Potential

And

Opportunities

Energy Communities

in Denmark

Jelena Nikolic, Peter Sorknæs and Gate 21

AALBORG UNIVERSITY

GATE 21

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

As energy communities are becoming increasingly important actors in the energy transition, the aim of this report is to demonstrate the potential for establishing energy communities between households and public buildings.

It should be noted that the results presented in this report are limited, as they do not include investment analyses nor a detailed economic analysis. Therefore, the findings cannot be used as a basis for decision-making. Nevertheless, the project results highlight the potential of energy communities and the importance of cooperation between citizens and public institutions in sharing energy through community-based systems, showing the need for future research in the field.

This report is a result of a research collaboration between reserachers in the Sustinable Energy Planing research group (SEP) at Aalborg University (Jelena Nikolic and Peter Sorknæs) and Gate 21 from August to November 2025. During the implementation of the project, SEP was responsible for data analysis, research, and report writing, while Gate 21 contributed by collecting data, providing comments, and reviewing documents. The authors from SEP had sole authority to decide on the final wording and content of the report.

Methodologically, the report employs a set of archetypes representative of rural and urban contexts, each comprising 300 households/apartments with optional inclusion of an educational institution and a public building. Electricity supply portfolios vary by context (wind and solar in rural energy communities; rooftop photovoltaic (PV) in urban energy communities), and scenarios systematically introduce electric vehicles (EVs), battery storage, and heat supply options (household air-to-water heat pumps, district heating with air-source or ground-source heat pumps, and heat storage). Hourly and monthly demand and production profiles are constructed from Danish data sources and used in the energy system analysis tool energyPRO to simulate scenarios. As a result, for each scenarios operation, import/export of electricity and peaks as well as cost of sale/purchase of electricity with different tariff schemes are provided for each scenario.

Across rural archetypes, results show that combining wind power and PV substantially help meet annual electricity demand, but seasonal variability necessitates both import and export from the surrounding electricity system. Adding battery storage alters import/export timing to capture price arbitrage (importing when prices are low and exporting at high-price periods), improving the community balance while supporting greater integration of renewables, though also increases the import and export peaks between the ECs and the surrounding electricity system. Inclusion of EVs raises demand primarily at night, partly due to driving demand profiles and partly due to grid tariffs, which can align well with wind power production. The inclusion of an educational building in an energy community alongside households improves daytime matching with PV, demonstrating the value of complementary demand profiles. Integrating heat in the analyses, both household heat pumps and district heating based on heat pumps, raises electricity demand in the colder months. In those systems using ground-source heat pumps over air-to-water heat pumps reduce overall electrical input for heat, reducing variable operational csots and decreasing peak electricity imports.

In urban archetypes reliant solely on PV, import are significant in winter months. Like for the rural archetypes, batteries can increase import and export to capture price arbitrage, though can only facilitate local integration of produced electricity in the summer months. Adding schools and public buildings in energy communities improve self-consumption through diversified daytime loads.

Comparative cash-flow tables indicate that energy communities with storage (batteries and/or heat storages) tend to increase revenues from electricity sales while decreasing purchase costs, with tariff impacts reflecting higher activity levels but not offsetting the systemic gains. Though, as investment and fixed operation and maintance costs are not included in this study, the economic results can not show if storages are relevant from an economic perspective for energy communities. It should be noted that this report does not identify if using batteries should be done in energy communities, as:

a) The results indicate an economic advantage of battery use exclusively among members of the energy community in terms of revenue from electricity sales and the possibility of purchasing cheaper electricity. However, this study does not include the investment cost, etc. of battery implementation;

b) Since such use of batteries leads to increased peaks in electricity imports and exports, it is necessary to assess their impact not only from the perspective of energy community members but also on the grid.

In this regard, the justification for investing in battery systems should be the subject of new comprehensive research that considers all the aspects mentioned above.

