A Multistep Optimization Procedure for a Fair Sharing of Profits in Energy Communities

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Abstract

Renewable energy communities offer the possibility to share energy excess in your neighborhood. Especially for electrical energy exchange in the case of photovoltaic systems, this community is both a sustainable and also an economically interesting option.

The necessary task of distributing the energy flows in such communities will lead to different economic impacts on the participants. This work proposes a mathematical multi-step procedure to find a fair distribution of the gained cost savings in an energy community, depending on the contribution of every member of the community.

Keywords: Energy communities, optimization, photovoltaics, storage systems, optimal power flow, Multi-step

1. Introduction

In renewable energy communities, energy can be exchanged beyond household or company borders, and every participant of such a community is allowed to produce, sell, buy or store energy (EE-RL. 2018). This energy exchange is a very interesting option, especially for PV systems, because a typical design often results in electrical surpluses at noon.

Potential members of energy are in most cases interested in a sustainable but also in an economic operation of their energy supply. Several test cases (Steinmaurer, 2020) show, that not all members of energy communities benefit to the same extent from their participation in this community. This work aims to present a methodological development towards a fair distribution of profits in such electrical energy communities.

The paper is organized as follows: after a short introduction, a developed optimization method for PV- and battery systems in energy communities is presented. This method evaluates the contribution of every participant and uses this information in a multi-step procedure to distribute the economic advantages in energy communities.

2. Method

The presented method for finding a fair distribution of advantages in electrical energy communities is based on a previous publication (Steinmaurer, 2020). For easier understanding, the method used there is briefly listed here again. Every participant in a renewable energy community has properties, according to Fig. 1. The states x_1 … x_8 are power values of this player in the community and describe the energy flow situation. State x_5 refers to the state of charge of the storage unit. Arrows indicate possible energy flow directions, like load and PV production, costs for energy purchase (x_1) as well as remuneration for feed-in (x_2) are assumed to be known.

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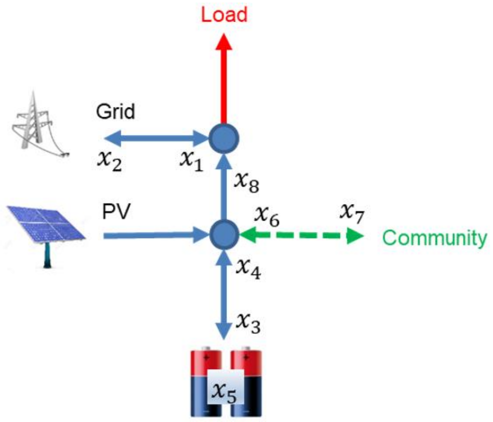

Fig. 1: Structure of energy flow optimization of one single participant in an energy community. States xi consider power flow at every time instant, from (Steinmaurer, 2020)

Every Energy community consists of *N* participants with properties of Fig. 1. Renewable energy will be exchanged via the public grid - but with different fees and costs (so the states x_6 and x_7 are necessary). Efficiencies for charging (x_3) and discharging (x_4) of the battery are also considered, the non-negative state x_8 avoids battery charging from the grid.

The overall energy flow coordination problem considering all time instants for every participating partner leads then to a linear programming procedure

$$\min_{\boldsymbol{x}} \boldsymbol{c}^T \boldsymbol{x} \qquad \text{(eq. 11)}$$

$$\boldsymbol{A}_{eq}\boldsymbol{x} = \boldsymbol{b}_{eq}$$

$$\boldsymbol{A}_{ineq} x \leq \boldsymbol{b}_{ineq}$$

$$\boldsymbol{x}_{lb} \leq \boldsymbol{x} \leq \boldsymbol{x}_{ub}$$

considering equality constraints $\boldsymbol{A}_{eq}\boldsymbol{x} = \boldsymbol{b}_{eq}$ ((eq. 1) to (eq. 4)) and inequality constraints for the states $\boldsymbol{x}_{lb} \leq \boldsymbol{x} \leq \boldsymbol{x}_{ub}$ (e.g. maximum and minimum power, storage limitations, …) and for additional limitations ($\boldsymbol{A}_{ineq} x \leq \boldsymbol{b}_{ineq}$). As mentioned, details can be found in (Steinmaurer, 2020).

