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Energy sharing in European renewable energy communities: impact of taxes, charges, fees and levies

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ABSTRACT
The financial benefits of energy sharing within a community is impacted by factors within the control of the community, such as internal rules for energy sharing, and by external factors, such as regulatory frameworks and fiscal policies. While much of the literature on energy sharing has focused on internal rules, there has been less attention paid to the role of external factors, despite their potential policy implications. This study aims to address this gap by examining the range of fiscal measures that can be used to regulate energy sharing in renewable energy communities in 39 countries. The study considers two community arrangements: one in which prosumers share their surplus energy, and another in which consumers shares the energy generated by a collectively-owned PV. The findings suggest that the annual savings from energy sharing in the first arrangement may not be significant enough to justify the formation of the community. In contrast, the cost savings from sharing energy in the second arrangement are much greater, but also more influenced by the fiscal support policies. Based on the results, the study offers policy recommendations for avoiding resistance from stakeholders and aligning their incentives when introducing energy sharing regulation.

Keyword: collective self-consumption, energy community, electricity tariff, fiscal policy, local energy planning

1 Introduction

As concerns about climate change and rising energy prices grow, households are increasingly interested in the benefits of investing in solar photovoltaic (PV) generation and sharing energy in communities [1]. This is particularly true in the European Union, where regulatory frameworks for energy sharing are starting to be established. There are two key aspects to energy sharing that are of interest to policy makers and researchers: the internal rules for distributing costs and benefits within the community, and the external regulations that establish the governing framework [2]. While both are important, the literature on energy sharing tends to focus more on the former than the latter.

Much of the research on energy sharing has focused on the internal rules by which energy is shared among community members [3]. A review of relevant models, solution concepts and algorithmic techniques can be found in [4]. With a theoretical basis grounded in game theory, this branch of the literature evolved from suggesting solutions such as the Shapley value [5], the nucleolus [6] and peer-to-peer pricing mechanisms without uncertainty [7] and with uncertainty [8], to more recent approaches that suggest solutions based on so-called repartition keys that are better aligned with EU legislation. An example is a previous work by the authors [9] in which they propose the virtual net-billing method as a fair energy sharing method that is based on a dynamic ex-post repartition key. The benefit of using this method is assessed in terms of its fairness and scalability by comparing it to five other energy sharing methods from the literature, on a sample of 600 hypothetical communities. Other similar works which compare multiple repartition keys are those of Li et al. [10], which compares ten repartitions keys, Mustika et al. [11], which evaluates the interplay various repartition keys and energy management strategies and the work of Minuto et al. [12], which considers energy sharing in communities with different ownership structures. While these works provide guidance to energy community members on setting up fair energy sharing rules, they do not address the full range of measures needed to maximize the benefits of energy sharing.

In contrast, there has been considerably less research focused on the impacts of different fiscal measures which outline the environment in which energy sharing takes place, leaving many questions unaddressed. Past research, such as [13] and [14], has studied how fiscal measures affect the economic benefits of individual prosumers. Along this line, we expand this line of research to energy communities and explore how the regulated charges (taxes, charges, fees and levies) applied to community members impact their benefits from sharing energy.

1.1 Related works

For energy consumers, fiscal policies are implemented through the design of electricity tariffs and the application of regulated charges [15]. Apart from ensuring the recovery of the infrastructure investment costs for the energy system, the tariff design should be simple, transparent and equitable [16], so as to effectively guide the investment and consumption behavior of energy consumers [17]. Having in mind that each tariff design comes with a compromise [18], it is worth exploring how the regulated charges should be included in the electricity tariffs so that they stimulate energy sharing in communities, instead of discouraging it.

Early research on the topic, which explored the allocation of network energy losses [19] and overall network charges [20], finds that network charges can be allocated in such a way that local energy exchanges are encouraged, but that this should be done equitably, in order to avoid discriminating against members in disadvantaged network locations. Later, Tsao et al. [21] illustrate the perspective of an energy company which determines the regulated charges of prosumers that share energy, considering the payback time of their investments when they are sharing energy with other prosumers. Radl et al. [22] compare the profitability of energy sharing in eight European countries, and, although they focus on optimal investment decision making, interesting insight can be drawn from their analysis, since each analyzed country differs in the composition of regulated charges in the retail price paid by consumers. From their analysis, the authors of [22] suggest that in the future, electricity tariffs should be redesigned following the polluter-pays principle and that further research is required to quantify the “sensitivity of the individual electricity price components” with a focus on “individual households”. Heinman et al. [23] draw similar conclusions, noting that energy communities could benefit from reduced network charges for the local energy sharing.

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Part of this research gap is addressed by Viti et al. [24], Schreck et al. [25] and Maldet et al. [26], which focus mostly on the network charges. Studying different economic scenarios for Italian energy communities, Viti et al. [24] find that when the community members pay the network charges, their cost savings reduce from 12% to 5%. On the other hand, Schreck et al. [25] compare four designs for the network charges applied in energy communities in Germany and find that charges based on the network connection capacity are more effective than volumetric changes in reducing peak power exchanges between the community and the distribution grid. Similarly, Maldet et al. [26] study how network charge designs affect the value of peer-to-peer energy trading, with a special focus on the regulation of Austria, Norway and Ireland. They also review the European regulation and conclude that the main barriers for implementing innovative network charges for energy communities stem from the trade-off between the economic benefits of community members and the ability of distribution system operators (DSOs) to fully recover their infrastructure investment costs. However, the total benefits from energy sharing go beyond only the network charge and also depend on the other regulated charges.

In practice, many European countries are yet to fully develop their regulation on energy communities. A comprehensive overview of the different implementations, both in the EU and worldwide, can be found in the works of Minuto et al. [12], Ines et al. [27], Frieden et al. [28,29] and Moura et al. [30]. Their findings show the convincing differences, both in terms of magnitude and implementation, of the support provided to energy communities. For instance, Austria and Portugal exempt communities from paying certain regulated charges, Italy and Germany incentivize communities to self-consume by paying them a premium for their self-consumption, Greece and Belgium apply implicit incentives by using virtual net-metering, while other countries have their regulation under development and are still evaluating how different configurations of energy sharing policies will support or hinder energy communities.

1.2 Contribution

The purpose of this paper is to explore the range of fiscal measures that policy makers can implement when establishing country-level regulations for energy sharing. We aim to quantify the impact of regulated charges (tax, charge, fee and levy) on the economic benefits of energy sharing across Europe. This research builds on previous work by offering a broader geographical perspective, studying 39 countries, and a broader conceptual perspective, examining all regulated charges. Through this study, we address the following research questions:

1. To what extent do different regulated charges applied to shared energy affect the cost savings in a community?
2. What is the impact of each regulated charge on community cost savings from energy sharing?
3. Given the post-pandemic energy crisis, how does increasing the energy and supply cost component of the electricity tariff affect cost savings?

