Cost Allocation in Energy Communities

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Abstract

Cost allocation is a crucial element in Energy Communities due to shared distributed energy resources between members. This review examines current and emerging methods before identifying challenges and future trends to ensure fair and stable sharing mechanisms among members while improving the overall feasibility of Energy Communities.

1. Introduction

Energy Communities play a pivotal role in the clean energy transition by promoting the local generation of renewable energy sources. Characterised by shared and often jointly-owned energy assets, Energy Communities actively engage in energy-sharing activities, which include the distribution of their locally generated power among community members and external markets.[1] Recent literature has focused on the development of various strategies and rules for allocating the generated electricity within the community, leading to different bill reductions for its members.[2] Thus, a direct implication of these energy-sharing practices between community members is the allocation of emerging costs and benefits. Although the allocation of costs between members needs to be clarified in every Energy Community, there are no clear legal regulations and only little research on this subject. Therefore, the economic question of how costs can be shared among community members reveals unsolved allocation issues, arousing interest in both academic and practical fields.[3]

2. Cost Allocation and its Importance for Energy Communities

Cost allocation methods determine how costs associated with the generation, distribution and consumption of energy within the community are assigned to community members. This is a fundamental aspect of the viability of Energy Communities, as it affects their short and long-term success. The costs of electricity supply as well as the costs of shared infrastructure, such as storage facilities and grid maintenance, should be shared among the involved participants in a way that reflects their contributions. In other words, the costs should be paid by those who cause them, i.e., those who consume energy and their energy-related services in the community system.[4]

As self-sufficiency is not economically viable due to the high costs of distributed energy resources, particularly storage systems, the community must import additional electricity from the grid at retail prices. The payments of the community to remunerate either the grid for the energy imports or the prosumers (users who both generate and consume electricity in the energy system) for energy exchanges are essential for the long-term feasibility of an Energy Community. The question that arises is how each member must contribute to these payments. Since there is only one electricity bill for the entire community, which calculates the difference between the costs for imported energy and the costs of exported energy via the smart meter, the bill is shared between the members of the community according to the established methods.

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However, if the Energy Community produces energy surplus, members can be remunerated for their energy exports to the grid through feed-in tariffs or agreed-upon wholesale prices. In some cases, the compensation for the sale of the energy production can be negotiated or even be completely eliminated.[1] The resulting profits should be distributed among the members by offering them either a reduced energy price or a reduced membership fee. This should be large enough to finance the capital costs of the community, especially if it does not have access to capital markets. Over time, the membership fee could even become negative, allowing the community to redistribute its profits to members in the form of dividends.[5] However, if there are no differentiated prices for the distinct contributions of the members, this will quickly lead to unfair results.[6] Hence, there is also a related but different task for the Energy Community, namely the distribution of the generated benefits among the members, which will not be elaborated further in this context.

The members of the Energy Community are active actors in an energy system who ideally participate in the planning, development and management of the community energy system, either directly or via a community manager who coordinates the community's trades. If this intermediary entity does not allocate costs to the members, there is ideally a community committee that develops a customised cost allocation model. To define a cost allocation method, the costs of energy exchanges within the community and with the grid must be considered and formulated. Subsequently, the community members must decide on a cost allocation method before the annualised costs can be distributed among the different participants.[4]

The chosen cost allocation method is therefore a central component in the design of the tariff structure and provides information on cost incurrence within the community. In order to design efficient tariffs, which should include non-discriminating, transparent and cost-reflective prices, suitable cost allocation methods need to be defined.[7] Firstly, the tariffs must reconcile the supply price of the energy producer with the demand price of the end-consumers. Secondly, it is imperative to take into account fundamental objectives

and principles, in particular with regard to the cost recovery of the community's investments. In addition, these tariffs must ensure that the community's activities create economic value, so that the costs of generating and selling energy is lower than the costs of supplying energy from the grid or opting for individual self-consumption.[8]

Before proceeding with the allocation design, the amount of costs and benefits to be allocated should be determined. The variable expenses associated with electricity imports and exports are shared between the community members based on their net loads at each time step. These net loads are measured in the beginning of the following day using smart meters installed at the end-consumers locations.[9] During this process, it is important to provide information transparency to the members by explaining the pricing and allocation methods to them in a simplified and comprehensive manner, ideally involving them in the decision-making process.[6]