The results of this study provide insights into the potential benefits and opportunities for establishing energy communities, as well as the importance of implementing self-consumption through the pairing of different energy demand profiles. However, due to limitations in this work these aspects should be further analysed in future research.

EXECUTIVE SUMMARY (PÅ DANSK)

Energifællesskaber bliver stadig vigtigere aktører i den grønne omstilling. Formålet med denne rapport er at demonstrere potentialet for at etablere energifællesskaber mellem husholdninger og offentlige bygninger.

Det skal bemærkes, at de resultater, der præsenteres i denne rapport, er begrænsede, da de hverken omfatter investeringsanalyser eller en detaljeret økonomisk analyse. Derfor kan resultaterne ikke anvendes som grundlag for beslutningstagning. Ikke desto mindre fremhæver projektets resultater energifællesskabernes potentiale og vigtigheden af samarbejde mellem borgere og offentlige institutioner om at dele energi gennem fællesskabsbaserede systemer, hvilket viser behovet for fremtidig forskning på området.

Denne rapport er et resultat af et forskningssamarbejde mellem forskningsgruppen for Bæredygtig Energiplanlægning (BE) ved Aalborg Universitet (Jelena Nikolic og Peter Sorknæs) og Gate 21 fra august til november 2025. Under projektets gennemførelse var BE ansvarlig for dataanalyse, forskning og rapportskrivning, mens Gate 21 bidrog med dataindsamling, kommentarer og dokumentgennemgang. Forfatterne fra BE havde enekompetence til at beslutte den endelige formulering og indhold af rapporten.

Metodisk anvender rapporten et sæt arketyper for energifællesskaber, der repræsenterer landlige og urbane kontekster, hver bestående af 300 husholdninger/lejligheder med mulighed for at inkludere en uddannelsesinstitution og en offentlig bygning. Elforsyningsporteføljer varierer efter kontekst (vind og sol i landlige energifællesskaber; tagmonteret solceller i urbane energifællesskaber), og scenarier introducerer systematisk elbiler, batterilagring og varmeløsninger (husstandsluft-til-vand-varmepumper, fjernvarme med luft- eller jordvarmepumper samt varmelagring). Time- og månedsprofiler for efterspørgsel og produktion er konstrueret ud fra danske datakilder og anvendt i energisystemanalyseværktøjet energyPRO til at simulere scenarier. Som resultat gives for hver scenarie drift, import/eksport af elektricitet og spidsbelastninger samt salgs-/købsomkostninger for elektricitet under forskellige tarifordninger.

På tværs af landlige arketyper viser resultaterne, at kombinationen af vindkraft og solceller i væsentlig grad hjælper med at dække det årlige elforbrug, men sæsonvariation kræver både import og eksport fra det omgivende elsystem. Tilføjelse af batterilagring ændrer import-/eksporttidspunkter for at udnytte prisarbitrage (import når priserne er lave og eksport i perioder med høje priser), hvilket forbedrer fællesskabets balance og understøtter større integration af vedvarende energi, men øger også import- og eksportspidser mellem energifællesskaberne og det omgivende elsystem. Inklusion af elbiler øger primært efterspørgslen om natten, dels på grund af kørselsprofiler og dels på grund af net-tariffer, hvilket kan passe godt til vindkraftproduktion. Inklusion af en uddannelsesbygning i et energifællesskab sammen med husholdninger forbedrer dagsmatchning med solceller og viser værdien af komplementære efterspørgselsprofiler. Integration af varme i analyserne, både husstandspumper og fjernvarme baseret på varmepumper, øger elforbruget i de kolde måneder. I systemer, der anvender jordvarmepumper frem for luft-til-vand-varmepumper, reduceres det

samlede elinput til varme, hvilket reducerer de variable driftsomkostninger og mindsker spidsimport af el.