We answer these questions for two arrangements of energy sharing. The first arrangement involves prosumers sharing their surplus generation among themselves, while the second represents a community of consumers sharing the generation of a collectively-owned PV system.

2 Methods

This section presents the applied methods in the analysis of energy sharing in both energy sharing arrangements.

2.1 Configuring the energy billing in energy communities

In the first arrangement, each member of the energy community is described by their electricity load $p_{l,i}(t)$ and generation $p_{g,i}(t)$ profile. Part of the electricity generation of member i is locally self-consumed $p_{sc,i}(t)$, while the rest is exported in the grid $p_{ex,i}(t)$.

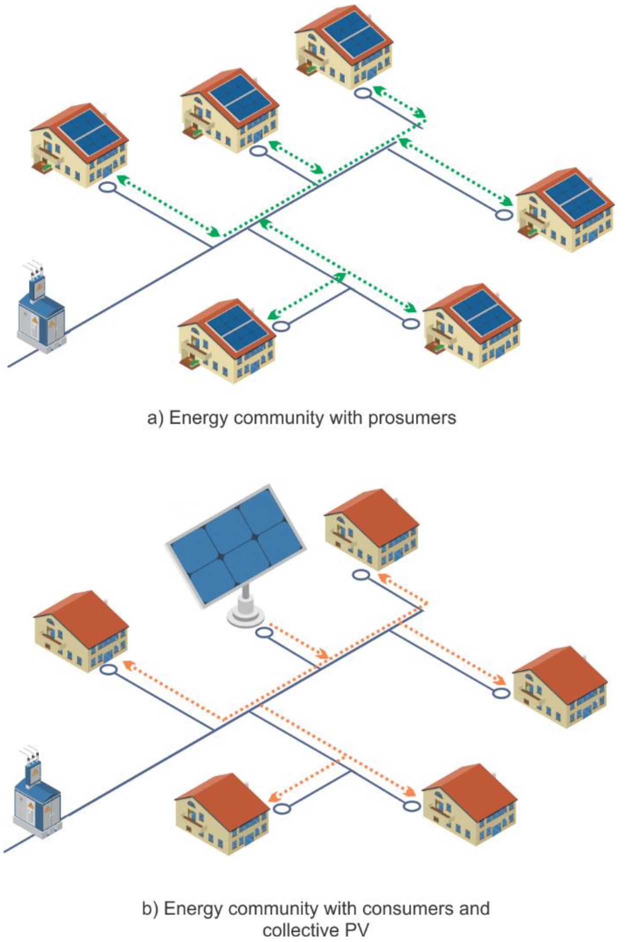

Fig. 1. Illustration of the two energy sharing arrangements analyzed in this paper

Energy sharing in the community takes place when the electricity exports of some community members are instantaneously imported $p_{im,i}(t)$ by other members in the community. The total shared electricity in the community in that case is calculated as follows:

$$p_{sh,N}(t) = \min\left(\sum_{i\in N} p_{ex,i}(t), \sum_{i\in N} p_{im,i}(t)\right) \quad (1)$$

If member i is not part of the community and instead acts as a single prosumer, their electricity bill, assuming flat tariffs for simplicity, is calculated based only on the electricity imports and exports:

$$C_{P,i} = E_{im,i}(c_{im} + c_n + c_t + c_v) - E_{ex,i}c_{ex} \quad (2)$$

where $E_{im,i}$ and $E_{ex,i}$ are the imported and exported electricity for a given billing period, c_{im} is the energy and supply price payed for the imported electricity, c_n is the network charge, c_t denotes other charges (environmental, renewable, nuclear etc.), c_v is the value added tax and c_{ex} is price of the exported electricity, usually determined contractually between the supplier and prosumer such that $c_{ex} \le c_{im}$. Given that the imported electricity is equal to the total load minus the self-consumed electricity $E_{im,i} = E_{l,i} - E_{sc,i}$, the previous equation can be rewritten as:

$$C_{P,i} = E_{l,i}(c_{im} + c_n + c_t + c_v) - E_{sc,i}(c_{im} + c_n + c_t + c_v) - E_{ex,i}c_{ex} \quad (3)$$

If being part of a community, member i can share (exchange) energy with other community members by importing electricity while other members are exporting. As a result, member i virtually self-consumes some amount of energy $E_{sh,i}$ for which he/she pays a price

c_{sh} to the other members of the community, such that $c_{ex} \le c_{sh} \le c_{im}$. Based on [9], the electricity bill of member *i* in this case is equal to:

$$C'_{EC,i} = E_{l,i}(c_{im} + c_n + c_t + c_v) - E_{sc,i}(c_{im} + c_n + c_t + c_v) - E_{ex,i}c_{ex} - E_{sh,i}(c_{im} - c_{sh} + \sum_{\varepsilon \in \mathrm{E}} c_\varepsilon) \quad (4)$$

Compared to the case when member *i* acts does not share energy, the cost savings from sharing energy are equal to $E_{sh,i}(c_{im} - c_{sh} + \sum_{\varepsilon \in \mathrm{E}} c_\varepsilon)$. Clearly, they are proportional to the price difference between importing and sharing energy $(c_{im} - c_{sh})$ and are also proportional to the regulated charges $\sum_{\varepsilon \in \mathrm{E}} c_\varepsilon$ from which the shared energy of member *i* is exempt.

In the second arrangement, comprised of consumers sharing energy from a collective PV, the electricity bill of member *i* is reduced only due to the energy sharing, i.e. virtually self-consumption of the collective PV generation:

$$C''_{EC,i} = E_{l,i}(c_{im} + c_n + c_t + c_v) - E_{vsc,i}(c_{im} - c_{sh} + \sum_{\varepsilon \in \mathrm{E}} c_\varepsilon) - E_{ex,i}c_{ex} \quad (5)$$

The term $E_{vsc,i}$ denotes the virtually self-consumed electricity and represents the energy that is shared between the collective PV and the community member *i*. It is equal to the sum of locally self-consumed and shared energy in the previous arrangement $E_{vsc,i} = E_{sc,i} + E_{sh,i}$, making the two arrangements comparable. As per (5), the benefit from energy sharing depends on the virtually self-consumed electricity, the price difference $(c_{im} - c_{sh})$ and the exemptions of regulated charges $\sum_{\varepsilon \in \mathrm{E}} c_\varepsilon$.