3. Cost Allocation Methods

To implement a cost-sharing model into practice, it is essential to establish rules for the cost allocation. These rules determine how costs are shared among the community members. Recent scientific contributions have analysed diverse cost-sharing mechanisms that have been discussed in the framework of local energy markets and distribution models. Within cost allocation models, many studies deal with the assessment of fairness principles, especially in scenarios with a community manager. To this end, various contributions use game theoretical methods to model fair cost allocations within Energy Communities. These models often include a cooperative setting and are based on solution concepts from coalitional game theory. Their fundamental concept focuses on the distribution of payoffs from the community coalition rather than on the factors that define how agents achieve those payoffs.[6]

The most frequently analysed cost allocation methods are described below:

- **The Equal-Split scheme** allocates the costs equally among all users, so that the total costs of the community are divided by the number of participating members.[10]
- **The Bill-Sharing scheme** shares costs of the community electricity bill between the members according to their individual total energy imports and exports, with each member paying the same unit price for their purchased energy and receiving a payment at a different unit price for their supplied energy.[11]
- **The Mid-Market-Rate scheme** sets exchange prices between members based on the average of electricity purchase and sale prices and adjusts them over time if the total energy generation does not match the total demand of the community. This encourages the adoption of flexible demand and energy assets that adapt to local generation patterns, leading to costs reductions compared to the conventional scenario.[10]
- **The Shapley Value** calculates the average marginal contribution of each member by considering all possible combinations of cooperation between the members in the community.[12]

Cost allocation methods vary according to their time horizons (daily, monthly or yearly) and their implemented distribution schemes, which may adopt more simple or complex computing systems. The Equal-Split scheme, for instance, is easy to compute but does not adequately guarentee fairness and stability within a community, as it does not consider individual contributions to the total costs of the community. On the contrary, the Shapley Value, which is known for its ability to include fairness in the results, is difficult to compute, especially for large Energy Communities.

To evaluate these cost-sharing mechanisms, the energy savings achieved by each community member must be compared with the benefits they would have yield individually outside of the Energy Community. The cost allocation method is evaluated as non-preferable if the sum of prosumers who are better off in the community is smaller than the sum of prosumers who are worse off. In that case, costs are reallocated such that all of them are at least equally off, as they would be without the community.[8] Additionally, the cost allocation is considered budget-balanced if each user contributes in a way that the total payment by all users corresponds to the costs incurred by the community.

The assessment of these methods remains very difficult and finding the right scheme for local energy trades inside Energy Communities is a complex task, accompanied by several challenges, especially in cases where multiple stakeholders are involved. Consequently, a thorough analysis of cost allocation methods is required and should be carefully evaluated on the basis of the principles for a sustainable energy distribution.

4. Challenges of Cost Allocation

Implementing cost allocation methods in local energy markets encounters significant obstacles that are distinct from those faced in larger energy systems.[4] Unlike traditional energy models, Energy Communities require tailored allocation strategies to take into account the dynamics and the structure of the participants.[6] To this point, there is no general framework available on cost allocation methods between Energy Community members. Among the emerging cost-sharing models, there exists no uniform acceptable consensus on how to allocate costs and benefits within Energy Communities. Additionally, there exists no one-fits-all cost allocation method, since the different schemes focus on different aspects of the energy demand profile.

The success of an Energy Community depends largely on its business model and its flexibility to adapt to evolving circumstances.[11] The Energy Community's environment is strongly influenced by diverse factors, including local regulations, governance structures and stakeholder preferences. Given the broad spectrum

of contexts, objectives and energy needs — especially considering their inclusion of diverse members from the residential, commercial, or industrial sector — the composition of an Energy Community will significantly influence the allocation of costs between members. It is therefore crucial to present a variety of allocation schemes to effectively manage cost-sharing practices within Energy Communities.