This optimization procedure was used to find an optimal discrete time sequence of all states $\boldsymbol{x}$ from (eq. 1) for several test cases. The example in (Steinmaurer, 2020) with 4 participating partners shows that in some cases the optimal solution for the energy community (minimal summed up costs for all participants) can lead to disadvantages for some individual partners in the community, e.g. increased costs for partner P3 (-3.78€), while all other participants gain an advantage (see Tab.1)

The individual cost savings of each partner (with and without being part of the energy community) are listed in Tab. 1 in an absolute (S_i) and in a relative ($S_{i,r}$) representation

$$S_{i,r} = \frac{S_i}{F_i} 100\% \qquad \text{(eq. 2)}$$

Tab. 1: Resulting costs for each participant and the saving in comparison to the individual costs without being part of an energy community, adjusted from (Steinmaurer, 2020)

		P1	**P2**	**P3**	**P4**		**Sum**
Individual costs of partner *i* without energy community $\boldsymbol{F_i}$	€	103.95	34.15	14.72	118.50		$\sum_{i=1}^{4} F_i =$ 271.33

Savings of partner *i* through community $\boldsymbol{S_i}$	€	8.87	2.58	**-3.78**	27.31		$\sum_{i=1}^{4} S_i =$ 34.99
Relative cost savings $\boldsymbol{S_{i,r}}$	-	8.53%	7.56%	**-25,6%**	23,1%		$\frac{\sum_{i=1}^{4} S_i}{\sum_{i=1}^{4} F_i} 100\%$ = 12.9%

Calculation of an Energy community contribution index

In (Steinmaurer, 2020) a first attempt to assess the importance of an individual participant was presented. This was done by eliminating single players from the energy community and observing the effects of cost savings on the community. This results in an assessment of the importance of participants to the economic viability of such energy communities (see Tab 2).).

In the next step, a community contribution index C_i of every participant $i = 1 \dots N$ is defined

$$C_i = \frac{S_{C,i} - \sum_{i=1}^{N} S_i}{\sum_{i=1}^{N} S_i} \qquad \text{(eq. 3)}$$

where $S_{C,i}$ are the savings of the community without participant P_i , S_i are the savings of the individual participant *i* in a complete energy community with all participants (see tab. 1). This index is able to measure the importance of a single participant in a community.

Tab. 2: Assessment of the individual contribution to the energy community

	Community Savings $S_{c,i}$	**Community Contribution index** C_i
Community without **P1**	$S_{c,1}$ =19.04 €	0,458
Community without **P2**	$S_{c,2}$ =10.04 €	0,71
Community without **P3**	$S_{c,3}$ =29.79 €	0.148
Community without **P4**	$S_{c,4}$ =19.25 €	0,449
Community with **all participants**	$\sum_{i=1}^{4} S_i$ = 34.99€	

Fig. 2 shows a possible result of the contribution index as a function of the individual savings for all players in an energy community. Because the optimization procedure minimizes costs to the entire energy community, some participants may experience slightly higher costs after the optimization, although savings are made by the community itself. It is obvious, that such a situation - with some participants (indicated in red) have a disadvantage while others benefit - does not offer a perspective for long-term cooperation in this community.

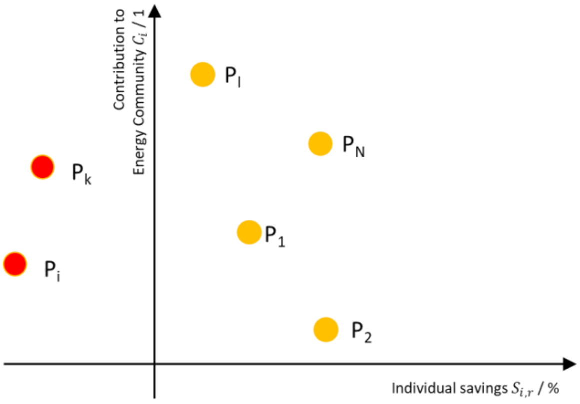

Fig. 2: Contribution index vs. individual savings in an energy community

There are two basic possibilities to avoid drawbacks for some participants:

- the community itself builds a mode for a financial balancing of these injustices after the energy exchange (cross-financing of the economic advantages) or
- a mathematical procedure to include the contribution index in the optimization task.