2.2 Calculating the shared electricity

The electricity sharing among the community members is settled using a dynamic, ex-post repartition key, meaning that the settlement for the electricity sharing is performed for each hour of the billing period, after the billing period ends. Then, the shared electricity is calculated as:

$$E_{sh,i} = \sum_{t \in T} p_{sh,i}(t)\Delta t \quad (6)$$

In this paper, the repartition key proposed in [9] is used, which underlies the virtual net-billing method. According to this method, at each time step *t*, member *i* is allocated $p_{sh,i}(t)$ which represents a portion of the total shared electricity in the community $p_{sh,N}(t)$:

$$p_{sh,i}(t) = \alpha_i(t) p_{sh,N}(t) \quad (7)$$

The amount $p_{sh,i}(t)$ allocated to member *i* is based on the repartition key $\alpha_i(t)$:

$$\alpha_i(t) = \begin{cases} \frac{1}{2}\frac{p_{ex,i}(t)}{\sum_{i \in N} p_{ex,i}(t)}, p_{ex,i}(t) > 0 \\ \frac{1}{2}\frac{p_{ex,i}(t)}{\sum_{i \in N} p_{ex,i}(t)}, p_{im,i}(t) > 0 \\ 0 \qquad ,\text{else} \end{cases} \quad (8)$$

This repartition key guarantees that the total benefit of the community is fully distributed among the members and that no member is left worse-off as part of the community. As discussed in [9], the method distributes the payoffs rather evenly, while ensuring that each member receives a payoff based on their contribution.

3 Results

To assess the impact of regulated charges on the benefits of energy sharing, we study the energy sharing in 39 countries, including EU Member States, members of the European Free Trade Association, and EU candidate countries. The analysis is conducted for energy communities which are given no additional incentives or subsidies, apart from the potential exemption of regulated charges.

3.1 A case study of European renewable energy communities

Each country has its own unique solar potential and electricity prices. To compare the benefits of energy sharing across countries, we adopt a single energy community with fixed electricity consumption and installed photovoltaic (PV) capacity. The community consists of 50 households with a PV generation capacity of 100 kWp, similar to previous studies such as [12] and [31].

Two different energy sharing arrangements for this community are studied: in the first arrangement, the PV capacity is distributed among households on their rooftops, while in the second arrangement, the PV capacity is located elsewhere (e.g. on the rooftop of a building or on a nearby field). For each arrangement, multiple scenarios are analyzed: an optimistic scenario (OS), in which the community is exempt from all regulated charges, a pessimistic scenario (PS), in which the community pays all regulated charges, and intermediate scenarios which are simulated in order to analyze the incremental effect of each regulated charge.

In the community, each member owns a portion of the total capacity proportional to their annual electricity demand. The electricity consumption profiles of the community members are adopted from [32]. Only households with annual electricity consumption between 2500-5000 kWh are selected, as this range reflects the average electricity consumption of European households.

While the electricity consumption and the installed PV capacity of the community are held constant, the conditions in which the community operates vary depending on the country in which it is located. The first condition that affects the energy sharing in the community is the PV electricity generation. To calculate the energy produced by the PV when the energy community is in given country, PVGIS [33] is used. Hourly generation profiles for the PV are calculated for the capital city of each country, assuming optimized azimuth and slope. The second condition which impacts the benefit derived from energy sharing is the composition of the retail electricity price. In general, the retail electricity price payed by households contains components for the energy and supply c_{im} , network c_n , value added tax c_{vat} and other taxes c_t . Deductions and tax returns on electricity bills are omitted from the analysis as they are variable, and potentially transitory. Moreover, c_{sh} and c_{ex} are assumed to be constant and equal to half of c_{im} , which should reflect the trend of lower wholesale prices during daytime and also stimulate self-consumption. The electricity prices used in the analysis are taken from the Eurostat database, which contains the average electricity price components for household consumers for 2021 [34].

3.2 Energy sharing between prosumers

In the first energy sharing arrangement, community members locally self-consume a portion of their on-site generation and share their excess generation with the other members that need it at that point in time. The community members therefore benefit from two simultaneous forms of self-consumption: the physical self-consumption that occurs behind-the-meter, and the virtual self-consumption which occurs due to the energy sharing. Figure 2 shows the relative reduction of electricity costs in the community, for a selected set of countries chosen to represent different geographical regions and different compositions of retail electricity price. In this figure, the yellow bar represents a business as usual (BaU) scenario, in which it is assumed that the community members have no PVs, the green bar (PV) shows the cost reduction obtained by local-self consumption of the rooftop PV energy, the blue bar represents the relative cost reduction from energy sharing (ES) and the purple bar represents the remaining costs of the community in the OS, when all the regulated charges are avoided.

Depending on the country, the collective costs of the community are reduced by (25.96 ± 4.79)% due to the local, behind-the-meter self-consumption. In comparison, energy sharing contributes to the savings on the collective bill considerably less, by about (3.80 ± 0.63)%. The community yields the biggest benefit from sharing energy when it is exposed to the conditions in Portugal, Cyprus and Italy, while it yields the lowest benefit when it is located in Iceland, Estonia and Latvia. Nevertheless, it is expected that the benefit from sharing energy decreases when regulated charges are introduced.

Figure 3 illustrates this point, showing how much the cost savings are influenced by each regulated charge. In the PS, when the community members pay all regulated charges, they benefit only because they share energy at a price c_{sh}, which is lower than the import price c_{im}. For the studied community, the cost reduction from this mechanism across the 39 countries is rather small and falls in the range (1.11 ± 0.54)%. It is only after the community is exempt from paying some of the regulated charges, that the benefit becomes more notable.