I urbane arketyper, der udelukkende er afhængige af solceller, er importen betydelig i vintermånederne. Ligesom for de landlige arketyper kan batterier øge import og eksport for at udnytte prisarbitrage, men kan kun facilitere lokal integration af produceret elektricitet i sommermånederne. Tilføjelse af skoler og offentlige bygninger i energifællesskaber forbedrer selvforbruget gennem diversificerede dagsbelastninger.

Sammenlignende pengestrømstabeller indikerer, at energifællesskaber med lagring (batterier og/eller varmelagre) har tendens til at øge indtægterne fra el-salg, samtidig med at købsomkostningerne falder, med tarifpåvirkninger, der afspejler højere aktivitetsniveauer, men ikke opvejer de systemiske gevinster. Da investerings- og faste drifts- og vedligeholdelsesomkostninger ikke er inkluderet i denne undersøgelse, kan de økonomiske resultater ikke vise, om lagring er relevant fra et økonomisk perspektiv for energifællesskaber. Det skal bemærkes, at denne rapport ikke identificerer, om brug af batterier bør ske i energifællesskaber, da:

a) Resultaterne indikerer en økonomisk fordel ved batteribrug udelukkende blandt medlemmer af energifællesskabet i form af indtægter fra el-salg og muligheden for at købe billigere elektricitet. Denne undersøgelse inkluderer dog ikke investeringsomkostningen og lignende ved batteriimplementering;

b) Da en sådan brug af batterier medfører øgede spidser i elimport og -eksport, er det nødvendigt at vurdere deres indvirkning ikke kun fra energifællesskabets perspektiv, men også på elnettet.

I denne henseende bør begrundelsen for investering i batterisystemer være genstand for ny omfattende forskning, der tager højde for alle de ovennævnte aspekter.

Resultaterne af denne undersøgelse giver indsigt i de potentielle fordele og muligheder ved etablering af energifællesskaber samt vigtigheden af at implementere selvforbrug gennem kombination af forskellige energiefterspørgselsprofiler. Dog, grundet begrænsningerne i dette arbejde, bør disse aspekter analyseres nærmere i fremtidig forskning.

Abbriviations

EC	**Energy Community**
EU	European Union
EV	Electric vechicle
PtX	Power-to-X
TSO	Transmission system operator
DSO	Distribution system operator
PV	Photovoltaic
MILP	Mixed-integer linear programming
HP	Heat pump
DH	District heating
hh	Households
sch	Educational building
pb	Public building
EC A1a	Households
EC A1b	Households and EVs
EC A1c	Households, EVs and battery
EC A1d	Households, EVs and HPs
EC A1e	Households, EVs , HPs and battery
EC A2a	Households, educational building and EVs
EC A2b	Households, educational building, EVs and battery
EC A2c	Households, educational building and HPs
EC A2d	Households, educational building with district heating system (air-to-water HP) without heat storage
EC A2e	Households, educational building with district heating system (air-to-water HP) with heat storage
EC A2f	Households, educational building with district heating system (air-to-water HP) with both heat storage and battery
EC A2g	Households, educational building with district heating (groungd-source HP) without battery
EC A2h	Households, educational building with district heating (ground-source HP) with battery
EC A3a	Households, educational and public building and EVs
EC A3b	Households, educational and public building, EVs and battery
EC A3c	Households, educational and public building and HPs
EC A3d	Households, educational and public building with district heating system (air-to-water HP) without heat storage
EC A3e	Households, educational and public building with district heating system (air-to-water HP) with heat storage
EC A3f	Households, educational and public building with district heating system (air-to-water HP) with both heat storage and battery
EC A3g	Households, educational and public building with district heating (ground source HP) without battery
EC A3h	Households, educational and public building with district heating (ground-source HP) with battery
EC A4a	Apartments and EVs
EC A4b	Apartments, EVs, and an educational institution
EC A4c	Apartments, EVs, an educational institution, and a public building
EC A4d	Apartments, EVs, and battery
EC A4e	Apartments, EVs, an educational institution, and battery
EC A4f	Apartments, EVs, an educational institution, a public building, and battery

1. INTRODUCTION

In this chapter, the concept of energy communities (ECs) is introduced. This is followed by an overview of their potential benefits and advantages, based on findings from previous studies. Finally, the main legal and regulatory aspects at the European Union (EU) and Danish levels are presented.

