A Framework for Shared EV Charging in Residential Renewable Energy Communities

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ABSTRACT

Renewable energy communities with members which own electric vehicles (EVs) can benefit financially from the flexibility that EVs provide to distributed energy resources, such as photovoltaic generators. However, in residential environments, this benefit is often lost because during working hours, most EVs are not plugged in at the premises of the community. In this paper, we hypothesize that such communities can regain some of this lost benefit by offering membership to outside EV owners which are interested in charging their vehicles using the community's charging stations during these periods.

This paper introduces an optimization model for energy communities consisting of prosumers, electric vehicles, and EV chargers. The model aims to evaluate the potential advantages of integrating external EV owners into an energy community. A hypothetical community representing a multi-apartment building is analyzed, considering scenarios both with and without external members. The analysis focuses on assessing the technical and economic benefits. The findings indicate that the economic benefits for the examined community are relatively small. However, a notable increase in these benefits is observed when the community is exempted from taxes and regulated charges for the energy shared among its members.

KEYWORDS

Energy community, energy sharing, electric vehicles, collective self-consumption, optimization model

INTRODUCTION

Maximizing the symbiotic relationship between electric vehicles (EVs) and photovoltaic (PV) generation offers significant opportunities for smoother integration of these technologies in future sustainable energy systems [1]. Both technologies follow trajectories of exponential growth and are likely to be found in many buildings in the future. While their separate, unmanaged deployment is considered a potential issue, an increasing body of scientific works shows that high shares of PV generation can stimulate daily charging of EVs [2]. As a result, smart charging has been reported to reduce peak power exchanges with the distribution grid [3], lower transmission and distribution losses [4] and improve demand side flexibility [5]. The scientific literature reports an abundance of technical approaches for smart EV charging [6],

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ranging from heuristic methods [7] to stochastic optimization [8], reinforcement learning [9], machine learning [10] and distributed optimization [11].

With that in mind, it seems that tapping into the potential of electric vehicle smart charging is not only a matter of deploying physical and digital infrastructure, but also a matter of laying down the necessary social and regulatory conditions. The Clean energy for all Europeans package aims to facilitate this process by introducing a number of regulatory innovations, such as energy sharing in communities and collective self-consumption. The revised Renewable energy directive (Directive (EU) 2018/2001) [12] formally defines the concept of renewable energy communities with the goal of empowering citizens to locally produce, consume, store and share energy. The regulatory support of this idea is further strengthened in the recast of the Energy performance of buildings directive [13], which states that 'zero-emission buildings' can cover their remaining low energy demand using nearby off-site generation or from renewable energy communities, as per Directive (EU) 2018/2001. The recast of Energy performance of buildings directive also grounds the notion that electric vehicle chargers are an integral part of future buildings, as it foresees pre-cabling for EV charging in new buildings and installation of suitable charging infrastructure for existing buildings undergoing deep renovation.

As a result, many opportunities for new business models emerge related to energy communities [14], such as the idea of making private EV chargers available to outside users. Currently, around 42% of households have challenges in installing private chargers [15], which has given rise to community financed electric vehicle charging [16] and shared EV charging services, such as Co Charger [17] and ChargeBnB [18]. In the context of energy communities, we hypothesize that sharing community-owned chargers with external users can be beneficial for both sides. On the one hand, it should increase the self-consumption of the community, giving community members additional economic benefits due to energy sharing incentives. At the same time, the external users should benefit from a charging service cost which is less expensive compared to a scenario where they charge elsewhere. For this reason, it is important to adequately model the energy sharing incentives when developing a smart charging algorithm for EV, that is tailored for communities with local renewable generation.