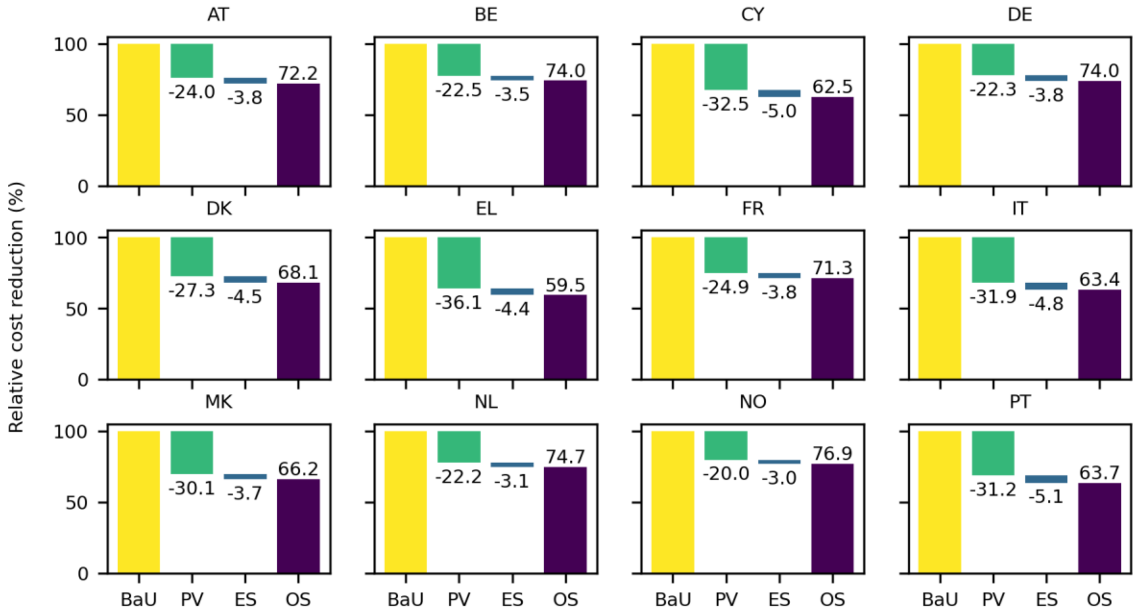

Fig. 2. Cost reduction of the community electricity bill in selected countries for the first arrangement

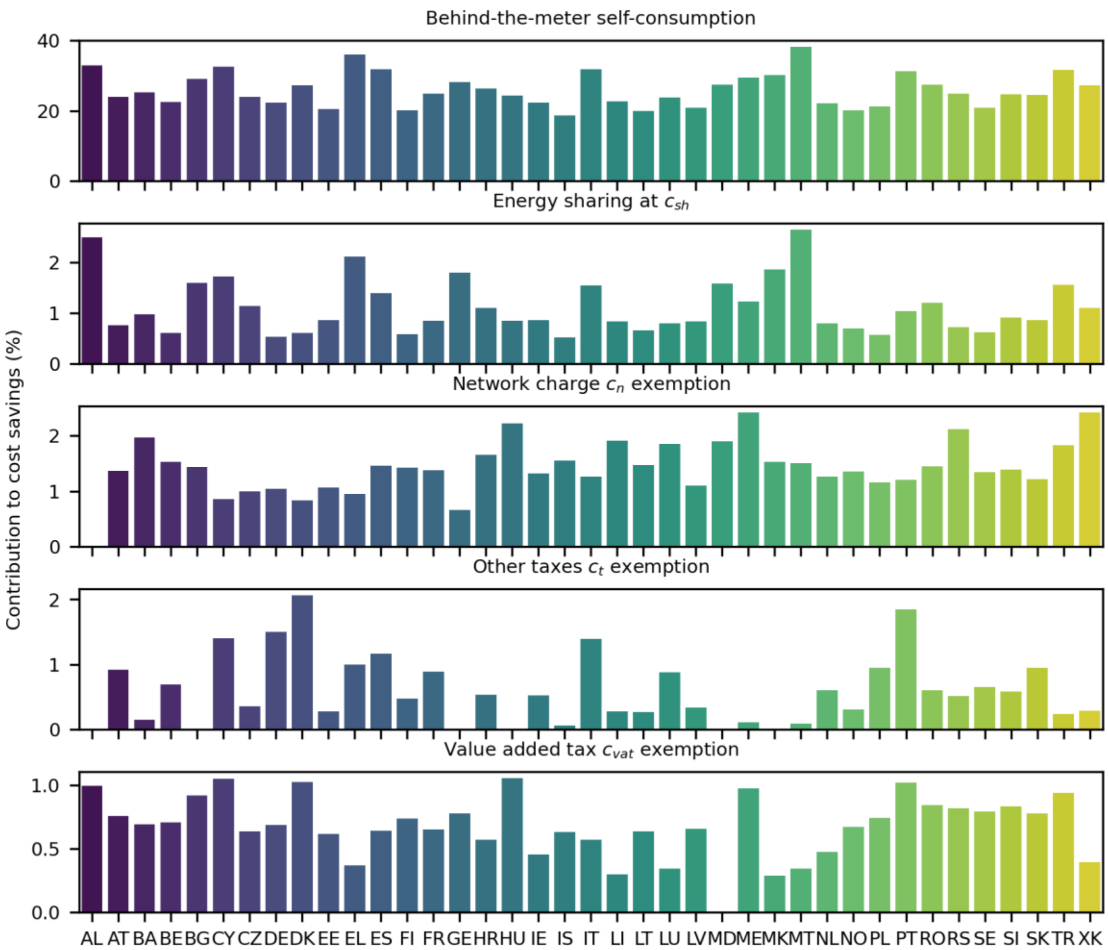

Figure 3. Contribution to cost savings in comparison to BaU scenario from PV and different electricity tariff components in the first energy sharing arrangement

The network charge c_n exemption has the biggest influence on the cost savings, additionally reducing the collective bill of the community by (1.42 ± 0.47)%. The impact of other taxes c_t varies widely from country to country, depending on country-specific policies. When community members are relieved from paying these charges, their costs drop by (0.59 ± 0.53)%. The benefit from this exemption is most pronounced in Denmark, Germany, Cyprus and Portugal, where energy consumers pay relatively high regulated charges. At the same time, consumers in Albania, Bulgaria, Georgia, Hungary, Moldova and North Macedonia pay little to no such taxes and therefore do not benefit from this mechanism. Finally, if the community is exempt from paying the value added tax c_{vat} for the energy sharing, its collective costs reduce by an additional (0.68 ± 0.24)%.

3.3 Sharing the generation of a collective PV generator

In the second arrangement, when the prosumers share energy from a collective PV generator, the magnitude of their cost savings are larger, but are also more dependent on the fiscal environment. Unlike actual prosumers, the members of such a community do not physically reduce their energy imports from the distribution grid. Instead, when their electricity bill is calculated, it must account for the virtual self-consumption calculated according to a pre-defined energy sharing method.

