Local Energy Communities: The Future of Flexibility?

An Assessment of Coordination Value, Tariff Structures and Benefit Allocation

Master's thesis in Sustainable Energy System

ISABELLE OVESSON

DEPARTMENT OF ELECTRICAL ENGINEERING
Chalmers University of Technology
Gothenburg, Sweden 2026
www.chalmers.se

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Supervisor: Araavind Sridhar, Department of Electrical Engineering
Examiner: David Steen, Department of Electrical Engineering

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Department of Electrical Engineering
Division of Electric Power Engineering
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

The increasing integration of distributed energy resources and rising electricity prices has created new opportunities for local energy communities (LECs) to improve self-consumption, reduce peak demand, and lower electricity costs. This thesis investigates how electricity costs can be reduced within LECs, how different electricity tariffs and spot price variations influence the economic outcomes, and how the resulting savings can be fairly distributed among community members. A simulation-based analysis was conducted using residential and commercial load profiles from Gothenburg, Sweden. Different community configurations, tariff structures, and allocation methods were evaluated and compared to individual operation, with a focus on shared photovoltaic (PV) generation and battery energy storage systems (BESS). The operational analysis was initially performed for two-household configurations to evaluate how different flexibility resources influence LEC performance. The results show that the largest economic benefits were achieved in communities consisting of members with complementary flexibility resources and load profiles, increasing the opportunities for local energy sharing and coordinated operation. The highest surplus reduction reached 3486.6 SEK (7%), while the largest peak reduction achieved was 3.92 kW (20%). The coordinated operation within the LEC significantly increased self-consumption, with levels reaching up to 100% in some cases, corresponding to improvements of up to 67% percentage points compared to individual operation. The evaluation of tariff structures showed that peak-based tariffs create the strongest economic incentives for cooperation within the LEC, whereas spot price variations had a smaller influence on the overall benefits. To evaluate the distribution of economic savings, larger 10-member communities were analyzed for the allocation analysis. The results show that the selected allocation method significantly affects how benefits are shared among participants. Among the evaluated methods, the balanced allocation approach appeared to provide the best trade-off between fairness and incentives for flexibility contributions. Overall, the study highlights the potential of LECs to support a more flexible and cost-efficient electricity system while emphasizing the importance of tariff design and fair benefit-sharing mechanisms for successful community participation.

Keywords: Local Energy Communities, Battery Energy Storage Systems, Photovoltaics, Self-Consumption, Peak Demand Reduction, Electricity Tariffs, Energy Flexibility

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Isabelle Ovesson, Gothenburg, June 2026

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

CEC	Citizen Energy Community
DSO	Distribution System Operator
EMS	Energy Management System
KPI	Key Performance Indicator
LEC	Local Energy Community
PV	Photovoltaic
REC	Renewable Energy Community
SOC	State of Charge
TSO	Transmission System Operator

Nomenclature

Below is the nomenclature of indices, sets, parameters, and variables that have been used throughout this thesis.

Indices

i	Household index
t	Time index (hourly time step)

Parameters

p_t	Electricity spot price at time t
c^{cert}	Additional energy-related fee
c^{comp}	Compensation for exported electricity
c^{trans}	Transmission fee for imported electricity
c^{health}	Compensation for exported electricity
c^{peak}	Peak power fee
c^{tax}	Energy tax
C^{sub}	Fixed subscription fee
$L_{i,t}$	Electricity demand of household i at time t
$PV_{i,t}$	PV generation of household i at time t
E_i	Battery capacity
$P_i^{\max}$	Maximum battery charging/discharging power
η	Battery efficiency
r	Time resolution factor
M	Large constant

Variables

P_t^{im}	Power imported from the grid at time t
P_t^{ex}	Power exported to the grid at time t
$P_{i,t}^{\text{ch}}$	Battery charging power
$P_{i,t}^{\text{ds}}$	Battery discharging power
$SOC_{i,t}$	State of charge of the battery
$B_{i,t}^{\text{ch}}$	Binary variable for charging/discharging
B_t^{im}	Binary variable for import/export
$P_{\text{max}}^{\text{month}}$	Maximum monthly demand
C^{tot}	Total electricity cost
C^{sup}	Electricity supply cost
C^{DSO}	Grid-related cost
C^{tax}	Tax cost

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1

Introduction

The ongoing transition of the energy system is driven by the need to reduce greenhouse gas emissions and decrease dependence on fossil fuels. To achieve climate targets established by the European Union and national governments, large parts of society are becoming increasingly electrified, particularly within the transport and industrial sectors. At the same time, renewable energy sources such as wind and solar power are expected to play a central role in future electricity systems. In Sweden, increasing electrification combined with the expansion of renewable electricity generation is expected to significantly increase electricity demand during the coming decades [2]. The growing focus on energy security and resilience has further emphasized the importance of reliable electricity systems capable of managing future challenges [3]. The increasing share of renewable energy generation and the rapid growth in electricity demand create several challenges for the electricity system. Renewable energy production from wind and solar power is weather-dependent and intermittent, making it more difficult to balance electricity supply and demand. At the same time, electrification of transport, industry, and heating contributes to higher peak loads and increased stress on local electricity grids. According to Svenska kraftnät, future electricity systems will require significantly greater flexibility in both production and consumption to maintain grid stability and avoid congestion problems [2].

To address these challenges, distributed energy resources such as photovoltaic (PV) systems, battery energy storage systems (BESS), electric vehicles, and flexible electricity demand are becoming increasingly important. These technologies enable consumers to actively participate in the electricity system by generating, storing, and managing electricity locally [4, 5]. Their growing deployment is expected to contribute to increased flexibility, improved utilization of renewable energy, and more efficient operation of electricity networks.

Local Energy Communities (LECs) have emerged as a potential approach for organizing and coordinating distributed energy resources at the local level. LECs enable households, municipalities, companies, and other local actors to collectively produce, consume, store, and share electricity within a community [6, 7, 8]. By facilitating local cooperation, LECs may contribute to improved utilization of renewable energy resources, increased local flexibility, and reduced reliance on the wider electricity grid. In addition to their technical role, LECs are also considered a means of increasing citizen participation in the energy transition. By involving local actors more directly in energy production and energy-related decision-making, LECs can support the broader transition toward a more decentralized and sustainable energy system [9]. However, the implementation of energy communities remains associated with challenges related to regulation, governance, market integration, and operational design [10]. As electricity demand continues to increase and renewable generation becomes a larger part of the energy mix, understanding how local flexibility resources can be coordinated within LECs becomes increasingly important. This is particularly relevant in Sweden, where growing electricity demand, transmission constraints, and the need for additional flexibility place increasing pressure on the electricity system [2].

1.1 Aim and Reaserch Questions

The aim of this thesis is to analyze the impact of formation of LEC in a Swedish residential context with following questions:

- Who benefits the most from participating in a LEC, and under which system conditions?
- How do different market mechanisms and tariff structures influence the value of coordination within the LEC?
- How do different allocation mechanisms (e.g., equal sharing, contribution-based, and hybrid approaches) affect the distribution of economic benefits between participants?

1.2 Limitations

Several limitations should be considered when interpreting the results of this study. The analyzed buildings were based on standardized load profiles, meaning that variations in occupant behavior and electricity consumption were not represented. In addition, all members within the LEC were assumed to share a common connection point, which simplifies the modeling of local energy sharing.

The study was further limited to Swedish conditions, specifically based on assumptions relevant to Gothenburg, including electricity prices and regulatory conditions. Finally, only PV systems and BESS were considered as flexibility resources, while other technologies such as electric vehicles, heat pumps, and demand response were excluded.

2

Theory

This section introduces the theoretical concepts relevant to this thesis, with a focus on LECs. The purpose of the section is to describe how LECs are commonly understood in the literature, how they are structured, and how they are framed from a regulatory perspective.

2.1 Local Energy Communities

LEC, often referred to as energy communities, are generally described as locally organized and legally recognized collaborations in which citizens, small businesses, public actors, and other organizations jointly produce, manage, share, and consume energy [3, 4]. They enable collective and citizen driven energy actions and are considered an important component of the clean energy transition in Europe [5]. A central idea is that energy related activities are coordinated at the local level, with a focus on creating local economic, environmental, and social value rather than only individual profit [3]. Energy communities typically involve local renewable energy production, shared use of electricity among members, and some form of joint ownership or governance structure [3, 4]. Through collective organization, members can invest in and operate distributed energy resources including PV systems, battery storage, and other flexible technologies. Acting as a collective entity also allows energy communities to participate in energy markets, flexibility services, and demand response activities that would often be inaccessible to individual small actors [4, 5]. In the technical and regulatory literature, LECs are described as a complement to the centralized energy system, where coordinated local operation adds an intermediate layer between individual users and the wider electricity system. By coordinating distributed energy resources and flexible demand, energy communities can improve local resource utilization, support renewable energy deployment, enable energy sharing and collective self consumption, and contribute to reducing peak demand and local grid congestion [6, 7]. Figure 2.1 illustrates an example configuration of a LEC. Within the community, prosumers and consumers interact through local energy exchange and coordinated operation of distributed energy resources such as PV systems and battery storage. An aggregator and an energy management system (EMS) coordinate the operation of the community and enable interaction with the distribution grid and the electricity market. Through this coordinated operation, the community can optimize local energy use, share flexibility between members, and participate collectively in external energy and flexibility markets.

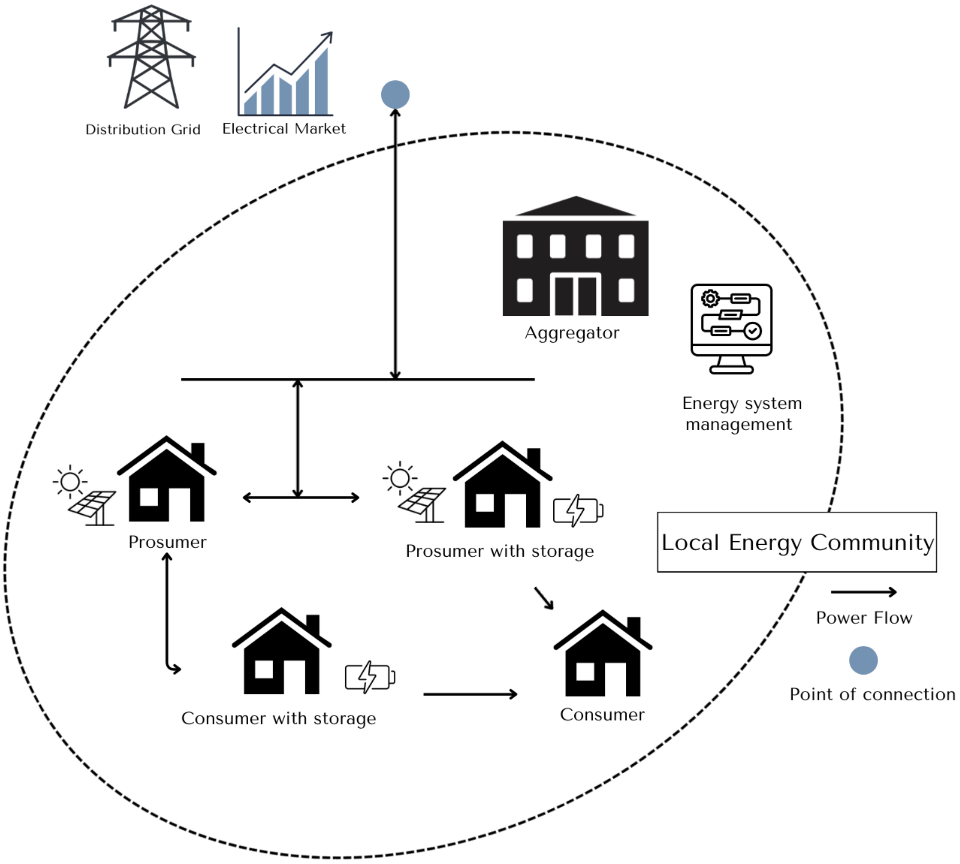

Figure 2.1: Example configuration of a LEC with prosumers, consumers, energy storage, an aggregator, and an EMS connected to the distribution grid and the electricity market.

Under EU legislation, energy communities are defined as legal entities with open and voluntary participation that enable members to produce, consume, store, share, and in some cases sell energy collectively across different parts of the energy value chain [4]. Two main categories are recognized: Citizen Energy Communities (CECs) and Renewable Energy Communities (RECs), each with distinct regulatory characteristics [5], as summarized in Table 2.1. CEC may involve various generation technologies and may operate across different energy sectors. Participation is open to natural persons, local authorities, and small enterprises, which must exercise effective control either individually or collectively. Unlike REC, geographical proximity is not a strict requirement for participation, and a wider range of entities, including municipal companies and non governmental organizations, may be involved under appropriate governance structures [5]. REC, by contrast, are specifically centered on renewable energy activities and may operate in both the electricity and heating sectors, provided the energy source is renewable. Participation is limited to natural persons, small and medium sized enterprises, and local authorities, and effective control must be exercised by actors located in proximity to the community owned renewable energy project. RECs are also required to maintain autonomy, ensuring balanced and democratic decision making among participating members. Figure 2.2 illustrates the difference between CEC and REC, showing that CECs allow more flexible participation while RECs are more locally constrained and restricted.

Table 2.1: CEC vs REC

	CEC	**REC**
Energy type	Any electricity activity	Only renewable energy
Who can control it	Citizens, SMEs, local authorities	Same actors, but must be locally connected
Location rule	No strict proximity requirement	Control must be exercised near the renewable project
Main aim	Community benefits	Local renewable energy benefits

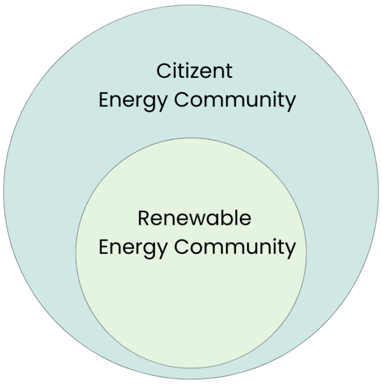

Figure 2.2: Illustration of the relationship between CEC and REC (REC), where REC can be viewed as a more specific subset focused exclusively on renewable energy activities.

Energy communities can have different legal forms such as cooperatives or companies, and they are recognised as legal actors that can take part in energy markets. This includes producing, storing, and sharing electricity. However, the exact design and implementation of energy communities are defined at the national level, meaning that rules, requirements, and available support can vary between countries. This makes it important to clearly define how energy communities are structured and regulated in each specific context [5, 8].

2.1.1 Actors in Local Energy Communities

LECs involve several actors with different roles, responsibilities, and interests within the local energy system. The central actors are typically households and prosumers, but the operation and economic performance of LECs are also influenced by external actors such as aggregators, distribution system operators (DSOs), and transmission system operators (TSOs).

Households form the core participants of a LEC and may act either as consumers or prosumers by owning distributed energy resources such as PV systems, batteries, EVs, or flexible heating assets [5]. In many cases, households remain owners of their distributed energy assets while participating in collective energy sharing and optimization. Their willingness to participate is strongly influenced by how costs, savings, and revenues are allocated within the community, making internal allocation mechanisms an important aspect of LEC design [5].

To enable coordination and market participation beyond the local level, LECs may interact with aggregators, which act as intermediaries between the community and external electricity markets. Aggregators combine and coordinate flexibility from multiple participants, enabling access to services such as balancing and flexibility markets that would otherwise be inaccessible to individual households [9]. Depending on the market structure, aggregators may consist of existing electricity suppliers or independent third-party actors. By procuring flexibility from energy communities and offering it to TSOs and DSOs, aggregators support both the economic operation of LECs and the integration of distributed energy resources into the wider electricity system [9].

The operation of LECs is also strongly influenced by the DSO, which is responsible for operating and maintaining the local electricity grid [10]. Although the DSO does not participate directly in the community, tariff structures and grid constraints significantly affect the economic benefits of local energy sharing. In particular, the treatment of internal electricity exchanges and network charges can strongly influence the incentives for participation and the overall value creation within the community [10].

At a higher system level, the TSO is responsible for maintaining the stability and reliability of the high-voltage transmission grid. While TSOs do not interact directly with individual LECs, aggregated flexibility from LECs may contribute to balancing services and other system-support functions. In this way, LECs can support both TSOs and DSOs through the provision of flexibility services that contribute to secure and reliable grid operation [9]. In cases where such services are remunerated through electricity markets, external revenues may indirectly flow back to the community through aggregators or other market actors.

2.1.2 Technologies in Local Energy Communities

LECs rely on a combination of technologies that enable local electricity generation, flexibility, and coordination between participants. Together, these technologies make it possible to reduce costs, increase self-consumption, and improve the overall efficiency of the energy system.

PV systems are a central technology in many LECs, enabling local renewable electricity generation through installations such as rooftop PV systems [11]. However, PV production is inherently variable, as it depends on weather conditions and follows both daily and seasonal patterns [11]. As illustrated in Figure 2.3 shows the simulated PV generation for a 5 kWp residential rooftop system located in Gothenburg, Sweden (57.707°N, 11.967°E), consisting of south-facing crystalline silicon (c-Si) modules mounted at a tilt angle of 35° with assumed system losses of 14%. PV generation is significantly higher during spring and summer months, while production is considerably lower during winter. This variability creates both challenges and opportunities for balancing local supply and demand within the community [11].

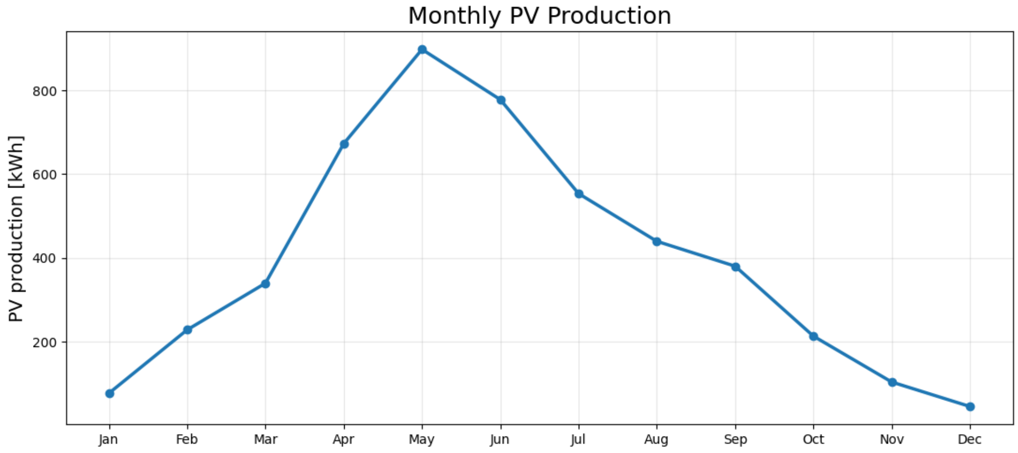

Figure 2.3: Monthly PV production.