Literature review

Energy sharing incentives can take the form of premiums for the self-consumed electricity, reduced network charges, tax exemption or some combination of these measures. The Italian and German incentive schemes, for instance, are designed around the self-consumption premium and tax exemptions for the shared electricity. In Italy, the premium of 110 EUR/MWh [19] has stimulated many new energy communities to be formed and motivated Cutore et al. [20] and Stentati et al. [21] to define optimization models for optimal design and management of renewable energy communities, considering the Italian regulatory framework. The German Tenant Electricity Law has a similar framework, but varies the incentive depending on the capacity of the local generation system. The framework is primarily aimed at motivating building owners to install local generation systems and sell their electricity directly to building tenants. Braeuer et al. [22] proposed a mixed-integer linear program (MILP) optimisation model which encapsulates the German Tenant Electricity Law and used it to evaluate the impact of different technologies, such as a PVs, combined heat and power generators, batteries and electric vehicles.

To incentivize energy sharing in Austria, community members benefit form a reduced network charge, as well as tax exemption of other relevant charges [19]. A hybrid energy sharing strategy for prosumers, considering both the electric and thermal network costs, has been proposed in [23]. Similarly, the impact of the distribution network cost has also been a focus of Schreck et al. [24] which evaluates four network charge designs applied in Germany and Maldet et al. [25], which explores the impact of network charge designs on peer-to-peer energy trading in Austria, Norway and Ireland.

Contribution

Informed by the existing literature on energy sharing and smart electric vehicle charging, and motivated by the potential of opportunities for future business models built around the sharing economy, this paper aims to provide the following contribution to the state-of-the art:

- Present a non-convex optimization model for smart charging of electric vehicles that can be tailored to represent different incentive schemes for energy sharing;
- Develop a mixed-integer linear optimization formulation of the non-convex model which can be used with readily available solvers;
- Quantify the economic and technical benefits of sharing EV charging infrastructure, for an energy community which owns a PV generator which is used for self-consumption;
- Discuss the value proposition of a business model for sharing community-owned EV chargers with external users.

METHODS

This section presents the non-convex and MILP formulation of an optimization model that describes the operation of an energy community consisting of prosumers with electric vehicles (EVs) and EV chargers. The presented model is part of a larger, ongoing research which aims to construct a comprehensive energy community model that addresses the challenges of optimizing energy generation, distribution, and utilization within a localized network. Beyond the scope of the current study, the broader model includes batteries for energy storage, as well as heat pumps integrated with thermal storage for district heating applications. The model is implemented using the Python programming language and the Pyomo optimization library.

Non-convex problem formulation

We consider an energy community composed of $N = \{1, 2, 3, \dots, n\}$ grid-connected prosumers. Each prosumer can have an electric load, a local generator and an electric vehicle. Hence, they can export and import electricity to and from the distribution grid in order to meet their electricity demand or inject excess generation in the grid. Various configurations of communities can be represented using such a model by combining prosumers with different features. The energy balance for prosumer i at time t is given with the following equation:

$$p_{l,i}(t) - p_{g,i}(t) - p_{im,i}(t) + p_{ex,i}(t) + p_{ch,i}(t) = 0 \quad (1)$$

In this equation, for member i, at time t: $p_{l,i}(t)$ represents the electricity consumption by the electrical devices at their premises, $p_{g,i}(t)$ is the electricity generated by their generator, $p_{ch,i}(t)$ is the electricity used to charge their electric vehicle battery, and $p_{ex,i}(t)$ and $p_{im,i}(t)$ represent the physically exported and imported electricity to and from the grid, respectively, at the point of common coupling. At time t, prosumer i can either export electricity to, or import electricity from the grid. Consequently, $p_{ex,i}(t)$ and $p_{im,i}(t)$ cannot simultaneously be non-zero:

$$p_{im,i}(t)p_{ex,i}(t) = 0 \quad (2)$$

The charging of the electric vehicle owned by prosumer i is formulated as follows:

$$SOE_i(t) = SOE_i(t-1) + \eta_{ch,i} p_{ch,i}(t-1) \quad (3)$$

In this equation, $SOE_i(t)$ represents the state of energy of the electric vehicle of prosumer i at time t, whereas $SOE_i(t-1)$ and $p_{ch,i}(t-1)$ are the state of energy and the electricity used to charge the EV's battery during the previous time interval $(t-1)$. $\eta_{ch,i}$ is the charging efficiency of EV's battery. The applied initial and terminal conditions are as follows:

$$SOE_i\left(t_{arr,i}\right) = SOE_{arr,i} \quad (4)$$

$$SOE_i\left(t_{dep,i}\right) = SOE_{dep,i} \quad (5)$$

In these equations, $t_{arr,i}$ and $t_{dep,i}$ are the arrival time and specified departure time of prosumer i's EV. $SOE_{arr,i}$ and $SOE_{dep,I}$ are the state of energy upon arrival and the desired state of the EV's battery at the specified departure time. Additionally, the electricity used to charge the EV, cannot be greater than the capacity of the EV charger, $\bar{p}_{ch}$:

$$p_{ch,i} \leq \bar{p}_{ch} \quad (6)$$

The constraints of the optimization problem formulated for the operation of the energy community over the time horizon T are represented by equations (1)-(6). The objective function of the model, to be minimized, expresses the total cost of electricity for the community and is defined in [26]. It is formulated as follows:

$$C = \sum_{t \in T} p_{im}(t)\,(c_{im} + c_n + c_t + c_v) - \sum_{t \in T} p_{ex}(t)\, c_{ex} - \sum_{t \in T} p_{sh}\,(c_{im} - c_{sh}) \quad (7)$$

This equation includes several variables representing different components of the cost of electricity. These variables are defined as follows: c_{im} represents the energy and supply price for imported electricity, c_n represents the network charge, c_t denotes other taxes such as environmental, renewable, and nuclear taxes, c_v represents the value-added tax, and c_{ex} represents the price of exported electricity, typically determined contractually between the supplier and prosumer, such that $c_{ex} \leq c_{im}$. The aggregate electricity export and import of the entire community are represented by $p_{ex}(t)$ and $p_{im}(t)$, respectively, and are calculated as:

$$p_{im}(t) = \sum_{i \in N} p_{im,i}(t) \quad (8)$$

$$p_{ex}(t) = \sum_{i \in N} p_{ex,i}(t) \quad (9)$$

When prosumer i is part of a community, they have the ability to exchange (share) energy with other community members by importing electricity while other prosumers export it. Consequently, prosumer i virtually self-consumes a certain amount of energy. To account for this, member i compensates the other community members by paying a price c_{sh}, typically such that $c_{ex} \leq c_{sh} \leq c_{im}$. The total shared electricity in the community at time t, $p_{sh}(t)$ is calculated as the overlap between the sum of net-exports and the sum of net-imports of all community members:

$$p_{sh}(t) = \min(p_{ex}(t), p_{im}(t)) \quad (10)$$

The problem formulation presented, however, is non-convex because of the complementarity constraint defined in equation (2) and is non-linear due to the min(.) operator in equation (10).

The subsequent section introduces an equivalent formulation using mixed-integer linear programming (MILP).

MILP formulation

In order to derive a MILP formulation of the problem equivalent to the one presented in the previous section, a binary variable, $\varepsilon_i(t)$ is introduced, such that:

$$\varepsilon_i = \begin{cases} 1, & p_{im,i}(t) > 0 \\ 0, & \text{otherwise} \end{cases} \tag{11}$$

Using this variable, the complementarity constraint defined in equation (2) can be replaced using the following two equations, where $\bar{p}_{gr}$ is the upper bound to power export or import to the grid at the point of common coupling for prosumer *i*:

$$p_{im,i}(t) \leq \bar{p}_{gr,i}\varepsilon_i(t) \tag{12}$$

$$p_{ex,i}(t) \leq \bar{p}_{gr,i}\big(1-\varepsilon_i(t)\big) \tag{13}$$

Furthermore, it is necessary to linearize equation (10) so that it can be used in the MILP model. This can be done by introducing a new binary decision variable $\delta(t)$, such that:

$$p_{im}(t) - p_{ex}(t) \leq M_\delta \delta(t) \tag{14}$$

$$p_{ex}(t) - p_{im}(t) \leq M_\delta\big(1-\delta(t)\big) \tag{15}$$

In these equations, $M_\delta > 0$ is a big-M parameter. The constraints given with the following equations enforce that $p_{sh}(t) = \min(p_{ex}(t), p_{im}(t))$:

$$p_{sh}(t) \leq p_{ex}(t) \tag{16}$$

$$p_{sh}(t) \leq p_{im}(t) \tag{17}$$

$$p_{sh}(t) \geq p_{ex}(t) - M_\delta\big(1-\delta(t)\big) \tag{18}$$

$$p_{sh}(t) \geq p_{im}(t) - M_\delta \delta(t) \tag{19}$$

Finally, with the complementarity constraint defined in equation (2) replaced with the constraints defined in equations (11)-(13), and the minimum function defined in equation (10) linearized by equations (14)-(19), the objective function of the model can be used in the form given with equation (7). The optimization problem is solved for each day of the month, over a 24-hour time horizon.

Distributing the shared electricity among community members

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 time step of the billing period, after the billing period ends. In this paper, the repartition key proposed by the virtual net-billing (VNB) method is used. 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 $p_{sh}(t)$. The virtual net-billing method and the repartition key used are described in detail in [26].

CASE STUDY

In order to test the hypothesis outlined in the introduction, a comprehensive case study is conducted using the model presented in the previous section. The case study aims to analyze a hypothetical energy community representing a multi-apartment building consisting of 30 households, a 100 kWp collective photovoltaic (PV) generator, and 10 electric vehicle (EV) chargers. Out of the 30 households, 10 own an electric vehicle, while the remaining 20 households do not have EVs. During the workday, an additional 5 EVs from external owners are charged at the community's EV chargers. The case study focuses on evaluating the community's self-consumption rate and exploring the benefits of including external EV owners in the energy sharing process of the community. The analysis is performed for three different months: February, June, and October, chosen to represent distinct weather conditions and varying energy demands throughout the year. The aim of this analysis is to assess the operation of the energy community across various scenarios and thereby obtain insights into its energy dynamics.

To assess the impact of including external EV owners, the analysis is conducted for two scenarios. In the first scenario, the analysis includes only the energy consumption and generation patterns of the 30 households within the community. This allows for establishing a baseline understanding of the community's self-consumption rate and other energy metrics. In the second scenario, the analysis incorporates the energy consumption of the 5 external EV owners who utilize the community's EV chargers during the workday. The objective is to quantify the benefits achieved by incorporating external EVs through the comparison of results from the two scenarios.

This case study aims to provide evidence regarding the effectiveness of the proposed framework in an actual energy community setting. By examining the energy dynamics of the community throughout different seasons and including external EV owners, we aim to demonstrate the potential benefits of integrating diverse stakeholders to enhance the economic benefits, the self-consumption rate and optimize energy exchange within the community. For the purpose of this case study, the hypothetical energy community is placed in the Netherlands, as it is one of the countries with the highest penetration percentages of EVs [27].

The arrival and departure times of electric vehicles, along with their daily travel distance, are simulated using probability distribution data. The daily travel distances are then used to simulate the EV's SOE at arrival. The used probability distributions are derived from the National Household Travel Survey (NHTS) and are published in [27]. By utilizing this data, realistic and representative EVs data is simulated for the purpose of this case study. For this case study, the battery capacity of all EVs is assumed to be 60 kWh. The average electricity consumption of all vehicles is assumed to be 0.15 kWh/km.

The electricity consumption profiles of the community members are adopted from [28]. The original dataset contains electricity consumption measurements of 200 households from a field study at 15-minute time intervals. From this dataset, electricity consumption data from 30 households for the months of February, June and October is selected. The selected households have an annual electricity consumption between 2500-5000 kWh, which reflects the average electricity consumption of European households (3700 MWh) [29] and should be representative of a large share of households in the Netherlands.