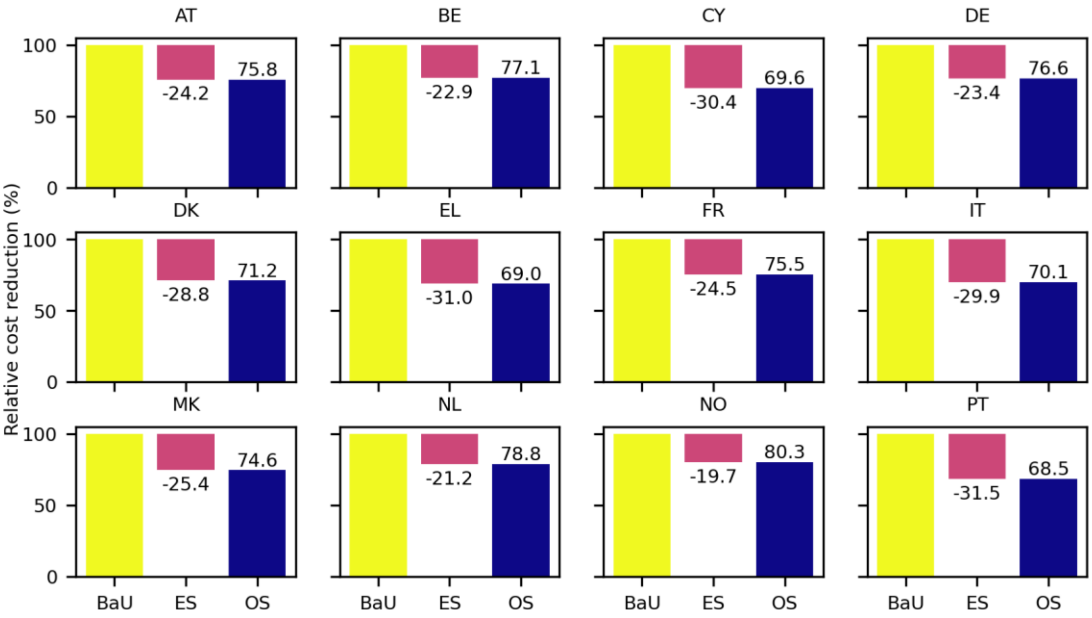

Fig. 4. Cost reduction of the community electricity bill in selected countries for the second arrangement

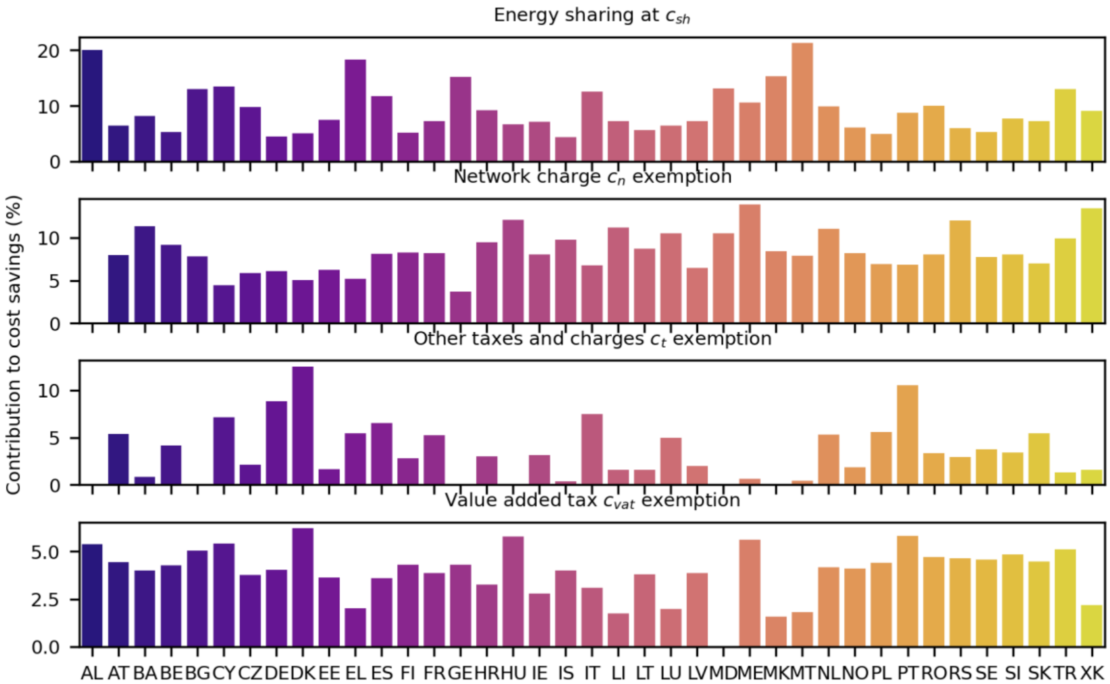

Figure 5. Contribution to cost savings in comparison to BaU scenario from PV and different electricity tariff components in the second energy sharing arrangement

Figure 4 shows the relative cost reduction of the community's bills in this arrangement for the same set of countries previously displayed in Figure 4. The results show that the community can reduce its electricity bill by (24.61 ± 3.69)%, compared to a BaU scenario without a PV, which is slightly lower than the combined cost savings from local self-consumption and energy sharing seen in the previous energy sharing arrangement.

These values also refer to the OS, under the assumption that the members of the community are exempt from the regulated charges for the energy that they virtually self-consume. Since the amount of energy that is shared in this arrangement is much greater than in the previous one, the application of regulated charges more notably impacts the costs savings. The relative contribution of each electricity price component on the costs savings in this case are shown in Figure 5. From these results, one finds that when the regulated charges apply, the collective electricity costs of the community decrease by (9.27 ± 4.35)%. However, if the community is exempt from (i) network charges, (ii) other taxes or (iii) the value added tax, its electricity costs reduce by (8.10 ± 2.64)%, (3.36 ± 3.04)% and (3.86 ± 1.34)%, respectively.

3.4 Impact of energy and supply costs

Abrupt surges of energy demand or constraints on the supply side may increase the wholesale prices in electricity markets. A combination of both of these effects are seen in many European countries in the post-pandemic period, leading to higher costs for energy and supply payed by final consumers. Since higher energy costs motivate households to invest in renewable energy sources for their own self-consumption, in this subsection, the impact of rising energy and supply costs on energy sharing are analyzed.

The results for a community with the first energy sharing arrangement (prosumers sharing their excess generation), are given in Figure 6. This figure enables a comparison of the annual savings from energy sharing to the monthly electricity costs without energy sharing. On the y-axis, the figure shows the cost savings of an average community member over one year, while on the x-axis it shows the average monthly electricity bill when no energy is shared. Each point in the plot represents a separate country. The yellow points represent the OS, while the blue points represent a PS. These two values should be seen as theoretical limits of the cost savings that an average member of this energy community can obtain when they share energy at a price $c_{sh} = c_{im}/2$.

Therefore, Figure 6 presents two key findings. The first finding is that applying regulated charges reduces annual savings by an average of 70.78%, or between 28.54% and 86.65% depending on the country (for price conditions in 2021). For example, in Cyprus, annual savings from energy sharing drop from 37.40 EUR to 12.82 EUR, a decrease of 65.73%. This difference is significant, as the savings in the first case amount to about 90% of an average monthly electricity bill in the BaU scenario, while in the second case they only account for 31%. The second finding supplements the first, showing that as energy and supply price increases, the benefit from avoiding regulated charges becomes less impactful. Instead, the main savings come from sharing energy at a lower price than c_{im}. This is illustrated in Figure 6 by the closing gap between the yellow and blue points for higher energy and supply costs.