To manage this variability, BESS play an important role by storing surplus electricity during periods of high PV production and discharging it when demand is higher [12]. In this way, BESS increase system flexibility, improve self-consumption, and contribute to a more efficient utilization of locally generated electricity [12]. In addition, battery storage can reduce peak loads and support grid stability, making it valuable for both economic optimization and system-level benefits [12].

Flexible loads, such as EV charging and heat pumps, can further enhance flexibility by shifting electricity consumption in time to periods with lower electricity prices or high local generation. Heat pumps are particularly relevant in LECs due to their interaction with both local renewable generation and seasonal electricity demand. Studies have shown that although heat pumps combined with PV systems can improve the yearly energy balance and increase the utilization of renewable electricity, they may also substantially increase winter peak electricity demand due to higher heating needs [13].

EVs are also expected to play an increasingly important role in future LECs, as the integration of electric mobility with renewable-based local energy systems is considered an important component of sustainable urban energy systems. In addition to introducing new electricity demand, coordinated EV charging can provide flexibility and support the efficient utilization of local renewable generation, microgrids, and storage systems [14]. Although EVs and heat pumps are not explicitly included in the simulations in this study, they are relevant for understanding the broader flexibility potential and future development of LECs.

The coordination of these technologies is enabled by smart meters and EMS, which monitor and control energy flows within the community. EMS use information and communication technologies, often referred to as smart energy solutions, to coordinate the operation of technologies such as PV systems, battery storage, and flexible loads [12]. Through this, energy flows can be optimized across generation, storage, and consumption, enabling more cost-efficient operation and improved system performance. In more advanced setups, EMS may also support participation in external electricity markets through aggregators, enabling LECs to create value both locally and at system level [12].

2.2 LEC in Sweden

Although the EU provides formal definitions of energy communities, their national implementation differs between countries. Sweden has not introduced a specific legal definition despite earlier proposals from the Swedish Energy Markets Inspectorate (Energimarknadsinspektionen) The government argued that existing legislation does not prevent the formation of energy communities, although the concept is still used broadly in practice beyond the strict EU definitions.

According to a report by the Swedish Energy Agency (Statens energimyndighet)[1], energy sharing in Sweden is mainly possible through three different approaches: complementary networks, private/internal networks, and virtual sharing. The legal possibilities differ between these alternatives.

A complementary network, shown in Figure 2.4, enables electricity sharing between buildings or properties through internal power lines while maintaining connections to the public electricity grid. In such systems, locally shared electricity can reduce the use of the public grid and lower certain grid-related costs and charges. This type of arrangement can support increased self-consumption and improve the local utilization of renewable electricity within the energy community [1].

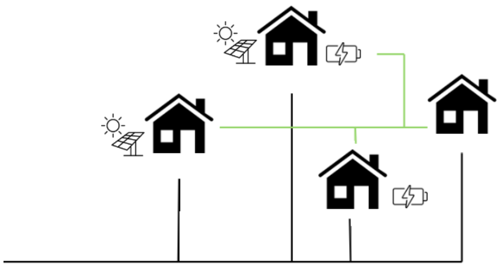

Figure 2.4: Complementary electricity-sharing network between households. Black lines indicate the DSO distribution network, and green lines indicate the internal local network. Figure inspired by [1].

Private or internal networks, illustrated in Figure 2.5, consist of several users sharing a common connection point to the public electricity grid. Such arrangements can reduce grid-related costs and enable locally produced electricity to be shared more efficiently within the community. Since electricity exchanged internally does not necessarily pass through the public grid, the use of local renewable generation can be increased while reducing the reliance on external electricity supply [1].

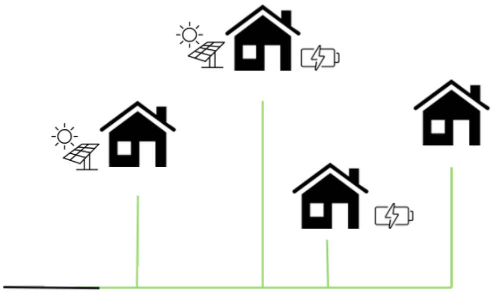

Figure 2.5: Private electricity-sharing network between households. Black lines indicate the DSO distribution network, and green lines indicate the private local network. Figure inspired by [1].

Virtual sharing refers to electricity sharing through the existing public electricity grid using metering and settlement calculations rather than physical internal cables, as illustrated in Figure 2.6. This approach enables participants to share locally generated electricity without requiring additional physical infrastructure, while still maintaining individual grid connections and the freedom to choose electricity suppliers. However, since electricity transferred through the public grid remains subject to grid tariffs and taxes, the economic benefits of virtual sharing may be lower compared to more locally integrated solutions [1].

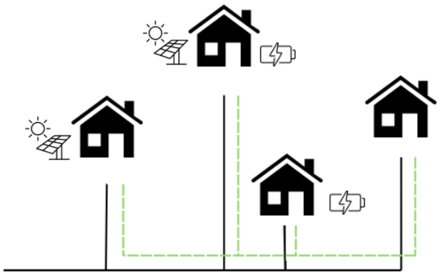

Figure 2.6: Virtual electricity sharing between households. Black lines indicate the DSO distribution network, and green lines indicate virtual electricity-sharing connections. Figure inspired by [1].

2.3 Electricity Markets and Economic Framework

The economic outcome of a LEC is not determined only by how well households coordinate internally. It is also shaped by the external market environment in which the community operates. In particular, time-varying electricity prices, network tariff structures, and regulatory charges define the economic signals that influence both operational decisions and the distribution of costs and benefits.

2.3.1 Cost Structure

The economic performance of a LEC is strongly influenced by electricity market conditions. Time-varying electricity prices, network tariffs, taxes, and regulatory charges determine the financial value of electricity imports, exports, and locally shared energy. Together, these factors shape the incentives for different operational strategies and ultimately affect the community's overall economic performance. Electricity trading in the Nordic region is organized through Nord Pool, where electricity is primarily traded in the day-ahead market. Market participants submit bids for each hour of the following day, and market prices are determined based on the balance between supply and demand. Since electricity cannot be stored economically at a large scale within the transmission system, generation and consumption must continuously be balanced, making electricity prices highly dependent on weather conditions, demand levels, fuel prices, and the availability of generation resources [15].

Sweden is divided into four bidding zones (SE1–SE4), shown in Figure 2.7. The division reflects transmission constraints within the national grid and allows electricity prices to vary geographically. Northern Sweden (SE1 and SE2) is characterized by a surplus of hydropower generation and generally experiences lower electricity prices, whereas southern Sweden (SE3 and SE4), where demand is higher and transmission capacity is limited, often exhibits higher price levels. The bidding zone structure enables congestion within the transmission system to be reflected in market prices and provides signals for efficient operation and investments in generation and grid infrastructure [2].

Figure 2.7: The Nordic synchronous area, including Sweden's four electricity bidding zones [2].

In addition to geographical variations, electricity prices also vary significantly over time. Figure 2.8 illustrates the hourly spot price in Sweden during 2023. Large fluctuations can be observed throughout the year, with periods of both low and high prices. Price volatility is driven by seasonal changes in demand, weather-dependent renewable generation, fuel prices, and transmission constraints. In particular, the increasing share of variable renewable energy sources contributes to greater price variability.

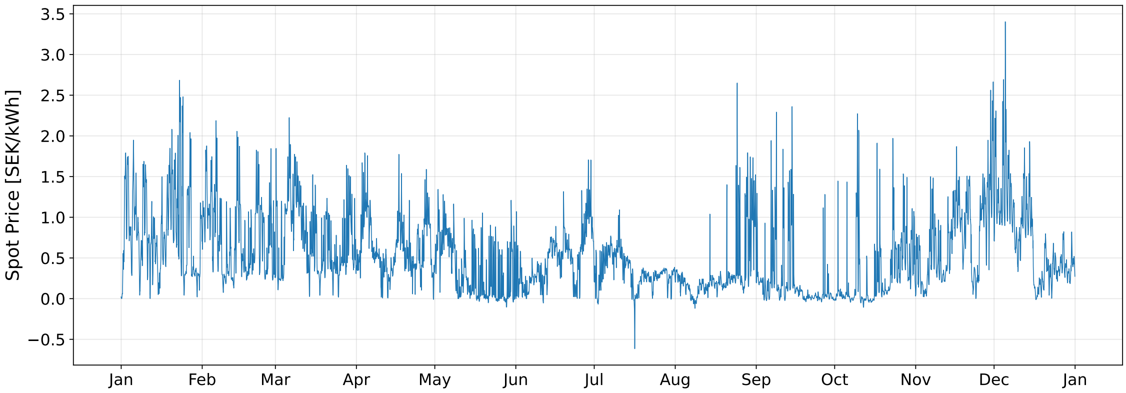

Figure 2.8: Annual spot electricity prices in Sweden during 2023.

The temporal variation in electricity prices creates economic incentives for flexible resources, such as battery energy storage systems and coordinated demand response, to shift electricity consumption from periods with high prices to periods with lower prices. Consequently, spot price variability constitutes an important external factor affecting the operation and economic performance of local energy communities.

This aspect is particularly relevant for the optimization framework employed in this thesis, where electricity prices are incorporated as part of the objective function. Electricity market prices alone do not determine the economic performance of local energy communities. The final outcome also depends on how network tariffs and grid charges are structured, since these directly affect incentives for coordination and peak reduction. Network tariffs are regulated charges paid for the use of the distribution grid. Their purpose is to recover the costs of operating, maintaining, and expanding the network, and they typically represent a substantial share of the total end-user electricity price [16]. To capture these effects in a more detailed way, different tariff components can be considered separately, as they influence costs through different mechanisms.

Table 2.2 summarizes the electricity cost components considered in this study and their corresponding base values. The values represent a reference tariff structure and are later varied in the model to investigate how different economic incentives, such as peak-shaving, affect the operation of the local energy community.

Table 2.2: Cost components and base values used in the model.

Component	Description	Base value
Subscription fee	Fixed monthly charge for grid access	205 SEK/month [17]
Transmission tariff	Energy-based network charge applied to imported electricity	0.23 SEK/kWh [17]
Peak power tariff	Charge based on the average of the three highest hourly average power demands each month	49 SEK/(kW·month) [17]
Energy tax	Government tax on electricity consumption	0.36 SEK/kWh [18]
Energy certificate	Policy-related charge supporting renewable electricity production	0.02 SEK/kWh [19]

The subscription fee represents a fixed monthly charge paid by consumers for access to the distribution grid. Since this cost is independent of electricity consumption, it does not influence the operational optimization but contributes to the total annual electricity cost. The transmission fee is an energy-based network charge applied to each kilowatt-hour imported from the grid. Consequently, reducing grid imports through local generation, battery storage, or coordinated operation decreases the transmission cost and increases self-consumption within the local energy community. The peak power tariff is a power-based charge determined by the average of the three highest hourly average power demands during each month. Unlike energy-based charges, this component depends on the magnitude of peak demand rather than the total amount of energy consumed. As a result, it creates an economic incentive to avoid simultaneous high loads and promotes coordinated operation and battery utilization for peak shaving. In this study, the magnitude of the peak power tariff is varied to investigate how stronger or weaker peak-based incentives influence the performance of the local energy community. The energy tax is a government-imposed charge proportional to electricity consumption. Similarly, the energy certificate charge is a policy-related surcharge intended to support renewable electricity generation. Both components are proportional to imported electricity and therefore contribute to the variable cost of grid consumption. Together, these cost components determine the total electricity cost faced by households and define the economic signals that influence the operation of the local energy community. In particular, the peak power tariff and time-varying electricity prices provide incentives for flexibility and coordinated energy management, which are central aspects investigated in this thesis.

2.3.2 Revenue Streams

In addition to reducing electricity costs internally, local energy communities may create economic value by offering flexibility to external electricity markets. The European electricity market design increasingly recognises the role of active consumers, storage, and demand-side flexibility in supporting system stability and integrating renewable electricity [20]. This creates opportunities for distributed resources to contribute beyond the local community boundary.

Potential revenue streams may arise from participation in flexibility or ancillary service markets, where adjustments in consumption, generation, or storage operation are used to support balancing and grid reliability. Since individual households are typically too small to participate directly, aggregators can play an important role by pooling flexibility from multiple actors and offering it as a combined resource [20].

Through aggregation, local energy communities may access external revenues in addition to internal cost savings. These revenues add another dimension to the community's economic performance and may influence both the total benefits and how they are allocated among members.

3

Methods

This chapter presents the methodology used to evaluate the performance of LECs.

3.1 Optimization Model Overview

The optimization framework developed in this thesis is formulated as a mixed-integer linear programming (MILP) problem and builds upon the methodology proposed in [21]. Figure 3.1 provides an overview of the methodological framework used in this study. Based on load demand, PV generation, BESS specifications, electricity prices, and tariffs, a mixed-integer linear programming (MILP) model is used to analyze individual and coordinated operation in terms of cost savings, peak reduction, and benefit allocation.

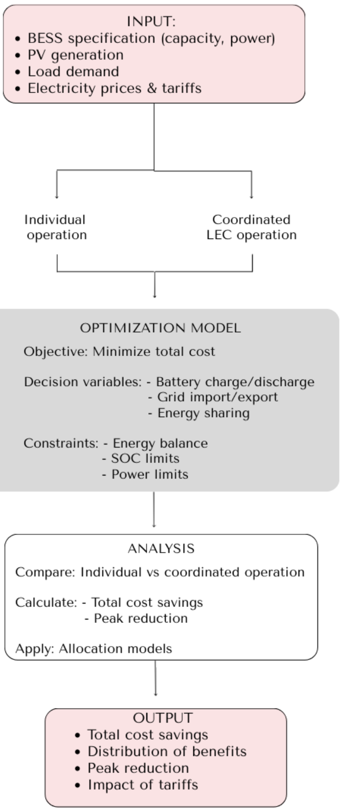

Figure 3.1: Overview of the methodological framework used in this study.

Purpose of the model

The optimization model is formulated as a mixed-integer linear programming (MILP) problem. It is implemented in Python using Pyomo and solved using the Gurobi optimizer. The model is used to simulate system operation on an hourly basis. At each time step, it determines whether households should purchase electricity from the grid or shift consumption over time, for example by utilizing battery storage when available. The model optimizes charging and discharging decisions based on electricity prices and system conditions, as well as import from and export to the grid. Furthermore, the model is used to compare individual household operation with coordinated operation within a LEC, in order to evaluate the economic value of cooperation. The objective of the model is to minimize the total electricity cost over the optimization horizon.

Key input parameters

The optimization model relies on a set of key input parameters that describe the technical and economic conditions of the system. These parameters are provided as input to the model and define the environment in which the optimization is performed.

The main input parameters are:
- time-varying electricity spot prices, p_t, which determine the cost of buying electricity and the revenue from selling excess electricity,
- Grid tariff parameters include both energy-based charges and peak power tariff. Because the peak charge is based on the monthly peak demand, the optimization keeps track of the highest peak reached so far within the month and penalizes increases in peak demand. The final peak costs are calculated and allocated after the optimization,
- household electricity demand, $L_{i,t}$, representing the consumption profile of each household i over time steps t, where i denotes the household and t the time step.
- PV generation, $PV_{i,t}$, describing locally produced electricity,
- battery characteristics, including energy capacity (E^{cap}), maximum charging and discharging power (P_t^{ch} and P_t^{ds}) and round-trip efficiency (η).

These inputs together define the operational constraints and economic signals that guide the optimization model.

Decision variables

The decision variables represent the operational choices made by the optimization model at each time step. They define how electricity flows within the system and between the households and the grid.

The model determines:
- how much electricity to import from or export to the grid (P_t^{im} and P_t^{ex}),
- when and how much to charge or discharge the battery ($P_{i,t}^{\text{ch}}$ and $P_{i,t}^{\text{ds}}$),

- the battery state of charge (SOC) over time ($SOC_{i,t}$).

These variables are optimized in order to minimize total system costs, while respecting all technical and operational constraints.

The optimization model does not explicitly model how electricity is allocated between individual households. Instead, the system is optimized at an aggregated level, where total electricity demand, generation and storage are considered jointly, as illustrated in Figure 3.2. As a result, the model implicitly assumes perfect coordination and sharing of resources within the system. The distribution of costs and benefits between households is therefore not determined within the optimization, but is analyzed separately using different allocation mechanisms.

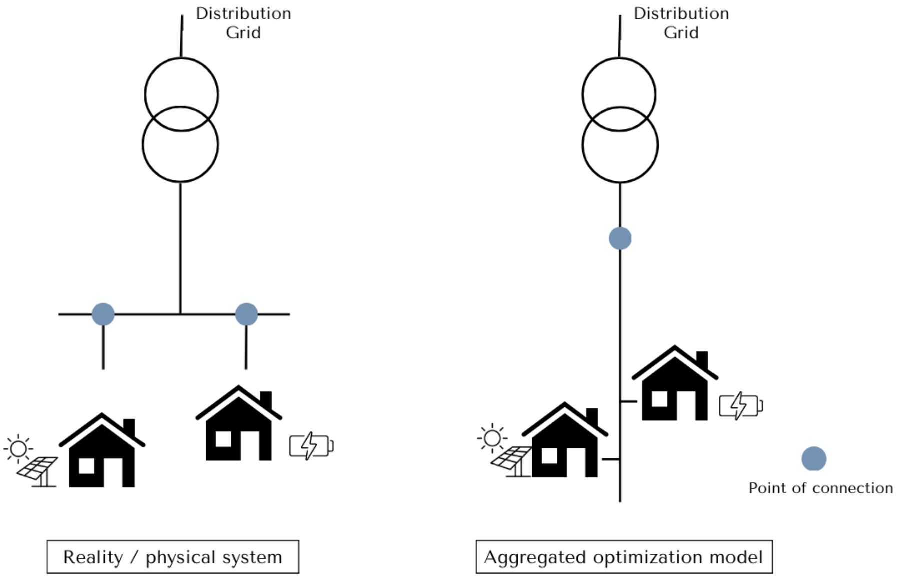

Figure 3.2: Illustration of the physical residential system (left) and the aggregated system representation used in the optimization model (right).

Objective function

The objective of the optimization model is to minimize the total electricity cost over the entire optimization horizon. This total cost consists of three main components: the cost of electricity supply, grid-related costs and taxes.

$$\min\ C^{\text{tot}} = C^{\text{sup}} + C^{\text{DSO}} + C^{\text{tax}} \tag{3.1}$$

Here, C^{tot} denotes the total electricity cost, C^{sup} the supplier cost, C^{DSO} the grid-related cost and C^{tax} the tax cost.