In this work, the second approach will be demonstrated.

Multistep-Procedure

The single-step procedure of (Steinmaurer, 2020) offers the drawbacks of non-consideration of negative savings of some participants, apart from that no information about the importance of a participant in an energy community is included in the optimization procedure.

The main concept of the proposed multistep procedure is

a) Compute the optimal solution (minimum costs) for the energy community

b) Compute the individual savings $S_{C,i}$ and the contribution index C_i of every participant

c) Define additional boundary conditions for minimum savings of every participant, depending on the parameters of b)

d) Solve the extended optimization task

e) If the solution of d) is feasible, then the requirements of c) are tightened and continue with c)

To realize a fair contribution of the economic advantages, the additional boundary conditions can be used to define the increasing minimum savings of every participant if the contribution index is increasing. This behavior can be realized with a simple linear function of minimum savings for all players. The minimum requirement and the starting point for further optimization for the energy community are, that no participant has higher costs for energy than without the community. To reward participants with higher contributions to the energy community, the minimum saving will be increased depending on the contribution. This will be done by restricting the solutions space of the optimization task linearly to Ci. As a result of that, the solutions must move to higher savings beyond the newly added minimum saving limit. The lower boundary condition for every participant is then calculated

$$S_{i,lb} = kC_i \tag{eq. 4}$$

The slope k starts with $k = 0$ (left diagram of Fig. 3) and is increased until no solution to the optimizing task can be found. The last feasible solution is the result of this multistep procedure. (right diagram of Fig. 3, the constraint of participant P_l is violated first while all other participants are still in the allowed Solution space).

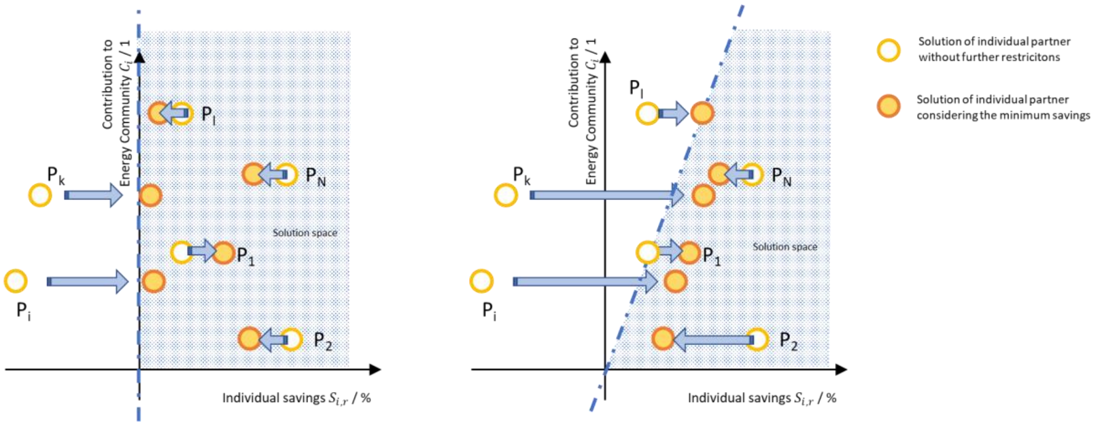

Fig. 3: Restriction of the solution space for the optimization procedure

3. Results

The multistep-procedure from chapter 2 is shown for the test cases with 4 participants of an energy community (from (Steinmaurer, 2020)). Starting with the initial optimization without restrictions on individual savings leads to a solution with an economic disadvantage for participant P3. Applying the presented multistep-procedure (starting with $k = 0$ leads then to the results of Tab. 3. The graphical representation can be seen in Fig. 4. Although all participants' solutions appear to lie on the optimal slope line, only P3 is exactly on this line, all other participants are inside the solution space.