Figure 7 presents similar findings for the second energy sharing arrangement. The orange points represent the OS, while the purple points represent PS. The results show that regulated charges reduce cost savings for community members by an average of 62.98%, or between 21.11% and 82.58% depending on the country. The difference in scale between Figure 6 and Figure 7 is due to the fact that the cost reductions in absolute terms are greater in the second energy sharing arrangement because they share more energy over a given billing period.

3.5 Relationship between cost savings, solar irradiation and regulated charges

When the relative costs savings of the community are visualized on a geographical map, some interesting patterns emerge, as shown in Figure 8. The results indicate that solar irradiation is not the only factor determining cost savings, and that there are countries in regions with high solar potential that have lower savings than their neighbors, and vice versa.

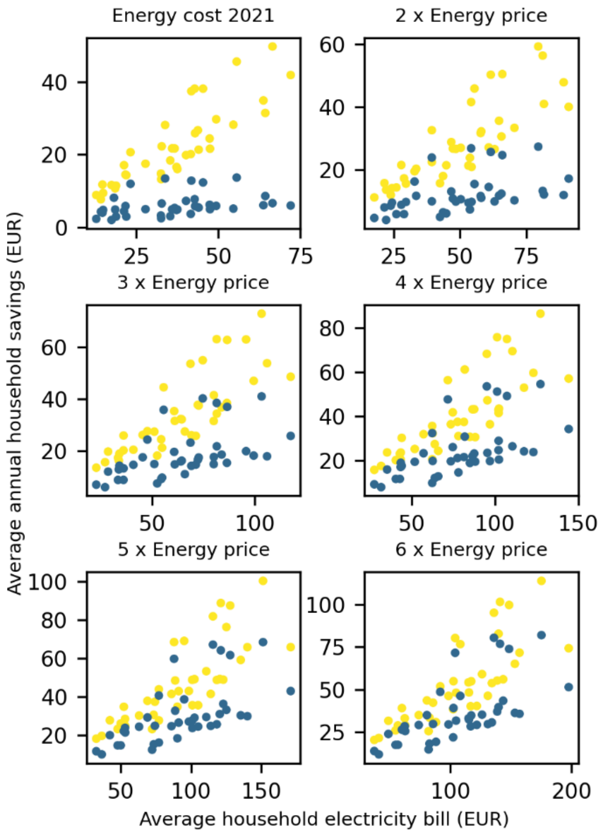

Fig. 6. Impact of energy and supply costs on energy sharing benefit – case of community with prosumers.

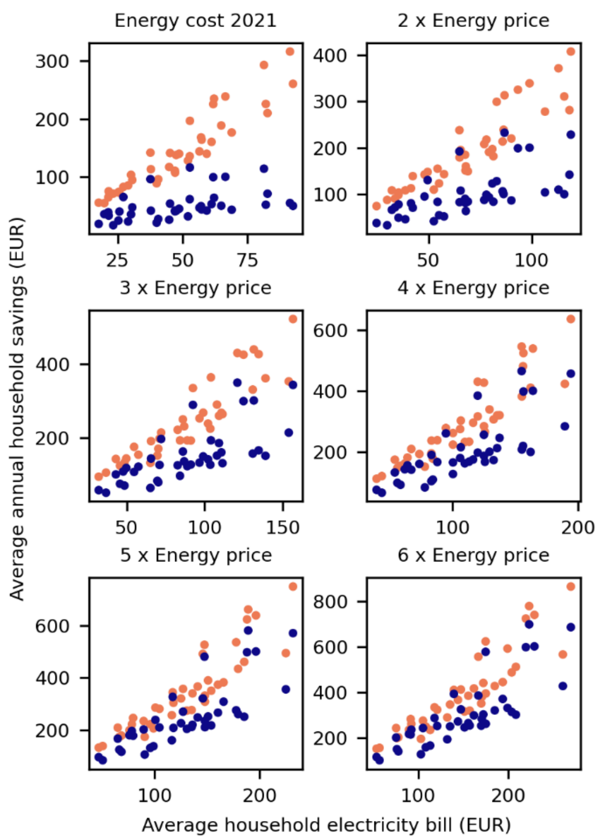

Fig. 7. Impact of energy and supply costs on energy sharing benefit – case of consumers with collective PV.

For example, communities in Denmark can have relatively high cost savings compared to the regional average, despite their low solar potential. This suggests that the level of regulated charges is the second factor impacting savings. To better understand this relationship, the relative costs savings are plotted as a function of (i) the share of regulated charges in the retail electricity price and (ii) the specific PV energy generation (kWh/kWp). The results are shown in Figure 9. The first plot refers to the community with prosumers, while the second refers to the community with consumers and a collective PV. The relative savings seem approximately constant over isolines which are slightly inclined from the upper left area towards the lower right area of the figure. This illustrates that the savings are proportional to both factor, meaning that largest savings are obtained by communities in areas with high solar potential, which are also exempt from paying relatively high regulated charges. All results obtained from the analysis are provided as a supplementary file to this paper.

4 Discussion

The European Union Directive 2018/2001 [35] establishes rules for renewable energy communities, stating that members should be able to freely share energy according to internally defined rules and be subject to "cost-reflective network charges, as well as relevant charges, levies, and taxes" that ensure their fair contribution to total systems costs. However, policy makers have found that implementing these guidelines is challenging, as it requires aligning incentives among different actors, balancing economic and administrative burden, and finding the appropriate timing. In this paper, we investigated the impact of fiscal measures on renewable energy communities and explore whether regulated charges paid by community members affect the amount of savings derived from energy sharing. Our analysis confirms that this is the case, but also reveals a number of nuanced outcomes.