The supplier cost, C^{sup}, represents the net cost of buying and selling electricity on the market. It accounts for both the cost of imported electricity and the revenue from exported electricity:

$$C^{\text{sup}} = \sum_{t} \frac{P_t^{\text{im}} \left(p_t + c^{\text{cert}}\right) - P_t^{\text{ex}} \left(p_t + c^{\text{cert}} + c^{\text{comp}}\right)}{r}. \tag{3.2}$$

Here, P_t^{im} and P_t^{ex} denote the imported and exported electricity at time step t, respectively. The parameter p_t represents the electricity spot price at time t, c^{cert} an additional energy-related fee and c^{comp} the compensation received for exported electricity. The parameter r is the time resolution factor, converting power (kW) into energy (kWh).

The grid-related cost, C^{DSO}, includes both fixed and variable components. It consists of a fixed subscription fee, energy-based transmission fees and a peak power fee:

$$C^{\text{DSO}} = C^{\text{sub}} + \sum_{t} \frac{P_t^{\text{im}} c^{\text{trans}} - P_t^{\text{ex}} c^{\text{health}}}{r} + c^{\text{peak}} P_{\text{month}}^{\text{max}} \cdot X. \tag{3.3}$$

Here, C^{sub} denotes the fixed subscription fee. The parameters c^{trans} and c^{health} represent the transmission fee for imported electricity and the compensation or incentive for exported electricity, respectively. The parameter c^{peak} denotes the peak power fee and $P_{\text{month}}^{\text{max}}$ is the maximum monthly net power demand. The factor (X) is introduced to account for the fact that the peak effect fee is determined by the monthly peak demand rather than by the cost or revenue of a single day. During the optimization, increasing the peak demand may appear profitable if only the current day is considered. However, a higher peak can increase the peak charge for the entire month. Therefore, a scaling factor (X) is applied to the peak-related term to discourage small increases in peak demand that may lead to higher monthly costs. In practice, this means that the optimization only accepts an increase in peak demand when the expected economic benefit is sufficiently large to outweigh the additional peak cost. The factor (X) thus provides a more conservative representation of the monthly peak tariff within the daily optimization framework. In this study, a value of (X=5) is selected.

The transmission fee is applied to imported electricity, while exported electricity may receive a compensation or incentive. In addition, the peak power fee depends on the maximum monthly power demand, which creates an incentive to reduce peak loads.

Finally, the tax cost, C^{tax}, is composed of a value-added tax applied to the total electricity and grid costs, as well as an energy tax based on net electricity consumption:

$$C^{\text{tax}} = 0.25 \left(C^{\text{sup}} + C^{\text{DSO}}\right) + 1.25\, c^{\text{tax}} \sum_{t} \frac{P_t^{\text{im}} - P_t^{\text{ex}}}{4}. \tag{3.4}$$

Together, these cost components define the economic signals that guide the optimization. By minimizing the total cost, the model determines when it is beneficial to import electricity, utilize local generation, charge or discharge the battery and export excess energy.

The parameter c^{cert} represents an additional energy-related fee, such as an energy certificate cost, applied per unit of electricity. The parameter c^{comp} denotes the compensation received for exported electricity, representing additional revenues beyond the spot price. The parameter c^{trans} is the transmission fee, which reflects the cost of using the electricity grid for imported energy, while c^{health} represents a transmission-related incentive for exported electricity. Furthermore, c^{peak} is the peak power fee, which is based on the maximum power demand during the billing period and creates an incentive to reduce peak loads. Finally, C^{sub} denotes a fixed subscription fee charged independently of electricity consumption.

Constraints

The optimization model is subject to a set of technical and operational constraints that describe the physical limitations of the system and ensure that all decisions are feasible in practice.

Power balance
At each time step, total import minus total export must equal the net power demand of the system:

$$P_t^{\text{im}} - P_t^{\text{ex}} = \sum_i P_{i,t}. \tag{3.5}$$

For each household i, the net household power is defined as

$$P_{i,t} = L_{i,t} - PV_{i,t} - P_{i,t}^{\text{ds}} + P_{i,t}^{\text{ch}}. \tag{3.6}$$

Battery dynamics
The battery SOC evolves according to

$$SOC_{i,t} = SOC_{i,t-1} + \frac{\eta P_{i,t}^{\text{ch}} - P_{i,t}^{\text{ds}}/\eta}{E_i}, \qquad t > 1 \tag{3.7}$$

and for the first time step

$$SOC_{i,1} = SOC_{i,0} + \frac{\eta P_{i,1}^{\text{ch}} - P_{i,1}^{\text{ds}}/\eta}{E_i}, \tag{3.8}$$

where E_i is the battery capacity and $\eta = 0.93$ is the assumed battery efficiency.

Battery operating limits
The SOC is constrained by

$$0.2 \leq SOC_{i,t} \leq 1, \tag{3.9}$$

and charging/discharging power is limited by the battery power rating:

$$0 \leq P_{i,t}^{\text{ch}} \leq B_{i,t}^{\text{ch}} P_i^{\max}, \tag{3.10}$$

$$0 \leq P_{i,t}^{\mathrm{ds}} \leq \left(1 - B_{i,t}^{\mathrm{ch}}\right) P_i^{\max}, \tag{3.11}$$

where $B_{i,t}^{\mathrm{ch}} \in \{0, 1\}$ ensures that the battery cannot charge and discharge simultaneously.

Grid import/export limits
Grid import and export are constrained as

$$0 \leq P_t^{\mathrm{im}} \leq M B_t^{\mathrm{im}}, \tag{3.12}$$

$$0 \leq P_t^{\mathrm{ex}} \leq M \left(1 - B_t^{\mathrm{im}}\right), \tag{3.13}$$

where M is a sufficiently large constant. This prevents simultaneous import and export. In the implementation, the upper bound is set sufficiently high such that no effective grid capacity limit is imposed.

Peak power constraint
The monthly peak demand variable satisfies

$$P^{\mathrm{peak}} \geq P_t^{\mathrm{im}} - P_t^{\mathrm{ex}}, \qquad \forall t \tag{3.14}$$

and the billed monthly peak is constrained by

$$P_{\max}^{\mathrm{month}} \geq P^{\mathrm{peak}}, \tag{3.15}$$

$$P_{\max}^{\mathrm{month}} \geq P_{\max}^{\mathrm{month,prev}}. \tag{3.16}$$

3.2 Input variables

The optimization model is based on hourly electricity demand profiles for residential and commercial buildings, together with PV generation and electricity price data for the year 2023. The residential load profile was based on a representative Swedish household electricity consumption profile, while the commercial load profile was based on the Swedish school Jättestenskolan located in Gothenburg. Figures 3.3 and 3.4 illustrate representative winter and summer weeks for the considered buildings. The residential load profile exhibits clear daily variations, with higher demand during mornings and evenings and increased overall consumption during winter due to heating requirements. In contrast, the commercial building is characterized by substantially higher loads during weekdays and lower demand during nights and weekends. The commercial demand decreases significantly during summer, reflecting reduced building activity, while a relatively constant base load remains throughout the week. These differences in consumption patterns provide complementary demand profiles and form the basis for evaluating the benefits of coordinated operation within the local energy community.

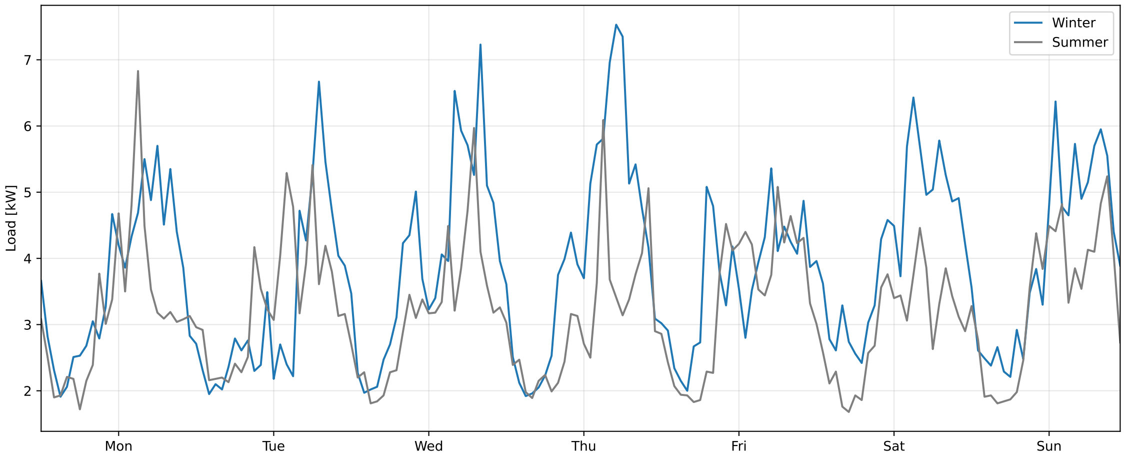

Figure 3.3: Representative residential load profiles during winter and summer weeks.

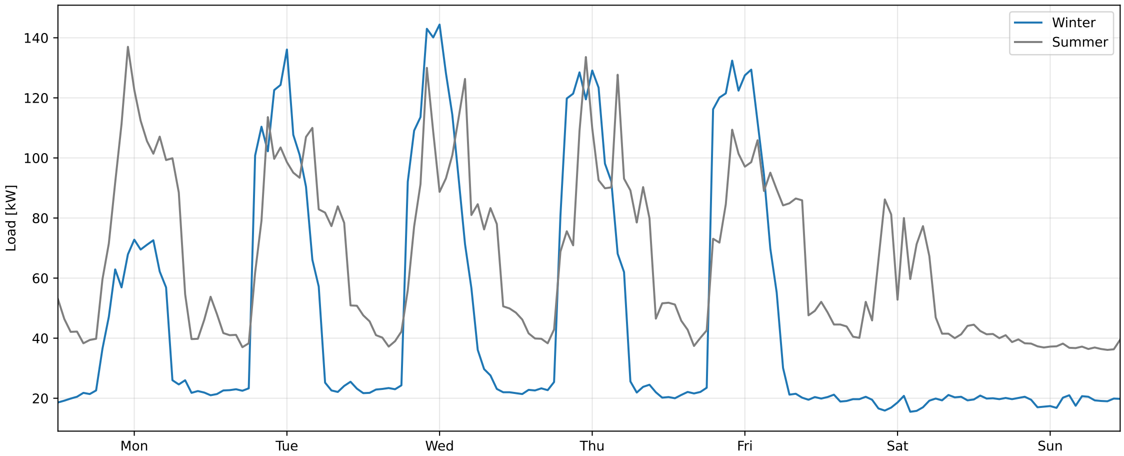

Figure 3.4: Representative commercial load profiles during winter and summer weeks.

The PV generation profiles used in this study were generated using the PVGIS tool with the SARAH3 radiation database [22]. The simulated PV system represents a residential rooftop installation located in Gothenburg, Sweden, at latitude 57.707° and longitude 11.967°, with an elevation of 11 m above sea level. The PV system was modeled with a nominal installed capacity of 5 kWp using crystalline silicon (c-Si) modules. The panels were assumed to be mounted with a tilt angle of 35° and an azimuth angle of 0°, corresponding to a south-facing orientation. System losses were assumed to be 14%, following the default assumptions in PVGIS. The BESS was modeled with a charging and discharging power of 5 kW and an energy storage capacity of 10 kWh. The selected assumptions were intended to represent realistic residential conditions for households in Sweden. Different PV and BESS sizes were later evaluated by multiplying these reference values with scaling factors.

Table 3.1 summarizes the annual demand and generation characteristics of the studied buildings. The commercial building has an annual electricity demand of approximately 365 MWh, compared to 28 MWh for the residential building. Furthermore, the commercial building exhibits substantially higher average and peak loads. Both buildings are equipped with PV systems with an annual generation of approximately 4.7 MWh. These values represent the reference PV systems used in the base case. To investigate the influence of PV capacity on the performance of the local energy community, the installed PV capacity is subsequently varied using scaling factors, as described later in this chapter. As discussed in Section 2.3, PV production exhibits strong seasonal variations, with significantly higher generation during spring and summer months. Together with the temporal variations in electricity prices, these characteristics create opportunities for battery operation and coordinated energy sharing within the local energy community.

Table 3.1: Summary of the building data used in the optimization model.

Building	**Demand** [kWh]	**PV gen.** [kWh]	**Avg. load** [kW]	**Peak load** [kW]
Residential	28 283	4 735	3.23	9.22
Commercial	365 155	4 735	41.69	167.29

3.3 Case creation

To evaluate value creation in LECs, a scenario-based comparative approach was used. The aim was to explore how coordination between households affects the overall economic outcome and under which conditions this coordination leads to higher value. The analysis is based on comparing two operational cases. In the first case, households are considered individually, meaning that each household operates independently without coordination. In the second case, the same households are analysed together as part of a coordinated LEC. The difference in total economic outcome between these two cases is used as a measure of the value created through coordination. This setup makes it possible to directly compare individual and joint operation under the same conditions. To explore how value creation depends on household characteristics, a set of scenarios was constructed. The focus was placed on variations in access to distributed energy resources, specifically PV systems and BESS, as these are central for enabling flexibility within a LEC. The size of PV and battery systems was varied using a simple scaling approach relative to a reference case, as shown in Table 3.2. This made it possible to create multiple scenarios in a structured way, while still keeping the setup easy to interpret.

Table 3.2: Scaling of the installed PV capacity and BESS size relative to the reference case.

Factor	PV capacity [kWp]	BESS energy [kWh]	BESS power [kW]
0×	0	0	0
1×	5	10	5
2×	10	20	10
3×	15	30	15

By combining different scaling factors across households, both symmetric and asymmetric cases were included. This allows the analysis to capture situations where households differ in terms of load, PV capacity and battery storage resources. To facilitate comparison between scenarios, the household configurations are ordered according to increasing levels of load, PV capacity and battery capacity, as shown in Table 3.3. The same ordering is used throughout the result matrices in Chapter 4. The main metric used to evaluate value creation is the total cost saving from coordinated operation, calculated as the difference between the sum of individual household costs and the total cost under joint operation within the LEC. The 18 configurations were selected to represent realistic variations in household electricity demand, PV generation and battery storage within a residential LEC. The combinations were chosen to capture the main factors that influence flexibility, self-consumption, peak reduction and energy sharing while keeping the number of analysed cases manageable.

Table 3.3: Overview of the analysed household configurations. The ordering follows the order used in the result matrices.

Case	Load	PV	BESS
1	0.5×	0×	0×
2	1.0×	0×	0×
3	1.5×	0×	0×
4	1.0×	1×	0×
5	1.0×	3×	0×
6	1.0×	0×	1×
7	1.0×	1×	1×
8	1.5×	1×	1×
9	1.5×	2×	1×
10	1.5×	3×	1×
11	1.0×	0×	2×
12	1.5×	1×	2×
13	1.5×	2×	2×
14	1.5×	3×	2×
15	1.0×	0×	3×
16	1.5×	1×	3×
17	1.5×	2×	3×
18	1.5×	3×	3×

3.3.1 Effect of Tariffs and Spot Prices

To investigate the influence of different economic signals on the operation of the local energy community, a sensitivity analysis is performed. The analysis considers variations in the transmission tariff, the peak tariff, the combined transmission and peak tariffs, the spot price, and the spot price amplitude. The different parameter levels are defined using the scaling factors shown in Table 3.4. Delta3 represents the base case, while Delta1 and Delta2 correspond to reduced values and Delta4 and Delta5 represent increased values. The table also shows the resulting transmission and peak tariff values corresponding to each scaling factor.

Table 3.4: Scaling factors and corresponding transmission and peak tariff values used in the sensitivity analysis.

Parameter	**Delta1**	**Delta2**	**Delta3**	**Delta4**	**Delta5**
Scaling factor	0.50	0.75	1.00	1.50	1.75
Transmission tariff [SEK/kWh]	0.115	0.173	0.230	0.345	0.403
Peak tariff [SEK/(kW·month)]	24.50	36.75	49.00	73.50	85.75

For the spot price scenarios, the hourly price profile is scaled according to the factors in Table 3.4. Table 3.5 summarizes the resulting average spot prices. Delta3 corresponds to the original price profile, whereas Delta1 and Delta2 represent lower average price levels and Delta4 and Delta5 represent higher average price levels.

Table 3.5: Average spot prices used in the sensitivity analysis.

Scenario	**Average spot price [SEK/kWh]**
Delta1	0.265
Delta2	0.397
Delta3	0.530
Delta4	0.795
Delta5	0.927

In addition to the average spot price, the influence of spot price amplitude is investigated. The average daily price level is kept constant, while the deviation from the daily average price is scaled according to

$$p_{t,\text{scaled}} = \bar{p}_d + \delta \left(p_t - \bar{p}_d \right), \tag{3.17}$$

where p_t is the original spot price at hour t, $\bar{p}_d$ is the average spot price of the corresponding day, and δ is the scaling factor defined in Table 3.4. Values of $\delta < 1$ reduce the daily price variation, whereas $\delta > 1$ increase the spread between low and high prices while preserving the daily average price. Figure 3.5 illustrates the effect of modifying the spot price amplitude over a representative week.

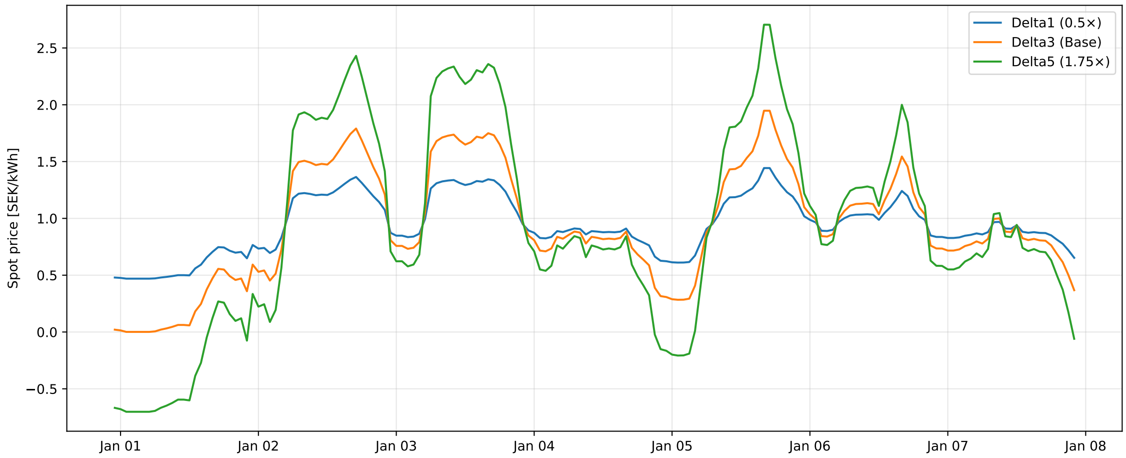

Figure 3.5: Illustration of the spot price amplitude scenarios over a representative week.

3.3.2 Allocation of surplus

For a more representative way of presenting how the distribution of the reduced electricity cost can be performed within a LEC, a system consisting of 10 buildings was evaluated together. The results were compared against a reference case where all buildings operated individually, allowing the total individual electricity cost to be compared with the electricity cost when the buildings instead operated collectively within an LEC.