Moreover, it is important to respect the rules of energy allocation to design cost and benefit distribution models, as the energy surplus allocation determines the benefits that each consumer derives from participating in the community in the long-term.[13] This includes the challenge of incentivising members to not leave the community by adapting prices and the existing cost allocation model for long-term plans. In addition, the amount of energy cost savings that an Energy Community can achieve depends on several factors. These include retail energy costs, applicable charges, taxes and levies, along with national regulations and economic incentives for energy-sharing pratices. Finally, the different types of practices, along with installed energy capacities play a crucial role in determining transaction and operational costs, which are pivotal for the community's profitability.[1]

Therefore, it is important to introduce a cost allocation method that is compatible with the economic objectives aimed at optimising trade within a collective economy.[14]

- First, the allocation needs to be **cost-efficient** in terms of the overall energy bills and benefits for members in contrast to trading exclusively with the grid. In this manner, an effective allocation method should be dynamic to incentivise consumers to shift their consumption to off-peak hours and reduce overall peak demand.[6]
- Another ultimate goal that affects the success of the cost allocation is its **social acceptability**. Cost allocation practices are socially accepted if it is perceived as fair in its final design, ensuring that members who are not involved in the costs do not unfairly harvest the resulting benefits. In addition, its process should be conducted in a fair, transparent and consistent manner, enabling broad citizen participation while empowering vulnerable groups.[15] Furthermore, fair and just prices should be maintained to discourage and prevent free-rider behaviours inside the community. Since fairness is a crucial element for prosumers to engage in aggregation schemes, its level is a highly discussed topic in terms of cost allocation methods.[16]
- Lastly, a **sustainable scale** constitutes a vital condition for well-functioning trades and highly impacts the social acceptance and thus the success of the implemented allocation method. Cost allocation methods are highly dependent on the size of the community, which should be adjusted to its members and capacities so that there is no energy over- or underproduction. Otherwise, this can lead to unstable communities, which is an important issue in scenarios where agents can act as self-sufficient prosumers.[17] If allocation rules do not integrate the individual's contribution to the value of the community, members might opt out, leaving the remaining agents with increased charges due to a redistribution among fewer users (also known under the snowball effect).[18] To mitigate such risks, it is imperative to assess the characteristics of the participants in advance.

However, there is an important trade-off between these three economic goals. Allocation methods that guarantee both fair outcomes (such as the Shapley value) and are robust to strategic behaviours are computationally complex and thus not easy to scale for larger communities. It is therefore crucial to evaluate the fairness and stability of a cost-efficient allocation design before implementing it in Energy Communities.

To find a balance between fairness and computational complexity, innovative schemes have been developed. For example, with the virtual net-billing method, each member's electricity bill is determined by their individual electricity imports from the grid and is reduced by costs savings achieved through virtually self-consuming a portion of the shared electricity. With this rule-based scheme, computation time savings are significantly improved, especially for large communities.[19] Also, a voting system, which considers the reputation of agents in the system, can optimise the computational complexity by ensuring fairness principles.[20] Another method consists in allocating costs based on the marginal contribution of each prosumer and with respect to the larger group.[6] This provides both a fair distribution and computation traceability, since it has an improved scalability as the number of members inside the Energy Community increases. Due to the complexity of the members' coalitions, the national context and the aim of Energy Communities, it is preferable to design different allocation methods that should be consistent with the goals, values and local context of the Energy Community.

5. Conclusion and Perspectives

Cost allocation is an important aspect of the management of an Energy Community, especially considering the shared resources and infrastructures that are involved. However, the choice of allocation rules remains challenging, as the adaptability of allocation schemes largely depends on the characteristics and circumstances of the community. Implementing effective cost allocation schemes not only contributes to the long-term sustainability of Energy Communities, but also fosters broad societal acceptance, thereby facilitating a smooth transition to sustainable energy practices.

Hence, efficient cost-sharing procedures should be designed in a way that they maintain stability within the community and fair conditions for the members. In addition, the cost allocation must be tailored to the participants' characteristics as well as to the size of the community, while being framed by simplified legal requirements. Moreover, strategic considerations and technological advancements are crucial aspects that should be carefully considered. Emerging future trends

include dynamic pricing models, blockchain technologies facilitating transparent and decentralised accounting processes as well as advanced algorithms to take into account peak in energy demands as well as member's resource contributions.

Overall, more clarity is needed on the allocation and distribution of costs and benefits among members. This includes a deeper understanding of how the performance of cost-sharing methods can be most meaningfully assessed. Finally, cost allocation schemes should define incentives that foster efficient energy usage and incorporate different options for distributed energy systems to achieve the most sustainable outcomes for Energy Communities.

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