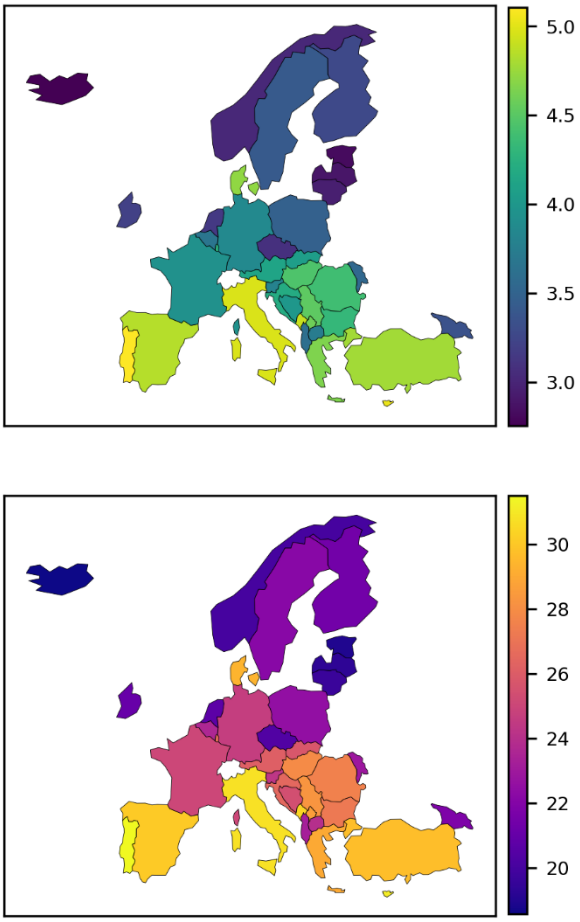

Fig. 8. Collective cost savings of the community from energy sharing in OS; Upper figure - first arrangement; Lower figure - second arrangemnt

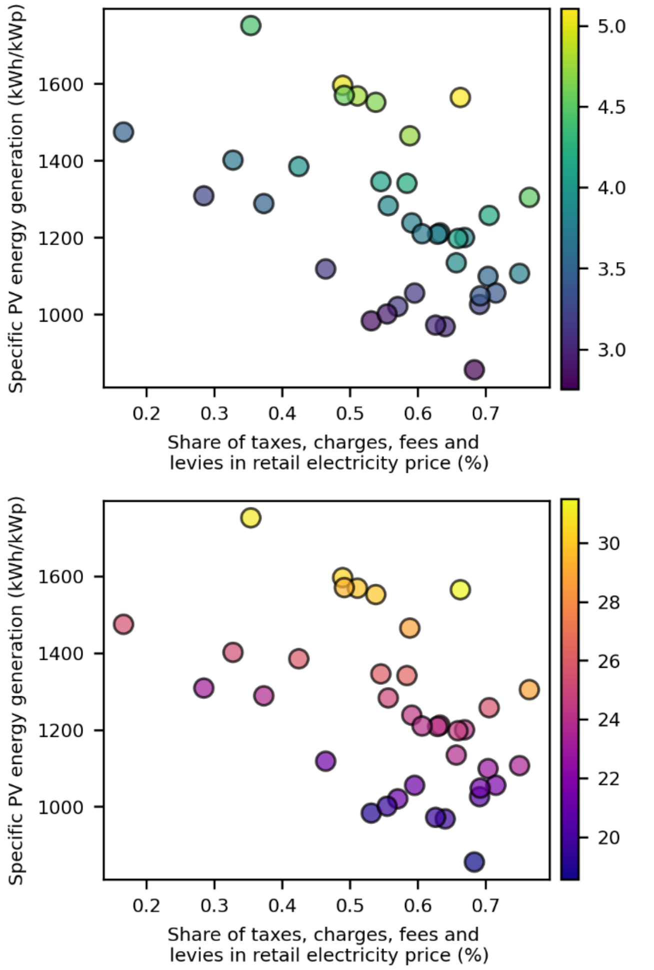

Fig. 9. Dependence of collective cost savings from energy sharing on solar potential and regulated charges; Result refer to OS; Upper figure – first arrangement; Lower figure – second arrangement

4.1 *Quantifying the benefit of energy sharing*

The findings from the comparison of the two energy sharing arrangements reveal that the potential monetary savings for households can vary significantly. As presented in subsection 3.2, the cost savings in the first arrangement are about (3.80 ± 0.63)%, in the OS. As shown in Figure 6, in the first arrangement, by sharing energy for one full year, a household saves less than a *monthly* electricity bill. More precisely, in the OS it saves about (62.32 ± 13.93)% of a monthly electricity bill, while in the PS, when all charges are payed, the *annual* savings drop to (18.65 ± 10.48)% of a monthly electricity bill.

In absolute values, the saving from sharing energy over one year range from 5.88-29.67 EUR in Austria, 4.97-17.46 EUR in Croatia, 5.97-41.83 EUR in Germany, 13.41-28.11 EUR in Greece, and 5.12-28.19 EUR in Sweden, among others. While specific to the community examined, these results suggest that the potential savings from energy sharing may not be significant on an annual basis and may not be sufficient to offset the costs associated with managing the community's energy sharing system [36]. These findings enhance our understanding of the issue obtained through previous research [37] and raise questions about the viability of this energy sharing arrangement as a means of reducing electricity costs, without implementing additional measures.

One potential measure is the introduction of flexible assets, such as energy storage systems, electric vehicles, or power-to-X elements [38], which can link different energy sectors within the community [39]. This provides the opportunity to researchers to explore the value that energy sharing communities can provide to the distribution network and the overall energy system, in order to compensate for any revenue loss experienced by various stakeholders. Another measure would be to vary the mix of prosumers and consumers in the community and therefore increase the savings by optimally aggregating community members [40].

In comparison, the community cost savings from sharing energy in the second arrangement are much greater, since considerably more energy is shared. An example of a community in this arrangement is a multi-apartment building with collective rooftop PV, where energy is shared behind the point of common coupling to the distribution network. It is therefore reasonable to relieve the community from paying network charges for this type of energy sharing. In the OS, depending on the country, by sharing energy in this arrangement for one year, a household saves about three monthly electricity bills (2.95 ± 0.44). This would be equal to about 188.76 EUR in Austria, 133.37 EUR in Croatia, 260.60 EUR in Germany, 186.85 EUR in Greece, and 176.71 EUR in Sweden. Conversely, if the community members and the collective PV generator are located at different points in the distribution network, they may be subject to paying a full or reduced distribution network charge. In the PS, compared their savings are reduced by (62.98 ± 14.29)% compared to the OS, depending on the country. This values are calculated based on the results shown in Figure 7 which refer to the base year of the analysis.

4.2 Distributing the fiscal support among stakeholders

From a zero-sum framework, the cost reduction of the community due to exemption of regulated charge are also the revenue losses for the external stakeholders. There are two main components of the regulated charge: the network charges collected by the transmission and distribution network operators and all other taxes, fees, levies and VAT, collected by governments. As a result, one should anticipate potential resistance from stakeholders such as DSOs, when drafting such regulation and should try to offer measures that introduce co-benefits in order to move from a zero-sum framework to a supperadditive one.