Tab. 3: Results of the multistep-procedure

		P1	**P2**	**P3**	**P4**		**Sum**
Individual costs of partner *i* without energy community F_i	€	103.95	34.15	14.72	118.50		271.33
Community Contribution index C_i	1	0.458	0.71	0.148	0.449		
Savings of partner *i* through community S_i / $S_{i,r}$ without minimum savings	€ %	8.87 8.52	2.58 7.56	-3.78 -25.65	27.31 23.05		34.99 12.90
Savings of partner *i* through community S_i / $S_{i,r}$ with $k = 0$	€ %	8.87 8.52	2.58 7.56	0 0	22.03 18.6		33.49 12.34
Savings of partner *i* through community S_i / $S_{i,r}$ with max k	€ %	10.47 10.08	5.33 15.62	0.48 3.25	11.84 9.99		28.13 10.37

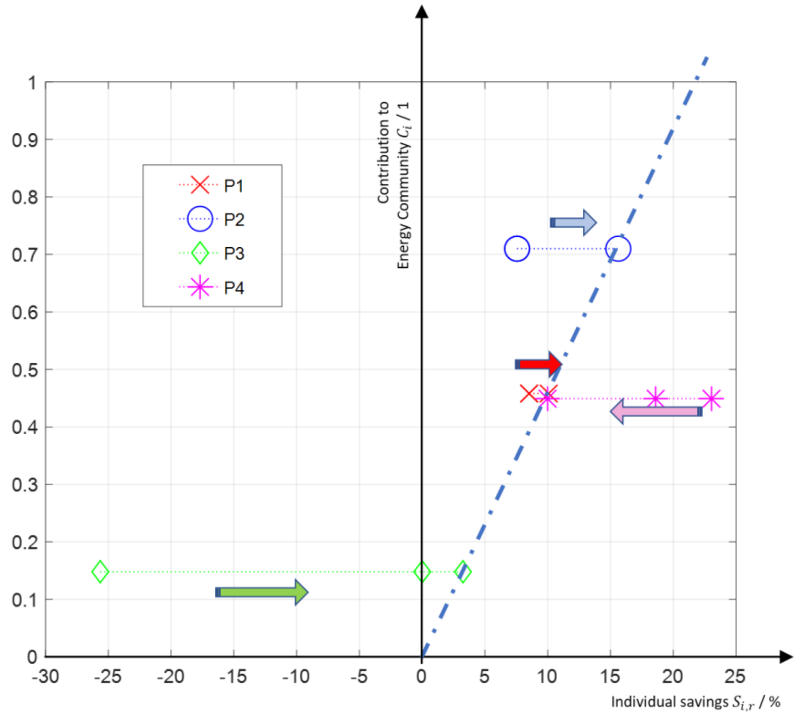

Fig. 4: Resulting individual savings of an energy community with 4 participants P1 … P4

4. Conclusions and Outlook

A renewable energy community is an ideal possibility to share excess energy with other participants and take economic advantage of this legal opportunity. The distribution of energy within this community can be seen as an optimization task, where the global costs of the community will be minimized. As demonstrated in an initial example, this minimization can lead to financial drawbacks for some community members. To avoid this injustice, a multistep-procedure was presented, where a community contribution index was used to determine a fair share of the community savings. This procedure can be used to define the economic advantages in energy communities of every participant in an understandable mathematical way.

5. Acknowledgments

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6. References

EE-RL (2018): Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources, Retrieved September 1, 2022 from *https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018L2001*

Steinmaurer, G. (2020). An Optimization Approach to Control the Energy Flows in Renewable Energy Communities. *EuroSun 2020*, *Athens*, *Greece*. doi: 10.18086/eurosun.2020.05.16