1.1. WHAT ARE ENERGY COMMUNITIES?

Energy transition and the shift towards low-carbon fuels represent one of nowdays challenges. In order to accelerate the energy changes and make it more accessible and inclusive for citizens, during 2019, the EU adopted the "Clean Energy for All Europeans" package [1]. The aim of the Package is supporting and facilitating the decarbonization of Europe by promoting energy efficiency, regulating the energy market, and establishing new regulatory frameworks. The Clean Energy for All Europeans initiative aligns with the European Green Deal [2], which emphasizes that the energy transition should leave no one behind, and that end-users should be the driving force behind a fair energy transition. Accordingly, and as a response to various energy monopolies and market instabilities, the concept of ECs has emerged, bringing a new model within the energy market that enables the decentralization of the energy system through the active involvement of citizens in the energy production process.

Essentially, ECs are local initiatives in which citizens come together to jointly produce, share, and manage energy in a democratic manner, where economic gain is not the primary motivating factor [3]. Fundamentally, Energy Cooperatives and therefore most of ECs[1] are based on seven cooperative principles [4], which are illustrated in Figure 1.1.

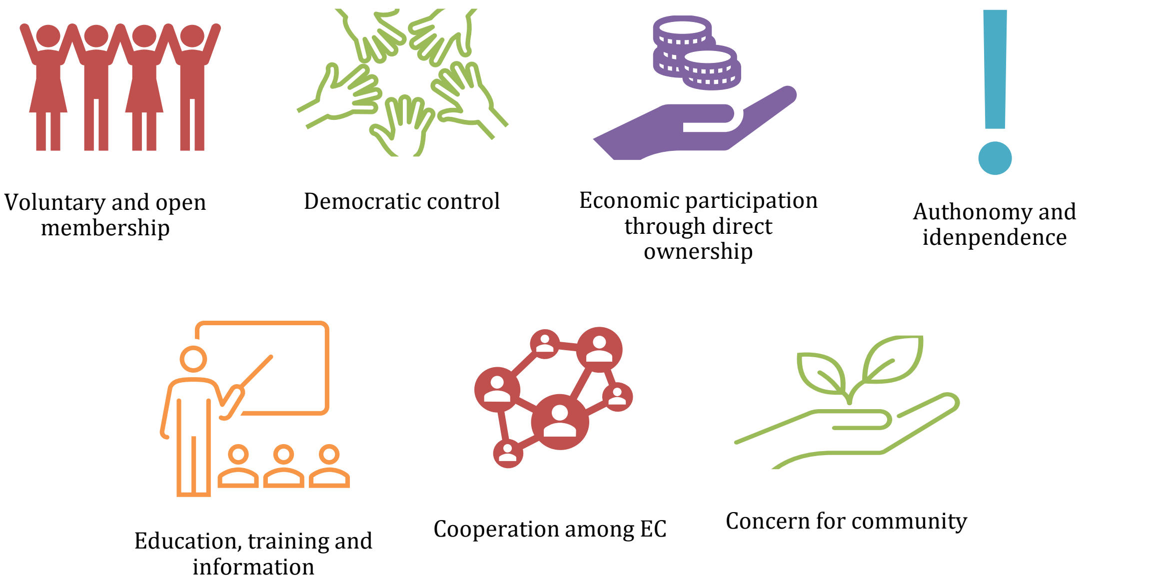

Figure 1.1. Cooperative Principles Underpinning Energy Communities

[1] These two terms often have the same meaning, and it can be said that the concept of energy communities originated from the idea of energy cooperatives. However, the new legal frameworks define the difference (more about this in Chapter 1.4.).

