade a significant amount of energy with the grid and have moderately low buying prices (see Fig.5.BS-C). These NCs have to share the grid bill with other NCs who have greater buying prices. Thus, the lower-buying-price NCs end up paying a greater price than they would if they did not have to share the bill (compare Fig.5.BS-B with Fig.5.PB-B and Fig.5.SB-B). Consequently, we can see that the *bill-sharing* method still fails to ensure that all participants benefit from participating in the EC, just like in the "Equal prices" scenario (Fig.4). This is in contrast with the *price-based* and the *surplus-based* methods, which guarantee that participation in the EC is beneficial (see Fig.5.PB-D, Fig.5.PB-E, Fig.5.SB-D and Fig.5.SB-E).

Note also that savings under the BS method do not significantly correlate with the amount of energy traded within the community (see Fig.5.BS-B and Fig.5.BS-C). This correlation is clearly greater under the PB method (see Fig.5.PB-B and Fig.5.PB-C) and even greater under the SB method (see Fig.5.SB-B and Fig.5.SB-C).

In contrast with the "Equal prices" scenario, the *price-based* and *surplus-based* methods are no longer identical under the "Different prices" scenario. The *price-based* method, by defining an exchange price p_{Tr} for every internal transaction in the time slot, effectively sets a distribution of savings between NCs and NPs that is conditioned by the shape of the supply and demand functions. In contrast, the *surplus-based* method bases the distribution of savings on the energy transferred, treating NCs and NPs in the same way (see Fig.5.SB-E). This also implies that the correlation between savings and energy transferred is significantly greater than in the other two methods (see Fig.5.SB-B). Naturally, in the *price-based* and the *surplus-based* methods, savings are positively correlated with buying prices for NCs, and negatively correlated with selling prices for NPs (see Fig.5.SB-C). In other words, agents with less favorable grid

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prices benefit the most from internal trading, since they are the ones with the highest capacity to generate savings. This correlation is not so strong in the *bill-sharing* method, since the lower-price NPs are the first ones forced to give away their energy for free.

5. – CONCLUSIONS

In this paper, we have compared three different methods (i.e. *bill sharing*, *price-based* and *surplus-based*) to allocate costs and benefits in energy communities where internal trading is allowed. We have conducted simulations with each of them using real consumption and price datasets, and we have discussed their fulfillment of certain desirable properties, such as beneficial participation [3]. An allocation method satisfies beneficial participation if it ensures that every agent is equal or better off if it participates in the internal energy trading. *Price-based* and *surplus-based* allocation methods ensure beneficial participation, but the *bill-sharing* method does not.

We have also seen that there are certain underlying characteristics of ECs that affect their functioning, namely complementarity of consumption profiles and the buying/selling price spread. Increasing the heterogeneity of consumption profiles generally increases internal energy trade. Greater price spreads lead to greater benefits through internal trading.

Regarding the three allocation methods we have considered, our simulations have led us to the following conclusions:

Even though the *bill-sharing* allocation method may seem logical and simple to implement, it does not guarantee that participation is beneficial for every member. This method heavily penalizes net producers, and also net consumers with low buying prices. The reason is that, under this method, net producers are effectively giving their excess energy for free to net consumers, and net consumers with low buying prices may have to pay a higher price when the EC has to buy energy from the grid and the bill is shared.

In contrast, *price-based* and *surplus-based* methods are efficient and guarantee that participation is beneficial. In ECs where all members have the same prices (“Equal prices” scenario), the *price-based* method considered here (with transfer price equal to the average of the marginal buying and selling prices) and the *surplus-based* method considered here (with surplus distributed proportionally to energy traded internally) are identical [3]. In both cases, savings are proportional to the amount of energy traded in the internal market and the share of savings between NPs and NCs is equal at each time slot.

These two methods differ when not all participants have the same price, like in the “Different prices” scenario. In such cases, members with unfavorable prices in their interactions with the grid (i.e. high buying price and low selling price) are better off under the *price-based* method than under the *surplus-based* method.

We can find valid arguments to defend both the *price-based* and the *surplus-based* methods. The allocation conducted under the *price-based* method effectively assigns the savings to the members that have created them: a NC with high buying price will get greater savings because if that consumer did not exist, those savings would not exist either. Similarly, a NP with low selling price will get greater savings because if that producer did not exist, those savings would not exist either. In contrast, the allocation conducted under the *surplus-based* method is more egalitarian, as it assigns savings proportional to the energy traded in the internal market, regardless of the prices that each member has in their interactions with the grid.

The share of savings that NCs and NPs get can also be very different under these two allocation methods. Under the *surplus-based* method, NCs and NPs get the same share of savings, i.e. 50% each group, since savings are proportional to the energy transferred. In contrast, under the *price-based* method, this share is strongly dependent on the shape of the supply and demand functions in the internal market. The group with the more elastic function will get a lower share of the savings. Nonetheless, in our simulations the difference between these two methods was very small.

We have shown that the *bill-sharing* method has the fatal flaw of not guaranteeing that participation in the internal market is beneficial for every member. This is an important issue, since in close-to-reality scenarios there may be many members that are better off outside the community. In contrast, both the *price-based* method and the *surplus-based* method are efficient and guarantee participation is beneficial. In contexts where not all participants have the same prices in their interactions with the grid, these two methods allocate savings differently and we have illustrated the main differences.

In summary, we have highlighted the importance of “ex-post” market power mitigation tools (i.e., mechanisms whose outcome does not depend on a prediction or previously estimated assignment), where the three methods considered are found, as an emerging tool for the efficient operation of ECs.

There are also other aspects which affect the performance of ECs that we have overlooked, such as cybersecurity. Although they have not been addressed in this article, we have proposed that the EC manager should have access to the same information as the existing market agents (system operator and energy traders), which does not create additional threats and adds the positive effect that the EC manager uses this information to act in the interests of the whole community.

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