An unusual example is the generous framework in Italy, through which the government gives an energy community 0.11 cEUR/kWh for each kWh that is self-consumes, while also offering reduced distribution network charges. In this case, the government covers the 0.11 cEUR/kWh incentive while the DSO bears the loss of reduced network charges. Given that the total regulated charges in Italy are approximately 0.12 cEUR/kWh (according to the Eurostat database) the outcome of this measure is as if the community is exempt from paying all regulated charges. This is unusual because the incentive offered by the government is larger than the combined revenue from all regulated charges it would have gotten (0.07 cEUR/kWh). This can be interpreted as an additional subsidy of 0.04 cEUR/kWh for each self-consumed to the community, on top of the exemption of regulated charges 0.07 cEUR/kWh. It should be noted that exempting the community from, for example, the tax for renewable energy, reduces the government revenue which can later be used to support other renewable energy projects. Such an exemption is a subsidy in itself. In order to ensure that the energy sharing framework is fairly set up, the issue of potential free riding should be taken into account.

Figure 10 shows a plot of the network charges versus the other taxes, fees and levies in the retail electricity price. Each point in the plot represents one of the examined countries. The points that fall below yellow line represent countries in which the network charge is larger than all other regulated charges, while the points above the yellow line represent countries where the opposite is true. Such mapping should help policy makers evaluate and prioritize the type of support they should provide to energy communities, considering how each support mechanism affects the relevant stakeholders, given local and national conditions.

4.3 Timing regulatory changes

One notable policy recommendation from our study is related to the timing of bringing forth regulatory change related to energy sharing. Our results suggest that regulatory changes may be more easily implemented and more beneficial for all parties when energy and supply costs are high. As illustrated in Figures 6 and 7, when energy and supply costs are 4-6 times higher than they were in 2021, the economic impact on community members of paying regulated charges for shared energy is minimal. This presents an opportunity for policy makers in Europe to introduce energy sharing regulations with minimal resistance from stakeholders. During times of high wholesale prices, energy consumers are more interested in investing in renewable energy for their self-consumption, since it enables them to significantly reduce their electricity bills. When this is done in an energy community, it may not be necessary to fully exempt community members from paying taxes, fees, and other charges for the energy they share in order to incentivize such behavior. The reason for this, as mentioned previously, is because community members in this case benefit from avoiding the high energy and supply costs, not from avoiding regulated charges. Instead, the main challenge will be to ensure that energy is consumed and shared within the community rather than sold on the market. If successful, energy sharing under these circumstances can align the incentives of energy consumers seeking to reduce their bills with those of policy makers seeking to implement new regulations, governments seeking to meet energy and climate targets, and distribution system operators looking to avoid revenue losses and avoid new investment.

4.4 Limitations and further research ideas

This study has several limitations that should be noted. One limitation is the use of fixed electricity consumption, which does not respond to PV generation or energy sharing. While this was done to explore the worst-case benefits that can be obtained when there is no flexibility on the demand side, a natural extension of this work would be to include flexible assets such as electric vehicles and heat pumps. An analysis including heat pumps would be particularly interesting, considering the impact of ambient temperature on heating and cooling demand and the coefficient of performance of the heat pumps.

Another limitation of this study is that it only examines fiscal measures implemented through electricity tariff design. There are other measures that can significantly support energy communities, such as subsidizing investments in collective infrastructure (such as PV systems, storage, heat pumps, or electric vehicle charging infrastructure) or offering reduced administrative procedures and technical support to community members. Future research could, for example, examine the impact of offering such support for investments in infrastructure that can also benefit other stakeholders (e.g. smart charging of electric vehicles or batteries to avoid overvoltage issues during peak PV generation for distribution system operators).

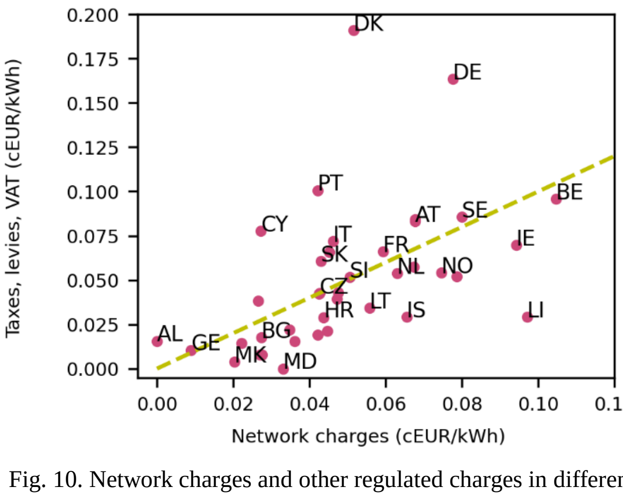

Fig. 10. Network charges and other regulated charges in different countries

5 Conclusion

This study has examined the impact of the regulated charges on energy sharing in European renewable energy communities. The results show that the potential savings for households from energy sharing can vary significantly, depending on the specific arrangement and the choice of fiscal support mechanisms. When the community is comprised only of households with PVs, without any regulated charges, a household can save approximately 62.32% of their monthly electricity bill over the course of one year through energy sharing in a community. However, when all regulated charges are taken into account, the annual savings drop to 18.65% of a monthly electricity bill. These findings suggest that the potential savings from energy sharing in this arrangement may not be significant on an annual basis and may not be sufficient to offset the costs associated with managing the community. However, introducing flexible assets or including consumers next to the prosumers in the community can increase the value of energy sharing in this arrangement.

In comparison, the community cost savings from sharing energy in the second arrangement are about 5 times greater and equivalent to nearly three monthly electricity bills, since considerably more energy is shared. These types of communities are possible in multi-apartment buildings or in suburban/rural areas, where collectively owned generation units can be located nearby the community members. It is worth noting that in this arrangement, although community members benefit more from sharing energy in comparison to prosumers share energy, they yield lower savings overall (since they have not local self-consumption) and their savings are *more* dependent on the charges, taxes, fees and levies applied to the shared energy.

The study also found that distributing the fiscal support among stakeholders, such as distribution network operators and governments, can be a challenge when implementing energy sharing regulations. In order to avoid resistance from these stakeholders, it was suggested to introduce energy sharing regulation when energy and supply costs are high, since during this period community member can highly benefit from self-consumption and energy sharing, even if they pay most regulated charges. Another suggestion for avoiding resistance is to move from a zero-sum framework to a superadditive one, by introducing measures that offer co-benefits, such as subsidies in demand side flexibility, so that communities can better balance local supply and demand and thus avoid overvoltage and overloading issues at the distribution level.

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7 Authorship contribution

Vladimir Z. Gjorgievski: Investigation, Software, Methodology, Formal analysis, Writing – Original Draft, Funding; **Bodan Velkovski**: Investigation, Software, Formal analysis, Writing – Review & Editing; **Francesco Demetrio Minuto:** Conceptualization, Formal analysis, Writing – Review & Editing; **Snezana Cundeva:** Methodology, Supervision, Writing – Review & Editing; **Natasa Markovska:** Conceptualization, Supervision, Writing – Review & Editing.

8 Competing interests statement

The authors declare no competing interest.

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