Two different configurations of the 10-building system were analyzed. The first case consists only of residential households, similar to the previous analyses presented in this study. The second case introduces a mixed composition where both residential households and commercial buildings are included within the LEC. This was done to investigate how different building types and energy profiles influence the distribution of economic benefits within the community.

For each member, variations in electricity demand, PV capacity, and BESS capacity were introduced through scaling factors. These variations create different levels of contribution to the LEC and therefore influence how the economic benefits can be distributed between members.

Table 3.6 presents the configurations and member variations used in the two analysed cases. It is important to note that the commercial buildings use a different electricity demand profile compared to the residential households. In addition, the commercial buildings generally have a significantly higher electricity demand, resulting in larger overall energy consumption and different load characteristics within the LEC.

Table 3.6: Overview of the analysed LEC member configurations.

Member	Type	Load	PV	BESS
Case 1 – Residential-only LEC				
HH1	Household	0.5x	0x	0x
HH2	Household	1.0x	0x	0x
HH3	Household	1.5x	0x	0x
HH4	Household	1.0x	1x	0x
HH5	Household	1.0x	1x	1x
HH6	Household	1.5x	2x	1x
HH7	Household	1.0x	0x	2x
HH8	Household	1.5x	2x	2x
HH9	Household	1.5x	2x	3x
HH10	Household	1.5x	3x	3x
Case 2 – Mixed residential-commercial LEC				
HH1	Household	1.0x	0x	0x
HH2	Household	1.0x	1x	0x
HH3	Household	1.0x	1x	1x
HH4	Household	1.5x	2x	1x
HH5	Household	1.5x	2x	2x
HH6	Household	1.5x	3x	3x
HH7	Commercial	1.0x	0x	0x
HH8	Commercial	1.0x	5x	0x
HH9	Commercial	1.0x	0x	5x
HH10	Commercial	1.0x	5x	5x

The surplus allocation was evaluated using four different weighting approaches, presented in Table 3.7. The weighting factors determine the relative importance of PV contribution, battery contribution, and electricity demand in the allocation model.

Table 3.7: Weighting factors used in the allocation model.

Allocation method	PV share (x)	BESS share (y)	Load share (z)
PV-focused	0.60	0.20	0.20
BESS-focused	0.20	0.60	0.20
Balanced contribution	0.33	0.33	0.34
Equal split	–	–	–

The contribution shares for each member were calculated based on how much each member contributed to the total PV generation, battery capacity, and electricity demand within the LEC:

$$PV_i = \frac{PV_{i,\text{tot}}}{PV_{\text{tot}}}$$

$$BESS_i = \frac{BESS_i}{BESS_{\text{tot}}}$$

$$L_i = \frac{L_{i,\text{tot}}}{L_{\text{tot}}}$$

where PV_i, $BESS_i$, and L_i represent the share of the total PV generation, the installed BESS energy capacity, and the total electricity demand belonging to member i, respectively. Thus, the BESS contribution is based on the installed battery energy capacity owned by each member rather than on the actual utilization of the battery during operation.

$$PV_i = \frac{PV_i}{PV_{\text{tot}} + BESS_{\text{tot}} + L_{\text{tot}}}$$

$$BESS_i = \frac{BESS_i}{PV_{\text{tot}} + BESS_{\text{tot}} + L_{\text{tot}}}$$

$$L_i = \frac{L_i}{PV_{\text{tot}} + BESS_{\text{tot}} + L_{\text{tot}}}$$

For the contribution-based allocation methods, each member was assigned an allocation score based on a weighted combination of these contribution shares:

$$S_i = x \cdot PV_i + y \cdot BESS_i + z \cdot L_i$$

where S_i is the allocation score for member i, and x, y, and z are weighting factors defining the importance of PV generation, battery capacity, and electricity demand in the allocation model.

Different weighting combinations were used to represent different allocation principles. In the PV-focused method, PV contribution was given the highest weight, while the BESS-focused method prioritized battery capacity. The balanced contribution method used equal weights for PV generation, battery capacity, and electricity demand, meaning that all three contribution categories were considered equally important in the surplus allocation.

The total surplus generated by the LEC was then distributed proportionally according to the calculated allocation scores, meaning that members with higher contribution scores received a larger share of the total surplus.

3.4 Key Performance Indicators (KPIs)

This study evaluates the performance of the LEC using three key indicators:

- **Surplus**: Total economic benefit of coordinated operation, calculated as the difference between the total cost under individual optimization and coordinated optimization:

  $$\text{Surplus} = C_{\text{individual}} - C_{\text{coordinated}}$$

  A higher surplus indicates greater value from coordination within the energy community.

- **Peak Reduction**: Reduction in maximum power demand achieved through coordinated operation:

  $$\text{Peak Reduction} = P_{\text{individual}}^{\text{max}} - P_{\text{coordinated}}^{\text{max}}$$

  Higher peak reduction reflects improved load balancing and can lead to lower costs in systems with power-based tariffs.

- **Self-consumption**: Share of locally generated energy that is consumed within the community or household:

  $$\text{Self-consumption} = \frac{E_{\text{PV produced}} - E_{\text{exported}}}{E_{\text{PV produced}}}$$

  A higher self-consumption (SC) value indicates that a larger share of the PV electricity production is utilized locally and/or that a smaller share is exported to the grid.

An optimal scenario is characterized by a high surplus, significant peak reduction and high self-consumption, indicating an economically efficient and well-coordinated energy community.

4

Results

This chapter presents the results of the analysis, with a focus on value creation within the LEC and how it is shaped by system design, tariff structures, and different approaches to distributing the benefits.

4.1 Model validation

To better understand the mechanisms behind the observed results to evaluate how variations in key parameters, such as spot prices and tariff structures, influence the results. To illustrate these effects, a representative day is analyzed. The selected day (2023-08-24) was chosen because its hourly price profile closely resembles the average daily spot price pattern over the year. It exhibits lower prices during nighttime and higher prices during daytime and evening hours, making it suitable for illustrating the typical variation in electricity prices.

4.1.1 Impact of Tariff Structures and Spot Prices under Individual Optimization

In the case without a peak power tariff, the optimization is driven solely by electricity spot prices, as shown in Figure 4.1. Since there is no penalty associated with high power demand, the model has no incentive to reduce peak loads. Consequently, the battery follows the spot price pattern, charging during low-price periods and discharging during high-price periods, thereby performing price arbitrage.

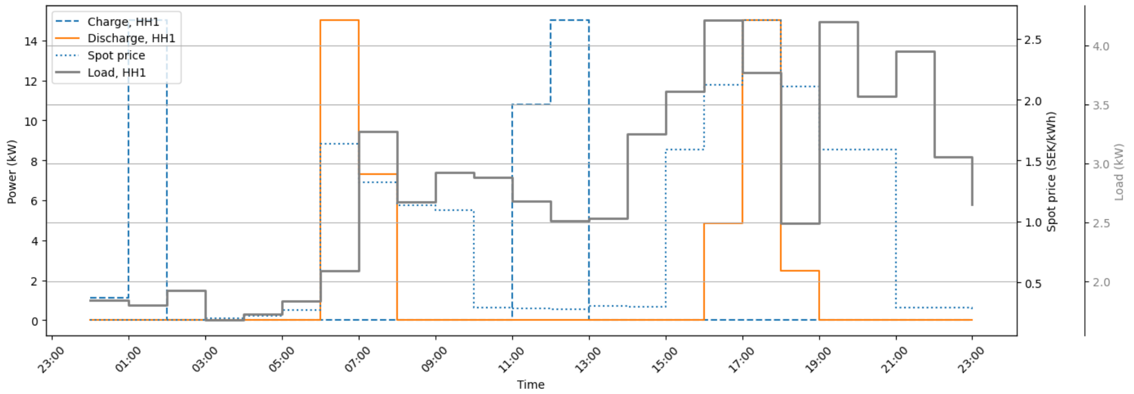

Figure 4.1: Hourly operation of BESS during a non-effective peak cost scenario.

In the business as usual case, the battery operation is primarily driven by variations in electricity spot prices, as shown in Figure 4.2. Charging occurs mainly during periods with low prices, typically during night-time hours, while discharging takes place during periods with higher prices, particularly in the evening. This behavior reflects a price arbitrage strategy, where electricity is stored during low-price periods and used during high-price periods to reduce costs. The business as usual therefore is a reference for the sensitivity analysis, illustrating how the battery operates under standard conditions before introducing variations in key parameters such as tariff structures and price levels.

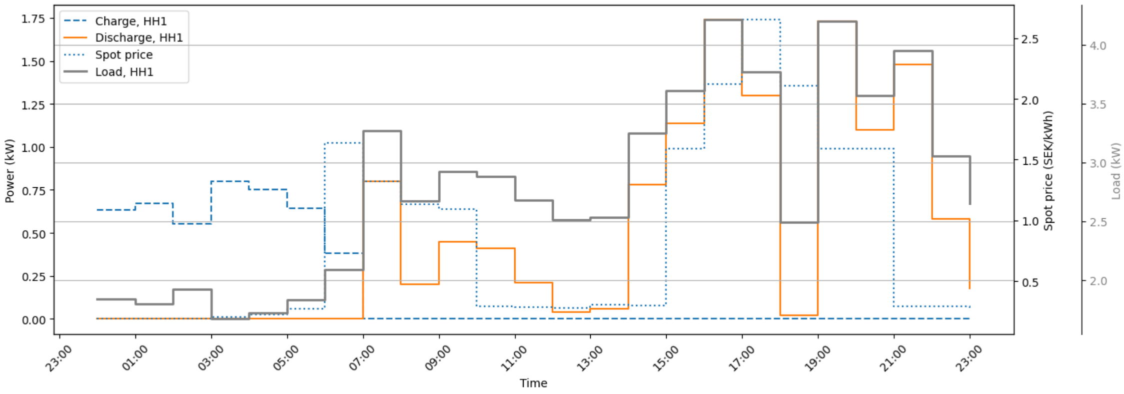

Figure 4.2: Hourly operation of BESS in the business as usual.

An elevated price scenario is included as part of the sensitivity analysis to illustrate how the optimization responds to stronger price signals. By increasing the spot price levels by a factor of five, the relative importance of price variations is amplified, making it easier to observe how the battery operation adapts to changes in electricity prices. As shown in Figure 4.3, the battery operation follows the overall trend of the spot price profile, with charging occurring primarily during low-price periods and discharging during high-price periods. Compared to the baseline case with the original spot prices, the response is more pronounced, indicating that the optimization is increasingly driven by price differences, although other factors still play a role.

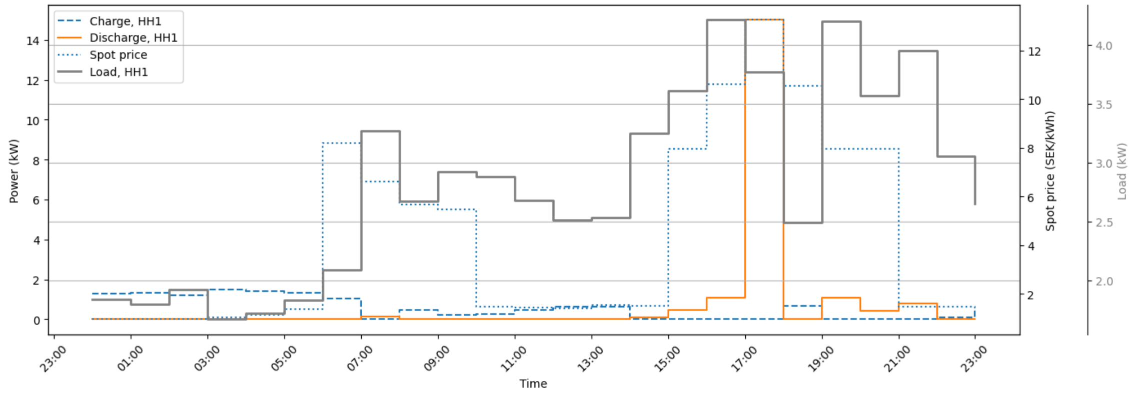

Figure 4.3: Hourly operation of BESS1 for a scenario with five times higher spot price amplitude, showing increased battery discharge during high-price periods.

4.1.2 Operational Behavior of PV and BESS within the LEC

The same type of analysis was performed for different PV and BESS configurations together with the resulting import, export, BESS charging/discharging behavior, and battery SOC. Figure 4.4 presents four representative summer scenarios with different household compositions: Case 4 and Case 5, Case 15 and Case 4, Case 4 and Case 3, and Case 7 and Case 5, respectively.

In the first scenario shown in Figure 4.4, both households are equipped with PV systems but no BESS. During the morning and evening hours, when PV generation is low, electricity is imported from the grid. Around midday, approximately between 10:00 and 15:00, PV production exceeds the local demand, resulting in electricity export to the grid. In the second scenario, one household is equipped with a larger BESS and the other with a smaller PV system. The battery charges mainly during the late morning and midday hours, approximately between 10:00 and 14:00, when PV generation is available and electricity prices are lower. During the afternoon and evening, approximately between 16:00 and 21:00, the battery discharges and reduces the need for grid imports during periods with higher electricity prices. The SOC increases during charging and decreases gradually as the stored energy is utilized. The third scenario consists of one household with a smaller PV system and another household with higher electricity demand. Consequently, electricity imports occur during most hours of the day. Although imports are reduced around midday due to PV generation, additional imports are still required during the evening hours because of the limited flexibility resources available within the LEC. In the final scenario, both households have PV systems and one household also has a smaller BESS. Similar to the first scenario, electricity is imported during the morning and evening hours, while surplus PV generation results in electricity exports around midday. The battery charges mainly between 10:00 and 14:00 and discharges during the late afternoon and evening, approximately between 17:00 and 21:00, thereby reducing grid imports during periods with elevated electricity prices.

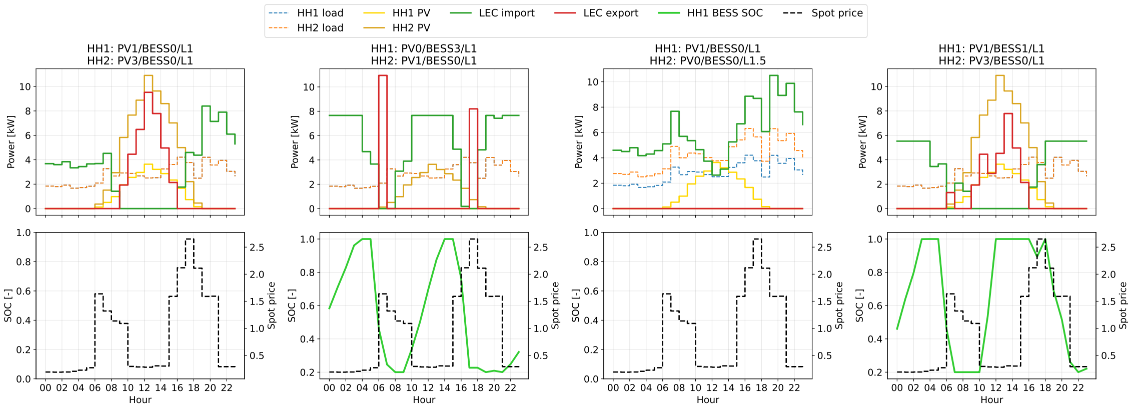

Figure 4.4: Hourly operation of representative summer-day LEC configurations, illustrating household load, PV generation, LEC import/export, and BESS operation.

The same type of analysis was performed for winter conditions, as presented in Figure 4.5. The figure includes the same four representative configurations: Case 4 and Case 5, Case 15 and Case 4, Case 4 and Case 3, and Case 7 and Case 5, respectively. Compared to the summer scenarios, the PV generation is significantly lower during winter conditions, resulting in higher electricity imports and reduced electricity export from the LEC.

In the first scenario, where only PV systems are installed in both households, the limited winter PV generation is only able to reduce imports slightly during midday hours. As a result, the LEC remains highly dependent on electricity imports during most of the day, particularly during the evening when both electricity demand and spot prices are high. The second scenario consists of one household equipped with a larger BESS and another household with a smaller PV system. In this case, the battery operation becomes increasingly important due to the reduced availability of PV generation. The battery charges primarily during hours with low spot prices and later discharges during periods with higher electricity prices, reducing the need for expensive electricity imports. The results further indicate that the battery is also used to export electricity during some high-price periods, suggesting that the optimization utilizes the battery both for reducing local imports and for creating economic value through electricity export. The third scenario includes one household with a smaller PV system and another household with higher electricity demand. Similar to the summer case, the LEC depends heavily on electricity imports throughout the day. Since the available PV generation is limited during winter conditions and no battery storage is installed, the community is unable to shift consumption away from periods with elevated electricity prices.

The final scenario includes PV generation in both households together with a smaller battery installed in one household. The operational trend is similar to the second scenario, where the battery provides flexibility by charging during low-price periods and discharging during periods with higher spot prices. The battery also appears to export electricity during some peak-price periods, further indicating that the optimization utilizes the stored electricity to maximize economic value during high-price events. However, due to the presence of PV generation in both households, the battery can additionally utilize part of the locally generated electricity, slightly reducing the dependence on grid imports during midday hours. The SOC profile further indicates that the battery operation follows the daily spot price pattern more closely during winter conditions, highlighting the increasing value of storage flexibility when PV generation is limited.

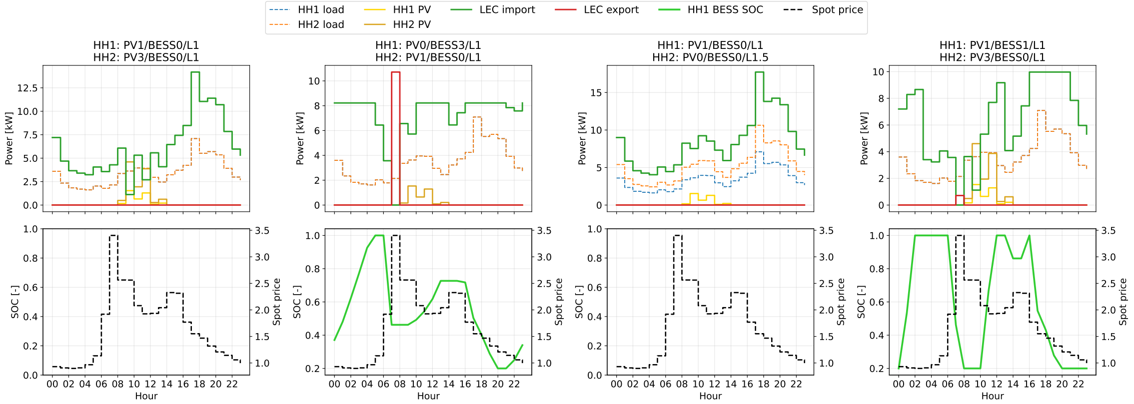

Figure 4.5: Hourly operation of representative winter-day LEC configurations, illustrating household load, PV generation, LEC import/export, and BESS operation.