PVGIS [30] is used to calculate the energy produced by the PV generator. Hourly generation profiles for the PV are calculated for the capital city of the Netherlands, using the SARAH-2 solar irradiation data, for the latest available year, assuming optimized azimuth and slope. The time step of the dataset is 1h, therefore, the electricity consumption data are aligned with this time step and averaged to 1-hour values.

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 [31]. The retail electricity price paid by households contains components for the energy and supply c_{im}, network charge c_n, value added tax (VAT) c_v and other taxes denoted as c_t (this includes renewable tax, capacity tax, environmental tax, nuclear taxes and other regulated charges), as defined in [31]. The costs of exported and shared electricity are assumed to be constant and equal to half of c_{im}. This reflects the trend of lower wholesale prices during daytime and should stimulate self-consumption. The results from the case study are presented and discussed in the following section.

RESULTS AND DISCUSSION

This section presents and discusses the outcomes obtained from the case study conducted, as described in the previous section.

Technical and economic benefits

To visualize the contrast between the two scenarios and the impact of the external EVs being charged during the day on the shared energy within the community, daily diagrams for a typical day in each of the analyzed months are presented in Figure 1 – Figure 3. Here, the community's net electricity import is denoted in red, the net export in grey, and the energy shared among community members in blue. On the left is the daily diagram for Scenario 1 – the baseline scenario without external EVs, and on the right is the daily diagram for Scenario 2 – where EVs from external owners are included in the community. This illustrates the differences in energy consumption, generation, and sharing, offering a visual understanding of the energy dynamics of the community under each scenario.

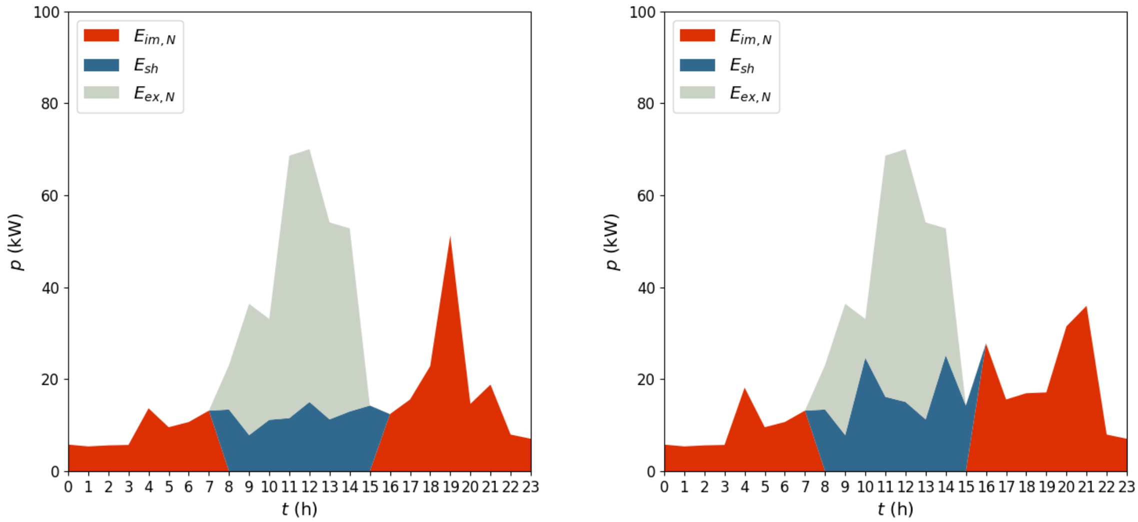

Figure 1. Daily energy balance for a typical day for the energy community in February. Left: Scenario 1, Right: Scenario 2