According to the principles [5], ECs should be based on voluntary and open membership, allowing the participation of all individuals who are willing and able to use the services of the EC. All members of an EC are expected to accept the responsibilities of membership and to treat other members in a non-discriminatory manner. Decisions within the community are made collectively, with each member having an equal voting right, typically following the principle of "one member, one vote."

Furthermore, all members may invest in community projects and participate in decisions regarding the distribution of financial gains. The EC should remain an autonomous organization, governed solely by its participants. Through collaboration with other communities at the local, national, and international levels, ECs engage in education, training, and information-sharing activities, promoting the concept of citizen-led energy while contributing to the social and economic well-being of the local community.

In this way, ECs are not merely market participants, but a concept that aim at fostering solidarity, local resilience, and democratic resource management. By investing in joint projects, promoting education, and ensuring transparent governance, ECs can offer innovative solutions to energy transition challenges that are tailored to local needs.

1.2. POTENTIAL BENEFITS AND ADVANTAGES OF ENERGY COMMUNITIES

Studies have shown that ECs can promote the use of renewable energy sources (RES), thereby encourage sustainable energy production. Through local control and citizen-owned infrastructure, studies also have found that ECs can help reduce dependence on external factors and price fluctuations in the energy supply process. Moreover, they can contribute to combating energy poverty by including energy vulerable households in the energy exchange process. In this way, energy production becomes a social good and a catalyst for societal change.

Based on data presented in a report drawing from the experiences of ECs in Greece and an analysis of available literature [6], as well as a study examining the potential benefits and opportunities for ECs [7], Table 1 provides an overview of the potential advantages of establishing ECs that has been identified in other studies.

The potential Benefits of Energy Communities. Based on [6] and [7]

Potential Economic benefits

Local Investment in the Community	Citizens can invest in projects and services that benefit their local community.
Inovation	Social challenges at the local level often give rise to new solutions, such as car sharing or energy sharing with energy-poor households.
Reinvestment Option	The profits generated can be used to implement new projects, with funds remaining in the community and directed to new opportunities and technologies.
Access to energy	Members of the EC use the energy they produce, which develops awareness of the responsible use of energy. Also, in times of crisis and possible energy sanctions, EC members may have energy available at the time of production.
Pooling resources	The distribution of financial investments within the community makes it possible to invest in energy projects even in cases where individual households do not have sufficient financial resources to develop the project on their own.
Creating new jobs and promoting local development	In projects for the realization of ECs, local labor should be engaged and support should be established for local sectors, such as agriculture or tourism. This creates an opportunity for new jobs at the community level.

The Potential Benefits of Environmental Protection

Environmental protection at the local level	ECs projects are smaller-scale, tailored to local needs and in the hands of citizens. In this way, the possibility of misuse of local natural resources is reduced because the projects are under the supervision of citizens.
A sustainable approach to energy use	Through education, the efficient use of available resources and changes in behavior are influenced, which enable the production and consumption of energy to be more in line.
Reducing CO_2 emissions	By investing in RES projects, ECs potentially reduce carbon dioxide emissions in the electricity generation sector and increase the share of RES in the country's overall energy mix.