Overall, the validation results indicate that the model captures the expected behavior of the system and provides consistent results. The model is therefore considered sufficiently validated and can be used for the subsequent analyses presented in this thesis.

4.2 Drivers of Value Creation in the LEC

The value created in the LEC is first evaluated by the amount of extra value that a joint operation of two households can create compared to operating each household individually. This section presents the potential cost reductions, peak reduction and self-consumption effects that an LEC can generate using the KPIs described in Section 3.4. From the household perspective, an important motivating factor for joining an LEC is the possibility of reducing electricity costs. Figure 4.6 shows the annual surplus generated in each case when the households coordinate their operation compared to individual operation. The combinations are presented in the same order as in Table 3.3, where the y-axis is read from bottom to top and the x-axis from left to right. Since the same configurations are used for both households, duplicate combinations appear across the symmetry line running from the bottom left corner to the top right corner. The yellow colour represents high values, while blue represents lower values.

Looking at the trends in the Figure 4.6, the upper left corner contains several yellow and green patterns, indicating cases with high generated value. One case that stands out strongly is the yellow case, corresponding to the combination of Case 15 and Case 5 (see Table 3.3). In these cases, the asymmetry in flexibility and energy assets creates favorable conditions for collaboration, allowing households to complement each other and generate additional value together.

Representative daily operating patterns for the Case 15 and Case 5 combination during summer and winter are provided in Appendix A.3 and Appendix A.4, respectively. The seasonal profiles illustrate how the available flexibility resources are utilized differently throughout the year. During summer, high PV generation creates surplus energy that can be stored and shared within the LEC, whereas during winter, when PV production is limited, the batteries are mainly used to shift consumption and reduce electricity imports. These seasonal differences further explain the high value observed for asymmetric household combinations.

Continuing towards the upper middle part of the heat map, the colours shift more towards blue, representing lower-value cases. These combinations correspond to households where both participants already have large amounts of PV and BESS individually. Since both households can already optimize their own operation efficiently, the additional value created through collaboration becomes smaller compared to the more asymmetric cases.

Blue patterns can also be seen in the lower left corner of the figure, where both households have little or no PV and BESS. In these cases, there is limited flexibility available to coordinate, which naturally reduces the potential value that can be created through collaboration in the LEC.

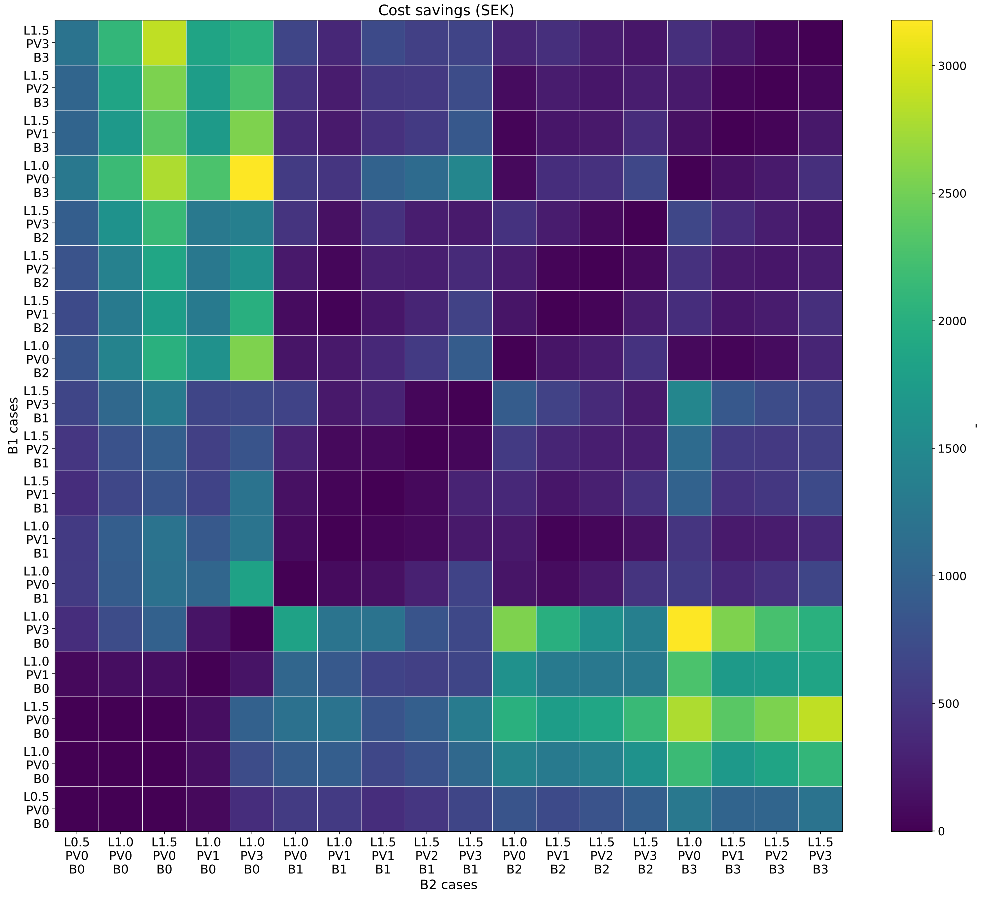

Figure 4.6: Matrix showing the surplus (SEK), defined as the difference in total electricity costs between coordinated operation in the LEC and individual optimization.

Another important factor is whether the LEC can contribute to reducing peak demand events and thereby help solve the lack of available electricity capacity in the power system. This benefits the grid owner by reducing stress on the local grid and potentially delaying expensive grid reinforcements. Figure 4.7 shows the peak reduction for the different cases, presented in the same order as described in the previous section.

Looking at the trends in the figure, the largest peak reductions are mainly found in asymmetric household combinations, where one household has available battery flexibility while the other household has higher load demand. One case that stands out is the combination of Case 15 and Case 3 (see Table 3.3). In this case, the battery flexibility can be used to reduce the combined peak demand during high load periods, creating a large benefit from coordinated operation. The results show similar trends to the surplus heat map, where asymmetric household configurations generally create larger value through collaboration. In contrast, combinations where both households already have similar flexibility resources or limited flexibility available show lower peak reduction values. This indicates that the ability to complement each other is also important for reducing peak demand within the LEC.

Representative summer and winter operating patterns for selected household combinations are provided in Appendix A.5 and Appendix A.6, respectively. The seasonal profiles illustrate the mechanisms behind the trends observed in Figure 4.7. During summer, surplus PV generation can be stored and later discharged to avoid high import levels, while during winter, when PV generation is limited, peak reduction is mainly achieved by utilizing battery flexibility during periods of high load demand. These seasonal differences further highlight the importance of complementary flexibility resources in achieving larger peak reductions through coordinated operation.

It should be noted that the values presented in Figure 4.7 represent the absolute reduction in peak demand (kW) achieved through coordinated operation in the LEC compared with the corresponding case of individual optimization without an LEC. Additional percentage-based peak reduction results are presented in Figure A.2. This is mainly because households with larger load demand, as in the case mentioned in the previous section, also have higher initial peak values. As a result, there is more potential available for peak shaving when flexibility resources such as BESS are introduced. Therefore, larger households can achieve higher absolute peak reductions in kW, even if the relative reduction may be similar to or lower than in smaller household configurations. Consequently, the absolute values shown in Figure 4.7 should be interpreted together with the relative reductions presented in Figure A.2. Although the maximum absolute peak reduction is approximately 3.9 kW, the corresponding relative reduction reaches 20%, illustrating that seemingly modest reductions in power can represent substantial reductions in peak demand.

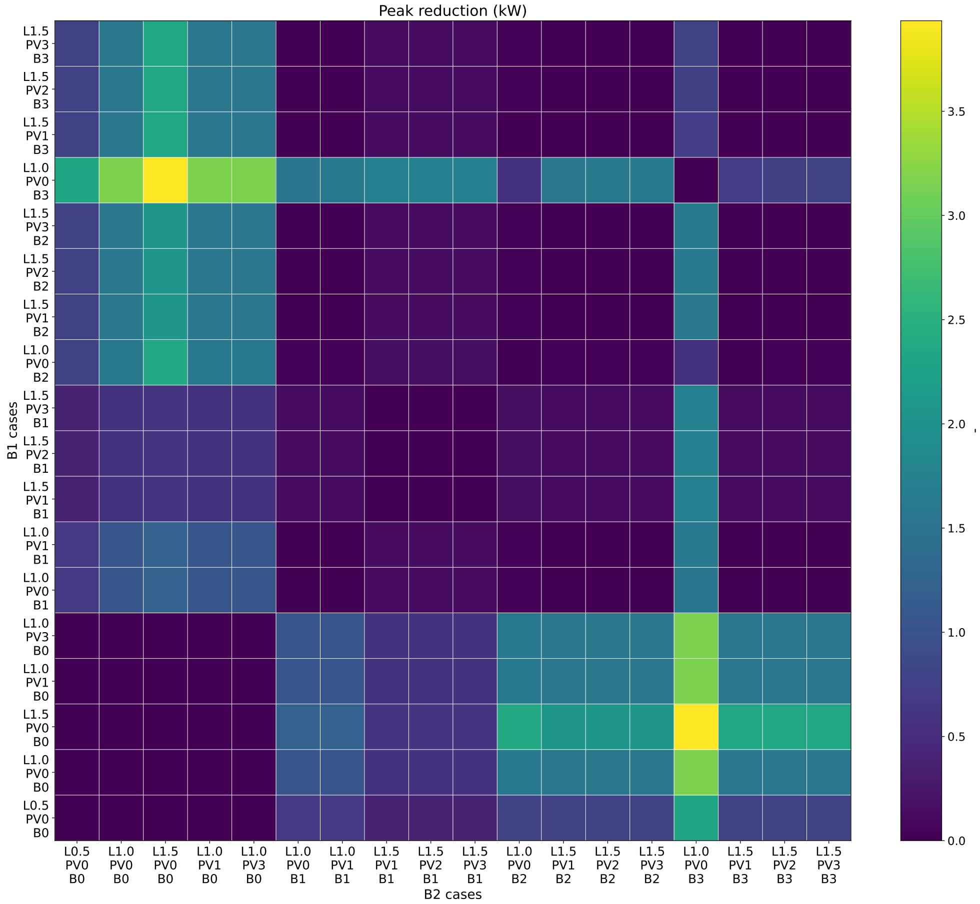

Figure 4.7: Matrix showing the peak reduction (kW) achieved through coordinated operation in the LEC.

The matrix in Figure 4.8 shows the improvement in self-consumption achieved through coordinated operation within the LEC compared to individual household operation. Positive values indicate that a larger share of the locally generated PV electricity can be utilized within the community when the households coordinate their operation, while lower values indicate that coordination provides only limited additional benefits.

The results indicate that the largest improvements in self-consumption are primarily achieved in asymmetric household combinations, particularly in cases where one household has high PV production while the other household has limited or no PV generation. In these configurations, coordinated operation allows surplus PV electricity from the producing household to be utilized by the other household instead of being exported to the grid. This creates a strong complementarity between local generation and electricity demand within the LEC, significantly reducing the exported energy.

The yellow-colored regions in Figure 4.8 indicate that asymmetric PV capacities create favorable conditions for improving self-consumption, as surplus generation from one household can be utilized by the demand of the other. A local maximum is also observed for configurations where a household with a large PV system is paired with a household having a smaller PV installation and a larger BESS. This suggests that battery storage complements differences in PV capacity by increasing the utilization of surplus generation. Overall, the results show that heterogeneous combinations of generation and storage resources lead to larger improvements in self-consumption than more symmetric configurations.

In contrast, the more purple-colored cases generally correspond to configurations where both households have similar PV capacities, similar flexibility resources, or limited differences in their demand profiles. In these cases, the households already consume a relatively large share of their own PV production individually, leaving less surplus energy available for beneficial exchange within the LEC. As a result, coordinated operation provides smaller additional improvements in self-consumption.

The results therefore indicate that the value of coordinated operation is strongly dependent on the diversity and complementarity between the participating households. Rather than maximizing PV capacity equally for all members, the findings suggest that LECs may benefit from combining households with different consumption patterns and generation capacities, as this creates greater opportunities for local energy sharing and reduced grid export.

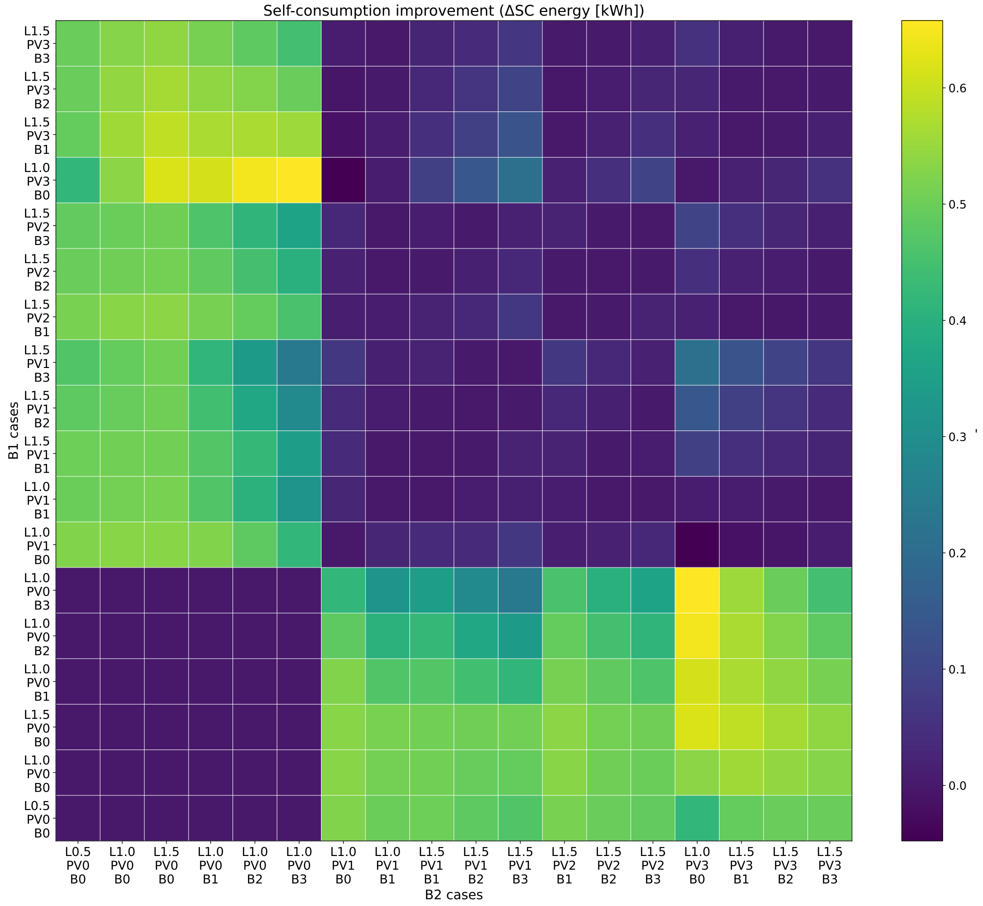

Figure 4.8: Matrix showing the self consumption achieved through coordinated operation in the LEC

Table 4.1 summarizes the best-performing configurations for the selected KPIs. The results show that different configurations favor different objectives, with complementary flexibility resources providing the highest self-consumption and economic benefits, while asymmetric household combinations are most effective in reducing peak demand.

Table 4.1: Best-performing configurations for selected KPIs.

KPI	Best configuration	KPI value	Relative change
Surplus	Case 15 + Case 5	3486.6 SEK	7.03%
Peak reduction	Case 15 + Case 3	3.9 kW	20%
Self-consumption	Case 15 + Case 5	93.3%	+66.8 percentage points

Overall Key Takeaways

- The largest economic benefits in the LEC are generally created in asymmetric household combinations.
- Households with complementary flexibility resources can create both higher cost savings and larger peak reductions through coordinated operation.
- Battery flexibility plays an important role in reducing combined peak demand within the LEC.
- Cases where both households already have similar PV and BESS capacities show lower additional benefits from collaboration.
- Households with little or no flexibility resources create limited additional value in both surplus generation and peak reduction.
- The results indicate that diversity in household configurations is an important factor for maximizing the benefits of coordination within an LEC.

4.2.1 Tariffs and Spot Price Effects on KPI:s

The section highlights how the value created by the LEC changes under different market conditions and shows that the impact varies significantly depending on the applied tariff structure. To illustrate these effects in more detail, the Case 15 and Case 3 combination was selected for further analysis, as it exhibited the highest value among all household combinations. Figure 4.9 presents the relative change in annual surplus compared to the reference case (Delta3) for the different tariff scenarios. The results demonstrate that the sensitivity of the LEC value depends strongly on whether the price signal originates from network-related tariffs or from the electricity market itself.

For Delta1 and Delta2, where tariff and spot price levels are lower than in the reference case, the surplus decreases for all tariff structures. This indicates that the economic incentive for participating in a LEC becomes smaller when grid-related costs are low. Under such conditions, the financial benefit of reducing grid imports and sharing electricity locally is reduced, making individual household operation relatively more competitive.

The largest changes are observed for the Peak, Transmission, and especially the Transmission+Peak tariffs. Since these tariffs are directly linked to grid usage, higher tariff levels increase the value of reducing simultaneous imports and demand peaks through coordinated operation. Consequently, the surplus increases significantly for Delta4 and Delta5, highlighting one of the main advantages of the LEC structure: households can cooperate to reduce transmission costs and peak demand charges that would otherwise be incurred individually.

In contrast, the Spot and Spot_Amp cases exhibit considerably smaller variations. Although increasing the average spot price or the price volatility affects the absolute electricity cost, the spot price signal is identical for both individual households and the LEC. Therefore, changes in spot price level or amplitude have a smaller impact on the relative advantage of coordinated operation than network-related tariffs.

Overall, the results indicate that the economic performance of the LEC is much more sensitive to changes in network tariffs than to changes in electricity prices. Additional results illustrating the seasonal variation of the surplus during winter and summer periods are provided in Appendix A.7, where the same trends are observed but with somewhat larger benefits during summer due to increased PV generation and opportunities for local energy sharing.