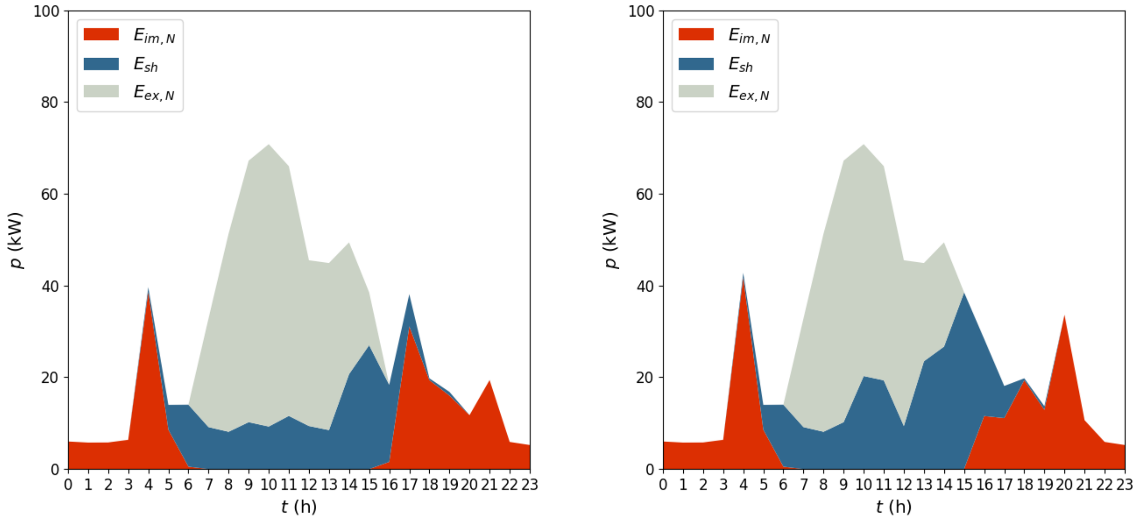

Figure 2. Daily energy balance for a typical day for the energy community in June. Left: Scenario 1, Right: Scenario 2

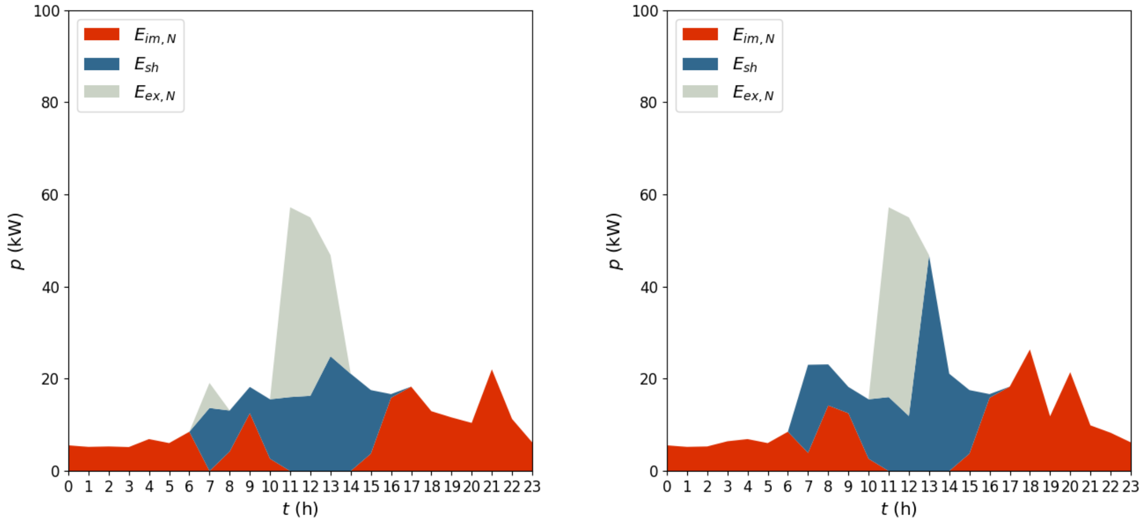

Figure 3. Daily energy balance for a typical day for the energy community in October. Left: Scenario 1, Right: Scenario 2

It is easily concluded that the community's self-consumption rate (SCR) and self-sufficiency rate (SSR), improve by including external EVs during times of high electricity generation by the PV generator. These indicators are calculated and presented in Table 1 for both scenarios for each of the analyzed months.