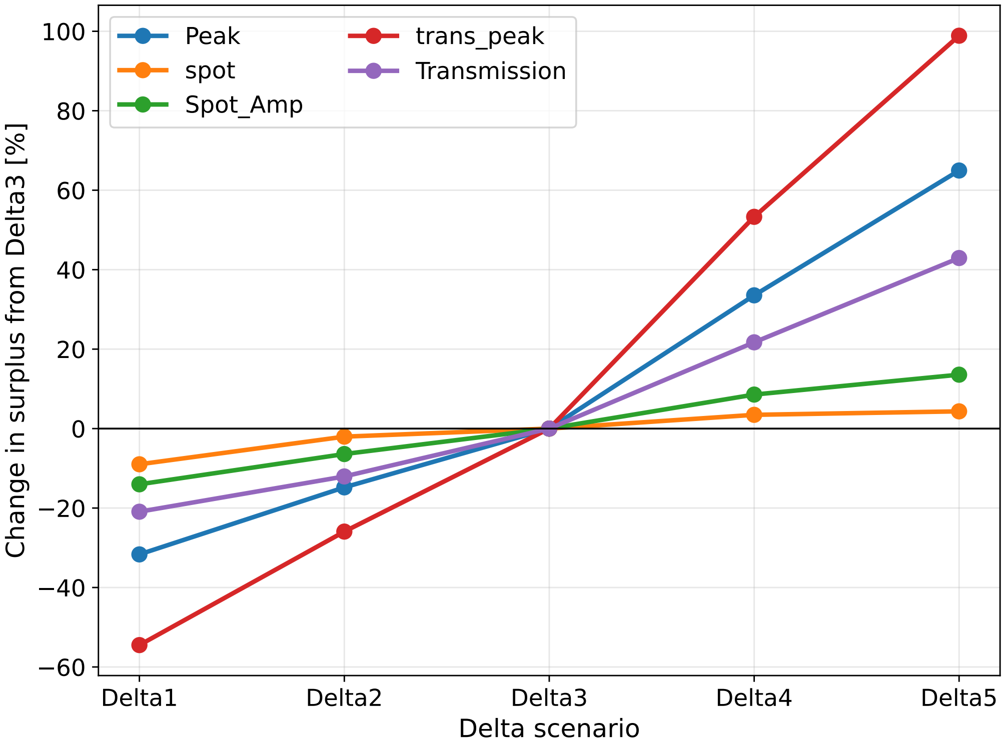

Figure 4.9: Annual variation in relative surplus changes for different tariff structures under varying delta scenarios.

Compared to the surplus results, the variations in peak reduction are generally smaller, indicating that changes in tariff and spot price levels affect the economic value of the LEC more strongly than its physical ability to reduce demand peaks. Figure 4.9 presents the relative change in annual peak reduction compared to the reference case (Delta3). The overall trends are similar to those observed for the surplus KPI, although the variations are less pronounced.

The Peak (blue), Transmission (purple), and Transmission+Peak (red) cases exhibit the largest variations. Since these tariffs are directly related to grid usage and peak demand, increasing the tariff levels creates stronger incentives for coordinated operation and peak shaving within the LEC. Consequently, the peak reduction increases for Delta4 and Delta5, although the magnitude of the increase is smaller than for the surplus KPI.

For Delta1 and Delta2, where the tariff levels are lower than in the reference case, the peak reduction decreases. Lower network tariffs reduce the economic incentive to actively limit simultaneous grid imports, resulting in smaller benefits from coordinated peak reduction.

In contrast, the Spot (orange) and Spot Amp (green) cases show only minor variations. Since peak reduction is primarily determined by the ability to reduce simultaneous imports rather than by the electricity price itself, changes in spot price level or price volatility have little influence on the physical peak reduction achieved by the LEC.

Overall, the results indicate that increasing network-related tariffs strengthens the incentives for peak reduction, whereas changes in electricity prices have a comparatively limited effect. Additional results showing seasonal variations in peak reduction are provided in Appendix A.8. These results demonstrate similar trends, with somewhat larger peak reductions during summer due to higher PV generation and increased flexibility available for coordinated operation.

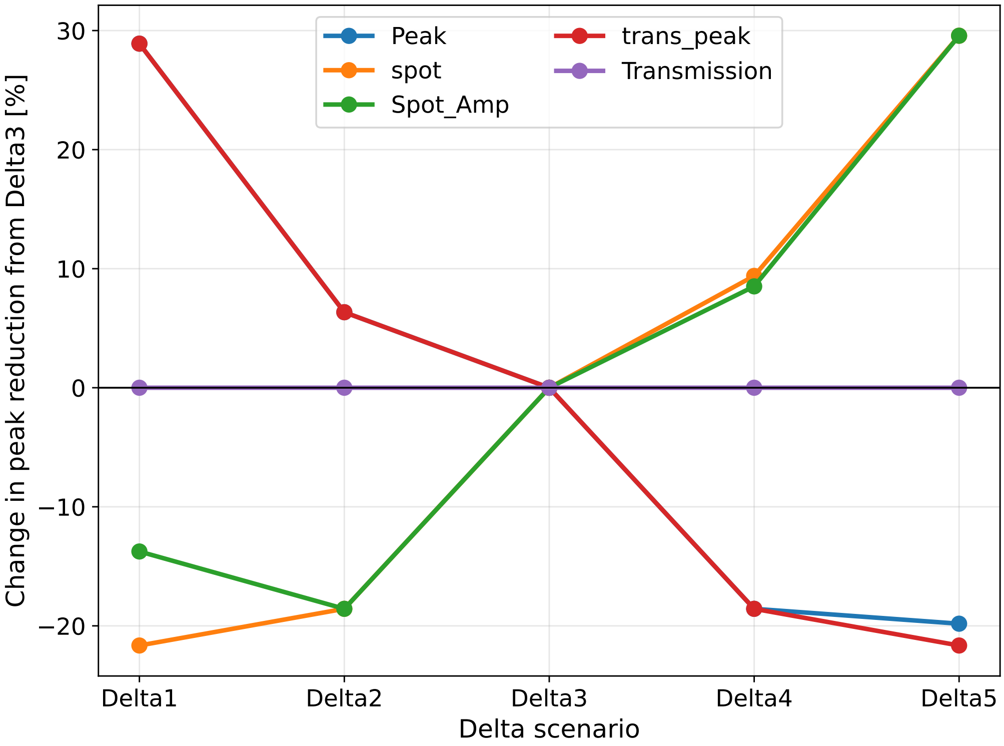

Figure 4.10: Annual variation in relative peak reduction changes for different tariff structures under varying delta scenarios.

Figure 4.11 presents the relative change in annual SC compared to the reference case (Delta3) for the different tariff scenarios. Positive values indicate that a larger share of PV generation is consumed locally within the LEC, while negative values indicate lower self-consumption.

For Delta1 and Delta2, self-consumption decreases for the Peak, Transmission, and Transmission+Peak cases. This indicates that lower network-related tariffs reduce the incentive to coordinate consumption and storage in order to use PV electricity locally. For Delta4 and Delta5, the network-related tariff cases instead show increased self-consumption. The largest increase is observed for the Transmission+Peak case, followed by Transmission and Peak. This suggests that higher network tariffs increase the value of reducing grid imports and encourage more local use of PV generation.

The Spot and Spot_Amp cases show the opposite trend. Self-consumption increases when spot prices are lower and decreases when spot prices are higher. This can be explained by the fact that higher spot prices make exporting PV electricity more valuable, while lower spot prices make local consumption relatively more attractive.

Overall, the results indicate that network-related tariffs increase the incentive for local PV utilization, whereas spot price changes mainly affect the value of exporting electricity. Seasonal self-consumption results are provided in Appendix A.9.

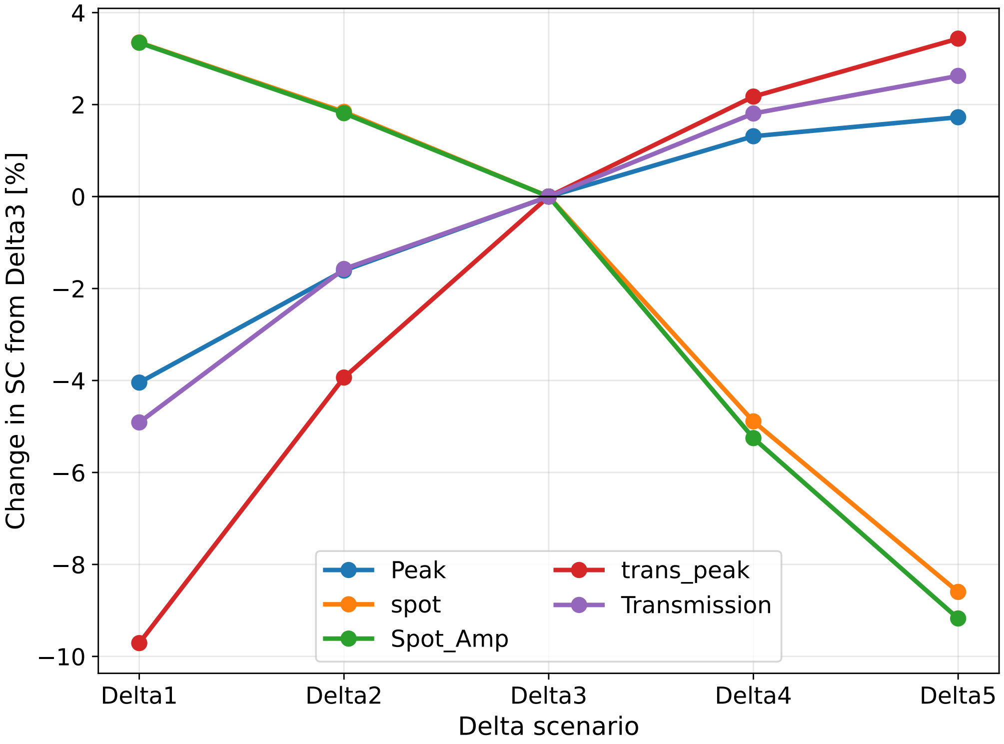

Figure 4.11: Annual variation in relative self consumption changes for different tariff structures under varying delta scenarios.

Overall Key Takeaways

- The value of the LEC is strongly dependent on the tariff structure.
- Peak and transmission-based tariffs create the largest benefits from coordinated operation.
- Higher tariffs increase the economic incentive for local energy sharing and peak reduction.
- Spot price changes have a smaller impact since the LEC cannot reduce electricity market prices directly.
- Higher PV production during spring and summer increases the value of cooperation within the LEC.
- Tariff changes affect the economic surplus more strongly than the physical peak reduction.

4.3 Allocation of Cost Reduction in LECs

Besides reducing the total electricity cost of the community, an important aspect of Local Energy Communities (LECs) is how the achieved savings are distributed among the participating members. Different allocation principles may favor households contributing with flexibility resources such as PV generation or battery storage, while other methods distribute the benefits more equally regardless of contribution.

To investigate this, the achieved cost reduction within the LEC was evaluated using four different allocation methods: PV-focused, BESS-focused, balanced contribution, and equal split. The analysis examines how the economic benefits from coordinated operation are shared between the members depending on their installed flexibility resources and contribution to the community. Figure 4.12 presents the annual results for the residential case. The figures compare the individual electricity cost before and after allocation for each member, together with the installed PV and BESS capacities.

The results show that the allocation methods based on contribution provide larger economic benefits to members with higher PV generation and battery capacity, while the equal split method distributes the savings more uniformly between the households. Members with larger flexibility resources generally receive a larger share of the total surplus, particularly in the PV-focused and BESS-focused allocation methods. The balanced contribution method creates a more moderate distribution by considering PV generation, battery capacity, and electricity demand simultaneously.

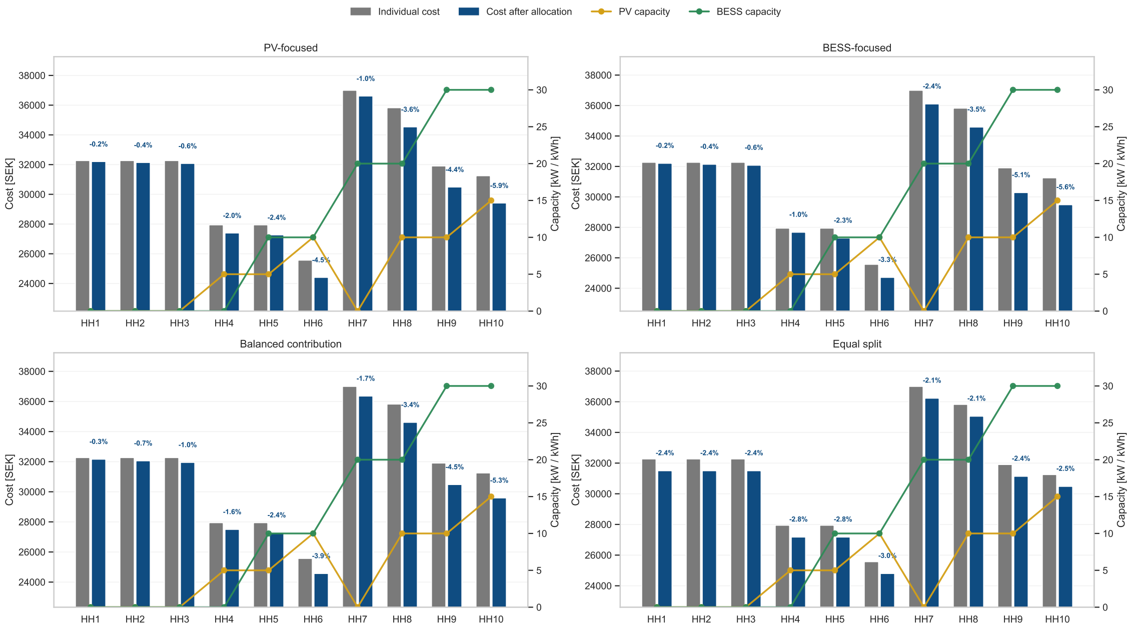

Figure 4.12: Annual electricity cost before and after allocation.

Figure 4.13 presents the annual cost allocation results for Case 2, which includes both residential households and commercial buildings. Compared to the residential-only case, the differences between the allocation methods become more pronounced due to the larger variation in installed PV and BESS capacities among the participants.

The PV-focused and BESS-focused methods mainly allocate the economic benefits to members contributing with the corresponding flexibility resources. As a result, members with large installed capacities, particularly the commercial buildings, receive a larger share of the achieved cost reduction. In contrast, the equal split method distributes the savings more evenly among all members, independent of their contribution to the community flexibility.

The balanced contribution method creates a more moderate distribution of the savings by considering both PV and BESS contributions. This results in a more even allocation while still rewarding members that contribute flexibility resources to the LEC.

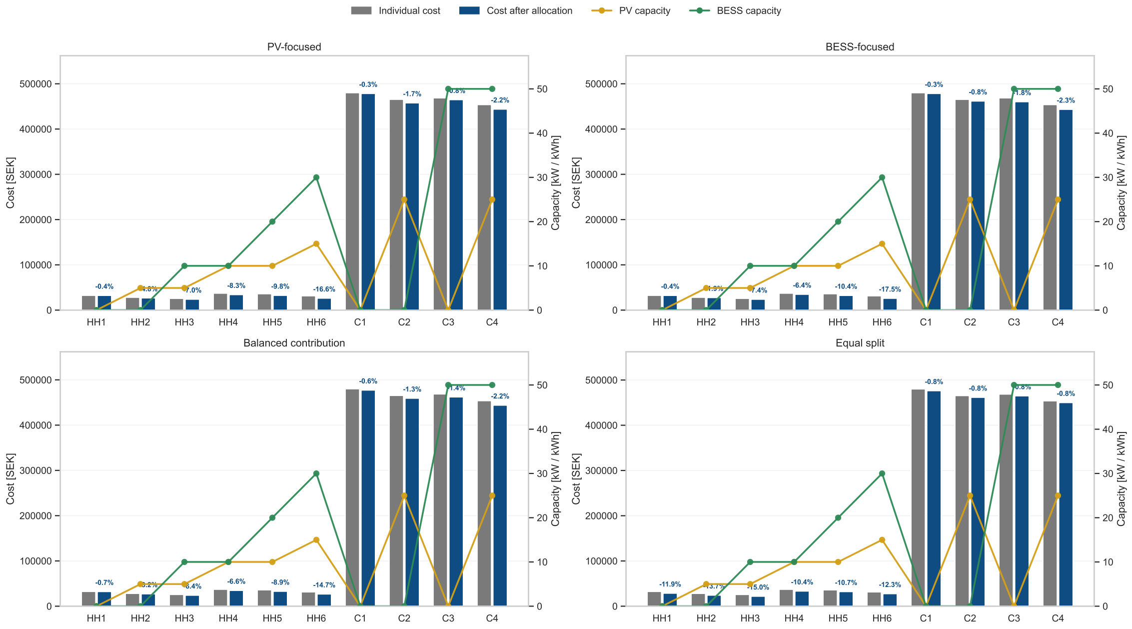

Figure 4.13: Annual electricity cost before and after allocation including commercial building.

Figure 4.14 illustrates the spread in cost reductions obtained by the different allocation methods for the two investigated cases and seasonal periods. The spread represents the difference between the maximum and minimum cost reduction among the participating members and therefore indicates how evenly the economic benefits are distributed.

For Case 1, the equal split method results in the smallest spread, indicating the most even distribution of benefits. In contrast, the PV-focused and BESS-focused methods produce larger spreads, since households with greater flexibility contributions receive a larger share of the savings. The balanced method provides an intermediate solution. The spreads are considerably larger in Case 2 due to the presence of commercial buildings with substantially larger loads and flexibility resources. As a result, the contribution-based methods exhibit the largest differences between members, while the equal split method reduces these differences. Seasonal variations can also be observed. For both cases, the spread is generally larger during April–September than during October–March. Higher PV production during spring and summer increases the value of local energy sharing and amplifies the differences between members under the contribution-based allocation methods.

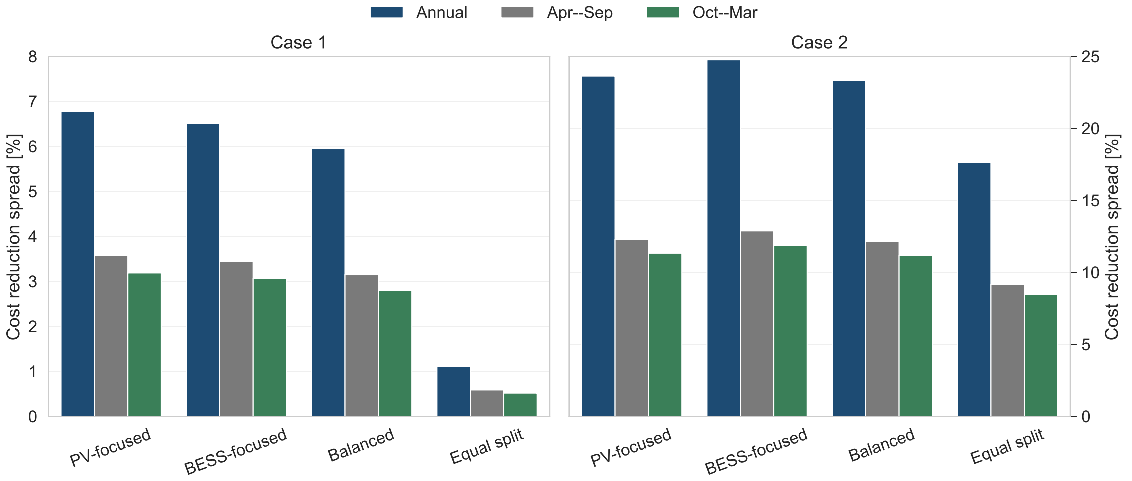

Figure 4.14: Spread in member cost reductions for different allocation methods and seasons.