Table 1. Self-consumption rate (SCR) and Self-sufficiency rate for both analyzed scenarios

	February		June		October	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
SCR	0.56	0.68	0.39	0.45	0.62	0.72
SSR	0.24	0.26	0.51	0.54	0.24	0.25

To evaluate the economic benefits of the community, it is essential to first establish a method for determining the electricity costs between the community and external EV owners. For this, we propose that the price of energy the external owner *i* pays the community, $c_{i,ext}$ be calculated monthly in regards to the ratio of their allocated shared energy $p_{sh,i}$ and the total energy they use to charge their vehicles, using the following expression:

$$C_{ext} = \sum_{t\epsilon T} p_{ch,i}(t) \left(c_{sh} + (c_{im} - c_{sh}) \left(1 - \frac{\sum_{t\epsilon T} p_{sh,i}(t)}{\sum_{t\epsilon T} p_{ch,i}(t)} \right) + c_n + c_t + c_v \right) = \sum_{t\epsilon T} p_{ch}(t)\, c_{i,ext} \quad (20)$$

Using method, the price $c_{i,ext}$ for each external EV owner is such that $c_{ex} \leq c_{i,ext} \leq c_{im}$, thereby ensuring that both the community members and the external EV owners benefit from the arrangement.

The savings for both the energy community and the external EV owners are calculated by comparing the total cost of electricity they would have to pay in both scenarios i.e., the cost that the community and the cost that the external EV owners would have to pay if the external EV owners charge their EVs at the community's chargers and if they charge them separately, paying the regular price to the supplier. The results are presented in Table 2.

Table 2. Monthly collective costs of electricity for the community members and the external EV owners for Scenarios 1 and 2 and the cost reduction for both groups

Month	Scenario 1		Scenario 2		Savings [%]	
	Community members cost [€]	External EV owners cost [€]	Community members cost [€]	External EV owners cost [€]	Community members savings [%]	External EV owners savings [%]
February	1738.07	195.43	1729.73	183.22	0.48%	6.25%
June	1180.42	181.97	1165.60	165.34	1.26%	9.14%
October	1792.82	223.35	1787.48	212.02	0.30%	5.07%

It is apparent that the economic benefits of the community are relatively small. Nevertheless, it should be noted that if the community's members were exempt from taxes and additional charges for the energy they share among themselves, the economic benefits would significantly increase.

Economic benefits under tax and regulated charges exemption

The benefits of tax and regulated charges exemption for the shared energy in energy communities is analyzed in great detail in [32]. To explore this possibility, this case study includes simulations for both scenarios defined previously under exemption of all charges and taxes for the shared energy. For this purpose, the total cost of electricity the community has to pay, and thereby the objective function of the optimization model, is adjusted as follows [32]:

$$C' = \sum_{t\in T} p_{im}(t)\,(c_{im} + c_n + c_t + c_v) - \sum_{t\in T} p_{ex}(t)\, c_{ex} - \sum_{t\in T} p_{sh}\,(c_{im} - c_{sh} + c_n + c_t + c_v) \quad (21)$$

Table 3. Monthly collective costs of electricity for the community members and the external EV owners for Scenarios 1 and 2 and the cost reduction for both groups if they are exempt from taxes and other regulated charges for the shared energy

Month	Scenario 1		Scenario 2		Savings [%]	
	Community members cost [€]	External EV owners cost [€]	Community members cost [€]	External EV owners cost [€]	Community members savings [%]	External EV owners savings [%]
February	1264.47	195.43	1154.53	183.22	8.69%	6.25%
June	214.03	181.97	43.67	165.34	79.60%	9.14%
October	1296.46	223.36	1208.64	212.03	6.77%	5.07%

The obtained results demonstrate a substantial rise in economic benefits for the community when such exemptions are applied. These findings emphasize the potential for significant economic advantages if the community's members are relieved from taxes and additional charges on the energy they share, which warrants further exploration and consideration for policy and regulatory frameworks.