Overall key takeaways

- Coordinated operation within the LEC reduced electricity costs compared to individual operation.
- The largest benefits were achieved in cases combining PV systems and BESS resources.
- Contribution-based allocation methods mainly rewarded members with larger PV and BESS capacities.
- The balanced allocation method created a compromise between equal distribution and contribution-based compensation.

5

Discussion

This chapter discusses the main findings of the study and how different household compositions, flexibility resources, tariff structures, and operational strategies influence the value creation within the LEC. Furthermore, the implications, assumptions, and limitations of the model are discussed.

5.1 Household Composition and Coordination Value

A central finding of this study is that the value created through coordinated operation within the LEC is strongly dependent on the composition of the participating households. The results indicate that households with complementary flexibility resources generally created the largest economic and operational benefits (see Table 4.1). This suggests that coordination value is determined not only by the total amount of flexibility available within the community, but also by how these resources are distributed among the participating households.

The results show that asymmetric household combinations often achieved larger benefits than configurations where both households had similar load profiles, PV capacities, and battery sizes. This finding is consistent with the work of Ercoli et al. [23], who showed that aggregating prosumers with different energy profiles improves supply–demand balancing and increases the flexibility available at the community level. Similar conclusions were reported by Casalicchio et al. [24], who found that complementary consumption and generation profiles among community members enable a more efficient utilization of local resources. The present results therefore support previous findings that diversity among community members can increase the value created through coordinated operation.

This behaviour can be explained by the operational characteristics of PV generation and electricity demand. As shown in Figures 4.4 and 4.5, households with large PV systems often generate surplus electricity simultaneously due to similar solar irradiation conditions. When both households already satisfy most of their electricity demand individually during these periods, the opportunities for additional local energy sharing become limited, resulting in increased electricity exports to the grid. Similar observations were reported by Huang et al. [25], who showed that increasing homogeneity among community members reduces the benefits of energy sharing, whereas more diverse communities achieve better balancing and higher local utilization of renewable generation. In contrast, households with different demand patterns and flexibility resources provide more opportunities for beneficial energy exchange, which explains the larger coordination benefits observed for asymmetric household combinations.

Another important observation is that the marginal value of flexibility resources appears to decrease when households already possess large individual flexibility capacities. Households equipped with batteries and high self-consumption capabilities are already able to optimize a significant share of their operation individually. Consequently, the additional value created through coordinated operation becomes smaller. Similar observations were reported by Weniger et al. [26], who showed that although increasing battery capacity improves self-consumption, the relative gains decrease as storage capacity becomes larger. This indicates that increasing the amount of flexibility resources alone does not necessarily create proportionally larger coordination benefits. Instead, the effectiveness of flexibility resources depends on the opportunities for beneficial energy exchange within the community and on how well the resources complement each other.

5.2 Self-Consumption and Local Energy Utilization

The self-consumption results further support this interpretation. As shown in Figure 4.8, increasing PV capacity alone did not necessarily maximize the utilization of locally generated electricity within the LEC. Increasing PV capacity alone did not necessarily maximize the utilization of locally generated electricity within the LEC. Instead, high self-consumption was achieved when a balance existed between electricity demand, PV generation, and battery storage capacity. In cases where PV generation increased faster than the local demand and available storage capacity, a larger share of the electricity was exported to the grid, reducing the self-consumption ratio. Similar observations were reported by Weniger et al. [26], who showed that increasing PV and battery capacities does not necessarily lead to proportional increases in self-consumption, as surplus generation increasingly exceeds local demand and storage capabilities. This highlights a potential challenge within LECs, where maximizing installed PV capacity does not automatically result in more efficient local energy utilization.

The largest improvements in self-consumption through coordinated operation were generally observed in asymmetric household combinations, particularly in cases where one household had significant PV generation while the other household mainly contributed electricity demand (see Table 4.1). As illustrated in Figures 4.4 and 4.5, coordinated operation in these configurations allowed surplus PV electricity to be utilized internally within the LEC rather than exported to the grid. This observation is consistent with the findings of Llera-Sastresa et al. [27], who showed that higher collective self-consumption can be achieved when participants with complementary production and consumption profiles are combined, thereby increasing opportunities for local energy exchange.

From the perspective of the distribution system operator (DSO), lower grid imports and reduced peak demand can simultaneously represent both a challenge and an opportunity. Since many network tariffs are volumetric or power-based, lower electricity imports and lower peak demand reduce the network revenues collected by the DSO. However, coordinated operation within LECs can also provide system-level benefits by reducing local peak loads and mitigating congestion in the distribution network. By utilizing local flexibility resources to smooth demand and increase local consumption of renewable generation, LECs may reduce the need for costly grid reinforcements and facilitate the integration of additional PV systems and electrified loads. Consequently, although coordination may reduce short-term network revenues, it can also postpone investments in new infrastructure and contribute to a more efficient utilization of existing grid assets.

The results also indicate that tariff design plays a key role in determining the attractiveness of coordinated operation. Since the analysis was performed using conventional tariff structures, the results may change under future regulatory frameworks specifically designed for energy communities. New tariff models that reward flexibility services, local balancing, or congestion management could increase the economic incentives for coordinated operation and further enhance the value created within LECs. Conversely, tariff structures with weaker network-related charges may reduce the incentives for cooperation. Therefore, future developments in tariff design and regulation are likely to have a significant impact on the economic viability and operational benefits of LECs.

5.3 Tariff Structures and Economic Incentives

The tariff analysis further demonstrates that the economic value of coordinated operation is strongly influenced by the surrounding tariff structure, as shown in Figure 4.9. The largest coordination benefits were observed for the Peak, Transmission, and Transmission+Peak tariffs, where costs were directly linked to grid usage and simultaneous power demand. This suggests that tariff structures which penalize high peak demand create stronger incentives for households to coordinate their operation and utilize local flexibility resources more efficiently.

In contrast, lower tariff levels reduced the economic advantage of cooperation within the LEC. When grid-related costs are low, the financial benefits achieved through reducing imports and sharing electricity locally become smaller, making individual household operation relatively more competitive. The results therefore indicate that the profitability of coordinated operation depend not only on the technical availability of flexibility resources, but also on the surrounding market design and tariff incentives.

The results also indicate that network-related tariffs had a larger impact on coordination value than changes in spot price levels. Since the spot price is equal for both the LEC and the individual households, the coordinated operation cannot directly reduce the electricity market price itself. Instead, the main economic value is created through reductions in grid-related costs by lowering simultaneous imports and reducing peak demand. This suggests that future tariff structures may play a significant role in determining how attractive coordinated operation becomes for households participating in LECs.

5.4 Peak Reduction and Coordinated Flexibility Operation

The results also highlight potential operational challenges associated with coordinated flexibility management. Coordinated battery operation may shift peak demand to other periods rather than completely eliminating it. If multiple households respond similarly to the same tariff signals, new synchronized charging or discharging peaks may emerge. Similar challenges have been highlighted by Arteconi et al. [28], who showed that demand-side management strategies may unintentionally create new load peaks when multiple consumers respond similarly to the same control signals.This illustrates a broader challenge within coordinated energy systems, where local optimization strategies may unintentionally create new system-level problems. While coordinated operation can reduce the original peak demand within the LEC, it may simultaneously increase the risk of creating new concentrated demand periods if flexibility resources operate too similarly.

This demonstrates that coordinated operation is not only about reducing total demand or maximizing self-consumption, but also about managing when and how flexibility resources are utilized within the community. The findings therefore indicate that future LECs may require more advanced control strategies and tariff designs that not only incentivize flexibility, but also avoid synchronized operation that could create new stress on the local electricity grid.

5.5 Seasonal Dependency of Coordination Value

A seasonal dependency can also be observed in the results. The value of coordination generally increased during spring and summer due to higher PV production and larger opportunities for local energy sharing. During winter periods, the lower availability of locally generated electricity reduced the possibilities for coordinated operation and local flexibility utilization. This suggests that the value of cooperation within LECs is not constant throughout the year, but strongly dependent on seasonal production patterns and the availability of local renewable generation.

5.6 Benefit Allocation and Practical Implications

The results also highlight that the distribution of benefits within the LEC is strongly influenced by the selected allocation method and the distribution of flexibility resources between the participating households. Since households contribute differently to the coordinated operation through PV generation, battery storage, and electricity demand flexibility, the allocation method plays an important role in determining how attractive and fair the cooperation becomes for the individual members.

The results indicate that households contributing large amounts of PV generation and battery flexibility generally create a larger share of the economic value within the LEC. These households increase the opportunities for local energy sharing, peak reduction, and flexibility utilization, which directly contributes to lower system costs and higher coordination value. However, the contribution of flexibility resources also appears to depend on the surrounding household composition. In some cases, large PV and battery capacities mainly improve the profitability of the specific household itself rather than creating substantial additional value for the entire LEC. This further supports the observation that coordination value depends not only on the amount of flexibility resources, but also on how complementary the participating households are.

The results further suggest that, for the household configurations considered in this study, the balanced allocation method provides a reasonable compromise between fairness and incentives for flexibility provision. Compared to equal allocation, the balanced method distributes a larger share of the economic benefits to households contributing flexibility resources such as PV generation and battery storage, while still allowing households with limited flexibility resources to receive part of the collective value created within the LEC. This creates a more proportional relationship between contribution and compensation while maintaining incentives for cooperation between heterogeneous households. However, this conclusion is based on the simplified household configurations considered in this study, which only include electricity demand, PV generation, and battery storage. The introduction of additional flexibility resources, such as electric vehicles, heat pumps, or more diverse consumption patterns, could alter the relative contributions of individual households and thereby influence which allocation method provides the most appropriate balance between fairness and investment incentives. Consequently, a more detailed representation of household flexibility resources may be required to fully evaluate the performance of different allocation mechanisms in future LECs.

In contrast, the equal allocation method tends to distribute a relatively large share of the benefits to households with limited or no flexibility resources. While this may improve perceived equality between members, it may simultaneously weaken the incentives for households to invest in PV systems or battery storage if the additional value they create is redistributed too evenly among all participants. Over time, this could weaken the incentives for households to invest in flexibility resources, even though households with PV systems and battery storage still benefit from participating in the LEC compared with operating individually under the tariff structures considered in this study.

The findings therefore illustrate an important trade-off between fairness, investment incentives, and long-term cooperation within future LECs. Allocation methods that strongly reward flexibility contributions may improve investment incentives but risk creating unequal benefit distributions between households. On the other hand, highly equal benefit-sharing approaches may improve social acceptance while simultaneously weakening the incentives for households to contribute flexibility resources. The results therefore suggest that future LECs may require allocation mechanisms that balance both technical contribution and social fairness in order to create economically sustainable and socially acceptable cooperation structures. Furthermore, the technical contribution of individual households could be represented more accurately by considering operational metrics rather than solely installed capacities. Metrics such as total PV energy production, battery utilization, and the actual provision of flexibility services may provide a more representative measure of the value created by each household. Incorporating such operational indicators could improve the fairness and effectiveness of future allocation mechanisms and provide a more robust basis for balancing economic incentives with social acceptance within LECs.

5.7 Assumptions and Limitations

The model is designed to minimize electricity costs either for individual households or for the LEC as a whole. However, several assumptions and limitations must be considered when interpreting the results, both with respect to the input data and the simplifications required to represent a real electricity system.

As mentioned in the theory section, the model assumes that the LEC operates through a joint connection point. This does not fully represent the current structure of most residential electricity connections in Sweden, where households generally have individual metering points, electricity contracts, and grid tariffs. In practice, network tariffs, capacity-based charges, and other cost components are normally applied separately to each household rather than collectively at the community level. In contrast, the model aggregates the electricity flows of all households before applying the tariff structure. As a result, the LEC can benefit from reduced aggregated peak demand and improved load balancing, which lowers the calculated grid-related costs. This creates a mismatch between the modeled system and how LECs can currently operate in practice, since the model effectively treats the community as a single customer from the perspective of the grid.

In addition to grid tariffs, the regulatory treatment of energy tax on locally shared electricity is also simplified in the model. The model assumes that electricity generated and used within the LEC can be shared internally through the joint connection point without explicitly accounting for how energy tax would be applied between individual households. In practice, the possibility of sharing locally produced electricity without additional taxes or charges depends on the legal and technical structure of the community. Since the regulatory framework for LECs in Sweden is still evolving, the treatment of energy tax, network charges, and shared electricity flows remains uncertain. Consequently, some of the economic benefits identified in the model, particularly those related to peak demand reduction, transmission tariffs, and internal sharing of PV electricity, may be overestimated compared with what is currently achievable under existing Swedish regulations.

At the same time, this simplified structure makes it possible to isolate and analyze the technical and economic potential of coordination between households. The model therefore represents a best-case or future-oriented scenario in which shared metering arrangements, complementary networks, or alternative tariff structures could enable more collective optimization of local energy resources. The results should therefore primarily be interpreted as indicative trends rather than exact predictions of future LEC performance.

In addition, the optimization assumes perfect foresight of electricity prices, demand, and PV generation. In practice, forecasting errors and uncertain user behavior may reduce the achievable coordination benefits and economic savings. The study also assumes rational and fully coordinated operation of distributed energy resources, while real households may prioritize comfort, convenience, or individual preferences over cost-optimal operation.

Furthermore, the results are highly dependent on the selected tariff structures and electricity market conditions. Since Swedish electricity tariffs and market regulations are continuously evolving, the economic incentives for coordination and the distribution of benefits within the LEC may change in future energy systems. Similarly, the analysis is based on a limited number of household configurations and one year of operational data, which may not fully capture long-term variations in weather conditions, electricity prices, or consumption behavior.

The model also simplifies the behavior of the electricity grid itself. Factors such as voltage constraints, line congestion, transformer limitations, reactive power, battery degradation, and dynamic grid stability are not included. The study should therefore primarily be interpreted as an economic representation of local energy sharing and coordinated operation rather than a complete simulation of the physical distribution grid. In addition, while self-consumption is useful for evaluating the local utilization of PV generation, it does not necessarily capture the wider system value of flexibility or electricity exports to the surrounding grid.

5.8 Future Work

Several aspects could be further investigated in future work to improve the understanding of LECs and their potential value creation. One interesting extension would be to develop and evaluate tariff structures specifically designed for LECs. Since the results show that current network tariffs strongly influence the economic incentives for coordination, alternative tariff designs could potentially better reward local flexibility, peak reduction, and energy sharing within the community.

Future studies could also investigate larger and more complex LEC configurations with a greater number of participating members and more diverse consumption profiles. This could provide additional insight into how community size and member composition affect both the economic value creation and the allocation of benefits.

Another relevant extension would be to include additional flexibility resources, such as electric vehicles (EVs) and heat pumps. These technologies could significantly increase the flexibility potential within the LEC and may change both the operational behavior and the economic performance of the community. In particular, EV charging flexibility and thermal storage from heat pumps could provide additional opportunities for coordinated operation and peak demand reduction.

6

Conclusion

This thesis investigated the impact of coordinated operation within LECs by comparing individual and community operation under different PV, BESS, and tariff configurations using residential and commercial load profiles from Gothenburg, Sweden. The analysis showed that coordinated operation improved the utilization of local flexibility resources and that the largest benefits were achieved in communities with complementary load profiles and flexibility resources. The highest surplus reduction reached 3486.6 SEK (7%), while peak demand was reduced by up to 3.92 kW (20%). Coordinated operation also increased self-consumption significantly, reaching 100% in some cases and improving self-consumption by up to 67 percentage points compared to individual operation.

The results further showed that tariff design strongly influences the value of coordination. Peak-based tariffs created the largest economic incentives for cooperation, whereas variations in spot prices had a smaller impact on the overall benefits. A clear seasonal dependence was also observed. Coordination benefits were generally higher during spring and summer due to increased PV generation and greater opportunities for local energy sharing and battery utilization, while lower solar production during winter reduced the available flexibility and the resulting coordination value.

In summary, the findings demonstrate that coordinated operation within LECs can improve both economic and operational performance. The largest benefits were achieved when complementary flexibility resources were combined and operated under tariff structures that reward peak demand reduction, highlighting the importance of both market design and fair benefit-sharing mechanisms for future LECs.

Bibliography

[1] Statens energimyndighet, “Energigemenskaper: Förutsättningar och förslag på främjandeinsats,” Tech. Rep. ER 2024:20, Energimyndigheten, Eskilstuna, Sweden, 2024.

[2] Swedish Energy Agency, “Energy sharing in sweden: Legal conditions and opportunities,” tech. rep., Swedish Energy Agency, Eskilstuna, Sweden, 2023.

[3] Sveriges Energigemenskaper, “Vad är en energigemenskap?,” 2025.

[4] European Commission, “Energy communities,” 2025.

[5] European Commission, “In focus: Energy communities to transform the eu’s energy system,” 2022.

[6] N. Johansson and J. Widén, “Market and revenue allocation models for local energy communities,” research report, Chalmers University of Technology, 2023.

[7] Sveriges Energigemenskaper, “Effektlogik,” 2023.

[8] European Commission Joint Research Centre, “Energy communities: An overview of energy and social innovation,” tech. rep., Publications Office of the European Union, 2025.

[9] “Local energy communities and flexibility services: A review of concepts, actors, and market integration,” *Smart Energy*, vol. 10, p. 100125, 2023.

[10] European Commission, “The role of distribution system operators (dsos) in supporting the growth of energy communities,” 2023.

[11] J. Jurasz and P. E. Campana, “The potential of photovoltaic systems to reduce energy costs for office buildings in time-dependent and peak-load-dependent tariffs,” *Sustainable Cities and Society*, vol. 44, pp. 871–879, 2019.

[12] L. Taieb, M. Neuwirth, and H. Mecit, “Battery energy storage concepts and their potentials for local energy communities from a local utility point of view,” in *Proc. IEEE REM*, 2024.

[13] F. Johnsson, J. Widén, and Åsa Wahlström, “Implications of heat pump and district heating solutions for positive energy districts with photovoltaic systems,” *Energy and Buildings*, vol. 325, p. 115060, 2025.

[14] M. Dassisti, N. Intini, M. Falagario, L. Schinaia, and V. A. Romano, “Optimal design of electric mobility services for a local energy community,” *Applied Energy*, vol. 259, p. 114150, 2020.

[15] Nord Pool, “Day-ahead market,” 2026.

[16] European Union Agency for the Cooperation of Energy Regulators (ACER), “Electricity network tariff practices,” tech. rep., ACER, 2025.

[17] Göteborg Energi, “Elnätsavgiften,” 2025.

[18] Energimarknadsbyrån, “Energiskatt,” 2025. Accessed: 2026-05-18.

[19] Energimyndigheten, “Elkundens bidrag till förnybar elproduktion,” 2025.

[20] European Commission, “Electricity market design,” 2026.

[21] M. Mazidi, A. Sridhar, D. Steen, E. Malakhatka, S. Abouebeid, F. Niklasson, L. A. Tuan, and H. Wallbaum, “Evaluating the potential for developing local energy communities in sweden: Case studies at jättesten and chalmers campus,” in *Energy Informatics* (I. Martinac, B. N. Jørgensen, Z. Ma, R. Unnthórsson, and C. Bordin, eds.), vol. 16096 of *Lecture Notes in Computer Science*, pp. 173–186, Cham: Springer, 2025.

[22] PVGIS, “Pvgis photovoltaic geographical information system,” 2026. Accessed: 2026-05-18.

[23] P. Ercoli, A. Mugnini, and A. Arteconi, “Demand response for renewable energy communities: Exploring coordination of prosumer-generated pv and flexible aggregated demand in the italian framework,” *Energy and Buildings*, vol. 340, p. 115814, 2025.

[24] V. Casalicchio, G. Barchi, F. Calabria, G. Manzolini, M. G. Prina, and D. Moser, “Advancing renewable energy community planning through integrated sector-coupling and economies of scale,” *Applied Energy*, vol. 395, p. 125942, 2025.

[25] P. Huang, M. Han, X. Zhang, S. A. Hussain, R. Jayprakash Bhagat, and D. Hogarehalli Kumar, “Characterization and optimization of energy sharing performances in energy-sharing communities in sweden, canada and germany,” *Applied Energy*, vol. 326, p. 120044, 2022.

[26] J. Moshövel (Struth), K.-P. Kairies, M. Leuthold, A. Aretz, M. Bost, S. Gährs, M. Cramer, E. Szczechowicz, B. Hirschl, A. Schnettler, and D. U. Sauer, “Pv-benefit: A critical review of the effect of grid integrated pv-storage-systems,” 11 2013.

[27] E. Llera-Sastresa, J. Gimeno, J. L. Osorio-Tejada, and P. Portillo-Tarragona, “Effect of sharing schemes on the collective energy self-consumption feasibility,” *Energies*, vol. 16, no. 18, 2023.

[28] A. Arteconi, N. Hewitt, and F. Polonara, “Domestic demand-side management (dsm): Role of heat pumps and thermal energy storage (tes) systems,” *Applied Thermal Engineering*, vol. 51, no. 1, pp. 155–165, 2013.

A

Appendix 1

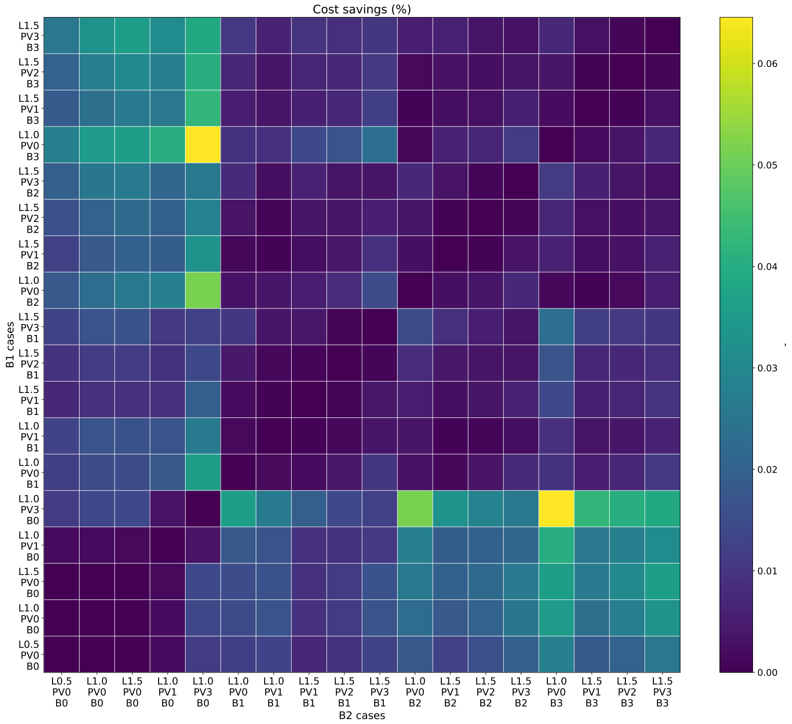

Figure A.1: Matrix showing the surplus(%).

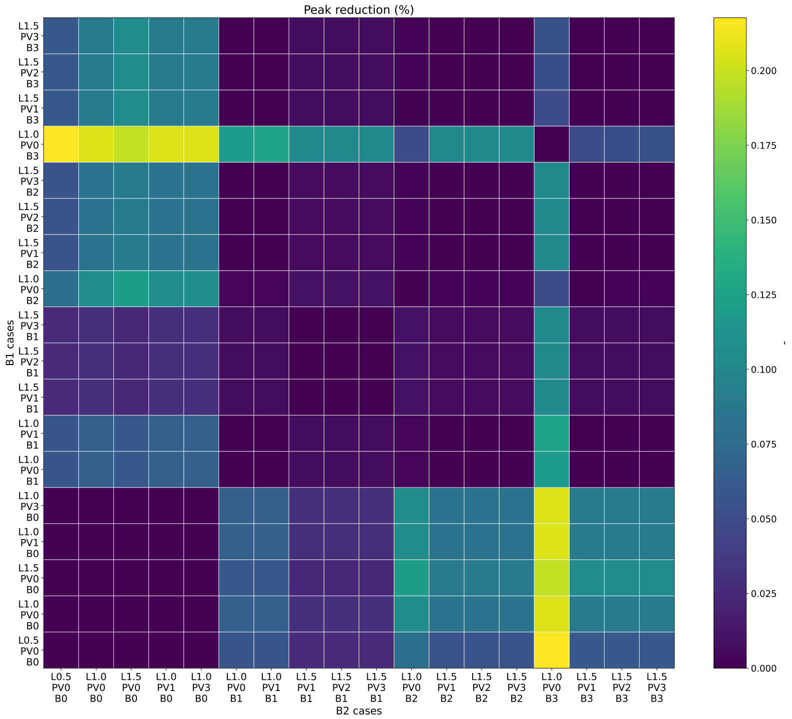

Figure A.2: Matrix showing the peak reduction (%).

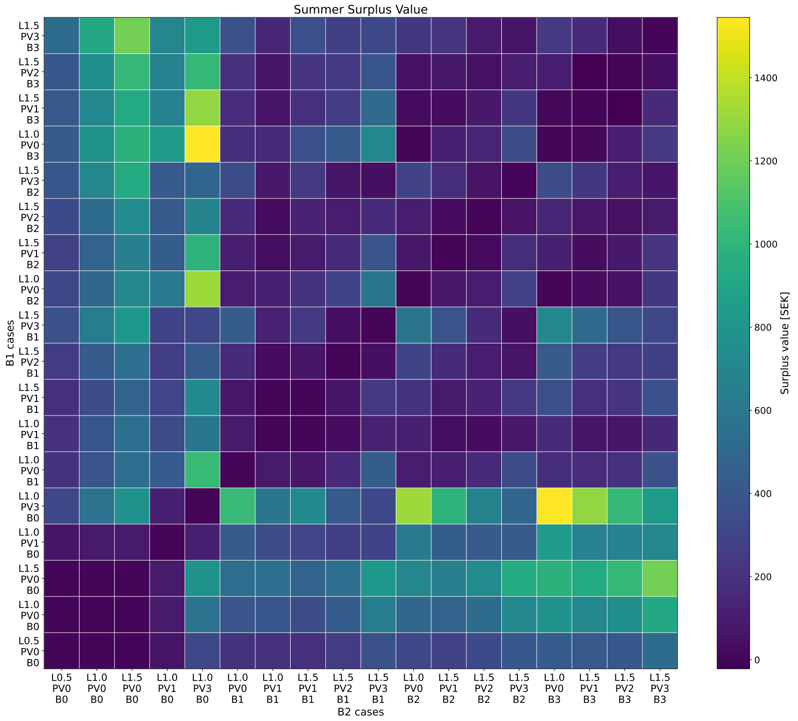

Figure A.3: Summer surplus heatmap.

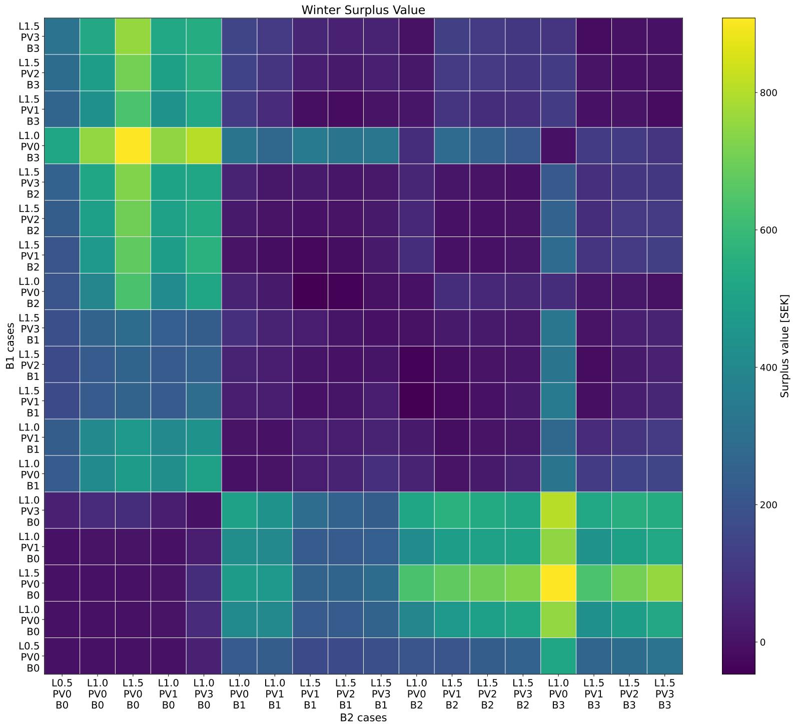

Figure A.4: Winter surplus heatmap.

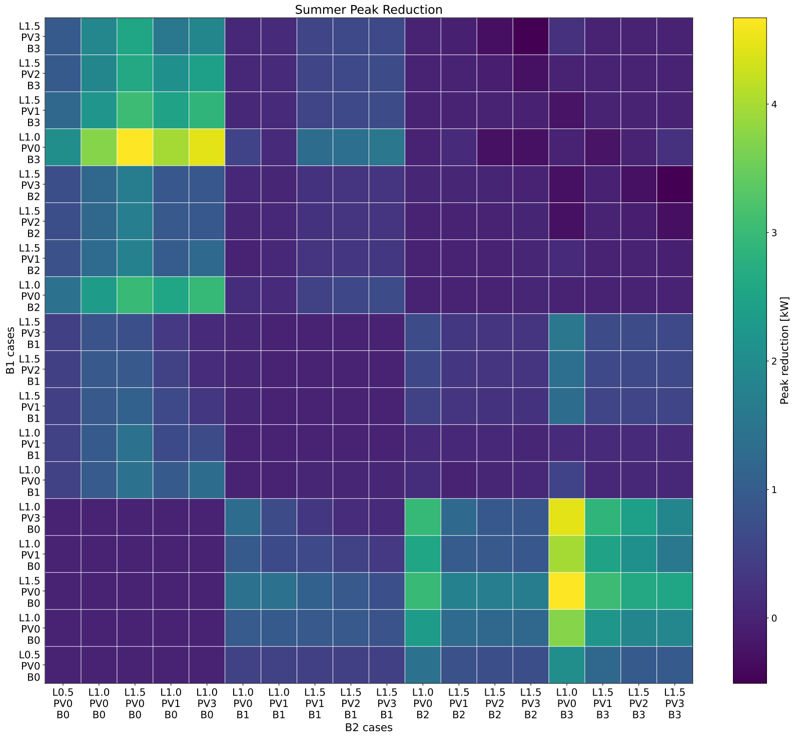

Figure A.5: Summer peak reduction heatmap.

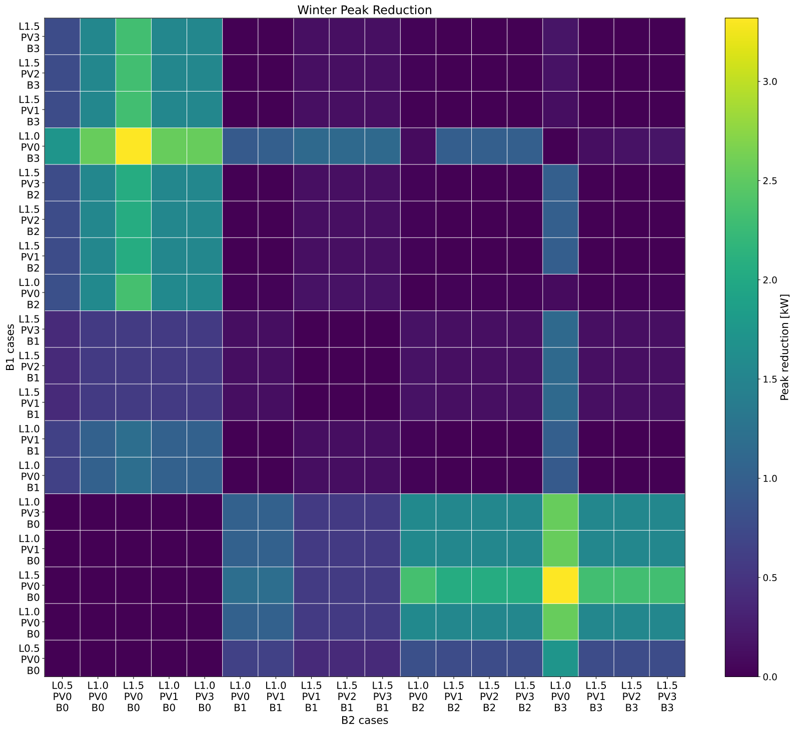

Figure A.6: Winter peak reduction heatmap

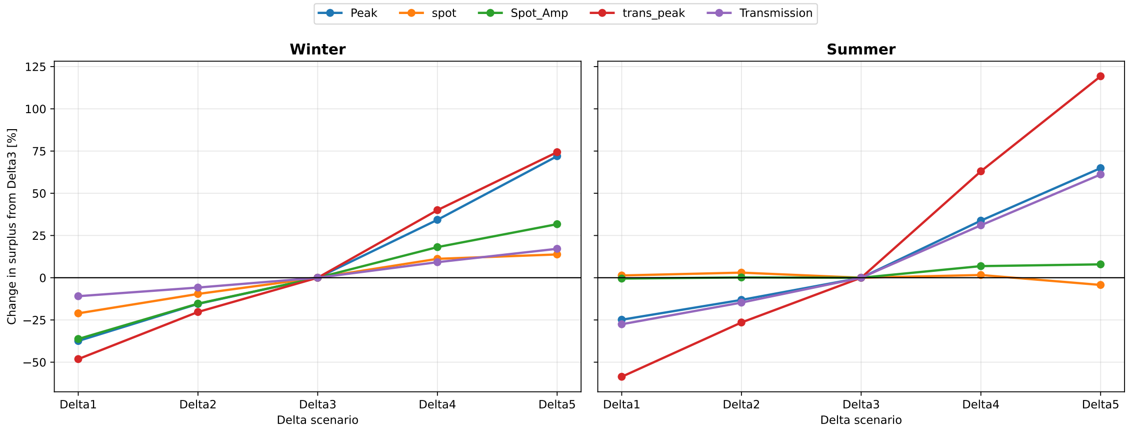

Figure A.7: Monthly variation in surplus changes for different tariff structures under varying delta scenarios.

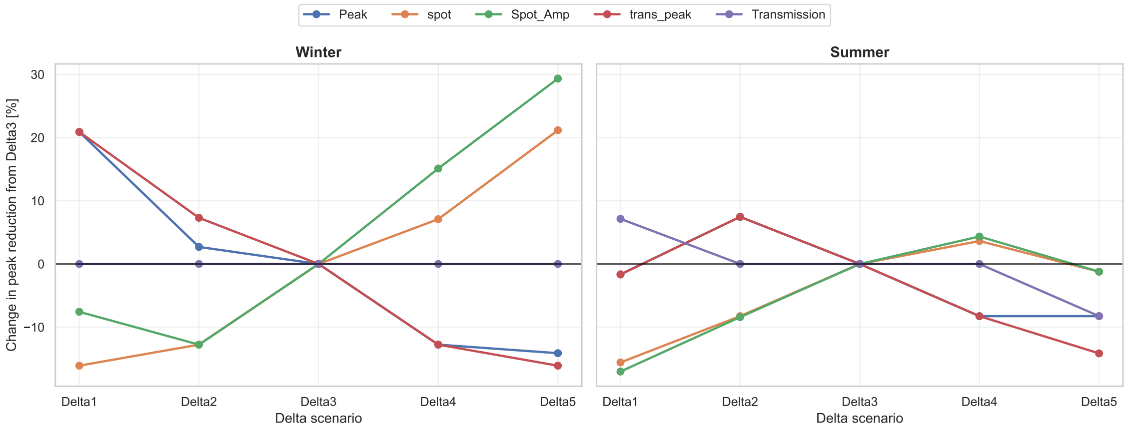

Figure A.8: Monthly variation in peak reduction changes for different tariff structures under varying delta scenarios.

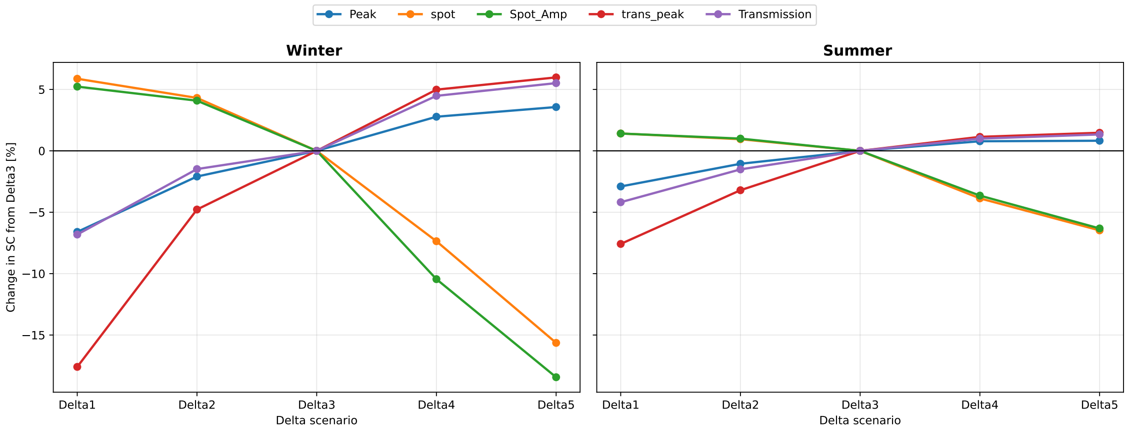

Figure A.9: Monthly variation in self consumption changes for different tariff structures under varying delta scenarios.

DEPARTMENT OF ELECTRICAL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

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