CONCLUSION

This paper presents a non-convex optimization model for an energy community consisting of prosumers, electric vehicles, and electric vehicle chargers, along with its equivalent mixed-integer linear programming (MILP) formulation. The model aims to optimize the economic benefits of the community. The model was used to analyze the possible technical and economic benefits of including external EV owners and allowing them to charge their vehicles using the community’s chargers, with the goal of increasing the local consumption of energy generated by the community’s PV generator. To accomplish this, a case study was conducted, which compared two scenarios: (1) the community with EV chargers exclusively used by community members, and (2) the community allowing external EV owners to access the chargers during high generation periods from the community's PV generator. The study assessed the energy dynamics and economic benefits of each scenario.

The findings from the case study revealed that, initially, the economic benefits of the community were relatively minor, ranging up to 1.26%. However, it is shown that if the community's members are exempted from taxes and additional charges on the energy they share, the economic benefits increase significantly. Simulation results demonstrated a substantial rise in economic gains for both the community and the external EV owners under such exemptions.

Moving forward, further research is needed to investigate additional factors that may influence the optimization model's performance and assess the long-term sustainability and scalability of energy communities. Addressing challenges related to policy, regulation, and economic incentives can significantly enhance the economic benefits and overall viability of such systems. Future work should focus on expanding the presented model to include additional components such as battery energy storage systems (BESS) to enhance energy management and storage capabilities. Such expansions would enable a more comprehensive approach to energy community optimization, incorporating diverse energy sources and storage technologies.

This research should contribute to the growing body of knowledge on energy community optimization, highlighting the importance of integrating renewable energy sources, EVs, and prosumers into a framework that maximizes efficiency, cost-effectiveness, and sustainability.

NOMENCLATURE

Parameter	**Definition**
i	Index of prosumer
N	Set of prosumers in community
n	Maximum number of prosumers in community
T	Set of time-steps in analysed time horizon
t	Time-step
$p_{l,i}(t)$	Electricity consumption by the electrical devices at the premises of prosumer *i* at time *t*
$p_{g,i}(t)$	Electricity generation by prosumer *i* at time *t*
$p_{im,i}(t)$	Electricity imported by prosumer *i* at the point of common coupling at time *t*
$p_{ex,i}(t)$	Electricity exported by prosumer *i* at the point of common coupling at time *t*
$p_{ch,i}(t)$	Electricity used by prosumer *i* to charge their EV's battery at time *t*
$SOE_i(t)$	State of energy of the EV battery of prosumer *i* at time *t*
$\bar{p}_{ch}$	Capacity of EV charger
$\eta_{ch,i}$	Charging efficiency of EV's battery for prosumer *i*
$p_{im}(t)$	Aggregate electricity imported by the entire community at the point of common coupling at time *t*
$p_{ex}(t)$	Aggregate electricity exported by the entire community at the point of common coupling at time *t*
$p_{sh}(t)$	Electricity shared among community members at time *t*
$p_{sh}(t)$	Portion of shared electricity allocated to prosumer *i* at time *t*
$\bar{p}_{gr,i}$	Upper bound to power export or import to the grid at the point of common coupling for prosumer *i*
c_{im}	Electricity tariff for the net-imported electricity
c_n	Network charges
c_v	Value added tax (VAT)
c_t	Price for additional charges (renewable tax, capacity tax, environmental tax, nuclear taxes and other regulated charges)
c_{ex}	Electricity tariff for the net-exported electricity
c_{sh}	Electricity tariff associated with the energy shared in the community
M_δ	Big-M parameter
$\varepsilon_i(t)$, $\delta(t)$	Auxiliary binary decision variables
C	Total electricity costs for the community for the analyzed time horizon
C_{ext}	Total electricity costs for the external EV ownersfor the analyzed time horizon
$c_{i,ext}$	Electricity price at which external EV owners remunerate the community
C'	Total electricity costs for the community for the analyzed time horizon, when tax exemptions for shared energy are enforced

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