Potential Social benefits

Strengthening Trust	Through the development of joint projects and transparency, the development of trust is influenced and the possibility of civic participation in new projects can increase.
Strengthening social equity and fighting energy poverty	ECs potentially enable the inclusion of vulnerable and marginalized groups, through the development of new projects, as well as the possibility of energy sharing and reinvestment in the construction of new special purpose projects and the provision of concrete assistance.
Self-sustainability and resilience of the local community while jointly fighting climate change	Energy produced locally can increase the security of energy supply and can facilitate the transition from fossil fuels to production capacities that use the potential of territorially available RES.
Empowering Democracy and Promoting Justice	ECs are based on democratic principles, through fair and equal participation of all members in decision-making processes. The benefits generated in the community are evenly distributed and decided by each member.
Achieving better social cooperation and local unity	EC projects involve local authorities and decision-makers, citizens, institutions and organizations. By advocating for the common good, they can influence the creation of social synergy and the fight for common local interests.
Education and dissemination of knowledge and experience	ECs, which are examples of good practice, through the processes of education and training, can contribute to the dissemination of knowledge, and the creation of proposals for solutions for developing new ECs. ECs can also be participants in (educational) projects and associates of educational institutions.
Improving health and quality of life	Via the use of RES, local pollution can be reduced, thus influencing the promotion of health. Also, by improving energy efficiency, or providing more efficient forms of heating and/or cooling, energy communities affect the improvement of thermal comfort and quality of life.

1.3. ENERGY COMMUNITIES IN EUROPEAN LEGAL FRAMEWORKS

Due to their numerous potential advantages, ECs have been recognized as a potential solution for helping to accelerate the decarbonization process, which is why they have become a subject of energy policy at various levels. Within the "Clean Energy for All Europeans" package, directives have been developed to regulate ECs, among which the most important are: the Renewable Energy Directive (EU 2018/2001) [8], the Directive on Common Rules for the Internal Market for Electricity (EU 2019/944) [9] and the Energy Efficiency Directive (EU 2023/955) [10].

Within the aforementioned Directives, ECs were defined for the first time through two legal forms: Citizen Energy Communities (CEC) and Renewable Energy Communities (REC)[2]. Although both models involve the active participation of citizens in the energy transition process, the key difference between them lies in ownership structure and organizational form. In both cases, the purpose of establishment is not to generate financial profit, but to achieve economic, environmental, and social benefits. ECs may engage in the production, distribution, or consumption of locally generated energy. It is important to highlight that citizens can collectively participate not only in the electricity sector, but also in the thermal energy sectors and in improving energy efficiency.

In September 2024, the European Commission published a guide intended for Member States and relevant stakeholders, with the aim of facilitating the implementation of the revised directives on RES and energy efficiency (EE) [11]. Among the numerous recommendations, particular emphasis is placed on the guidelines from Article 20a, which relate to the sectoral integration of RES [12], highlighting the importance of ECs through the active involvement of consumers, which can contribute to greater flexibility in the energy system. Additionally, distribution system operators (DSO) are required to provide access to (anonymized) data on the potential use of electricity supplied to the grid by ECs, thereby improving the position and economic sustainability of citizen-led RES projects.

Projections are indicating that by 2050, citizens could participate in the production of 45% of energy from RES [13]. In this context, clearly defined legal frameworks play a key role, and EU Member States, as well as countries in the accession process, are required to align the aforementioned directives with their national legislation.

[2] A Citizen Energy Community (CEC) is a legal entity based on voluntary and open participation, under the effective control of its members or shareholders, who may be natural persons, local authorities—including municipalities—or small enterprises (Directive (EU) 2019/944).

A Renewable Energy Community (REC) is a legal entity which, in accordance with applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members who are natural persons, small and medium-sized enterprises, or local authorities, including municipalities (Directive (EU) 2018/2001).

1.4. ENERGY COMMUNITIES IN THE LEGAL FRAMEWORKS OF DENMARK

Denmark stands out for its long tradition of citizen cooperation and is considered one of the EU countries with the highest share of citizen ownership in energy projects, with more than 633 Energy Cooperatives. Members of these cooperatives have most commonly come together around district heating projects or renewable energy production, primarily wind, solar, and biogas. Estimates indicate that approximately 52% of the total installed wind turbine capacity in Denmark is under some form of citizen ownership, as well as 64% of district heating systems [14], with more than 320 registered district heating cooperatives [15].

In order to adequately respond to new European regulations and enable energy sharing, the Danish Energy Agency (DEA) introduced a new concept of ECs in 2019. In line with Denmark's National Energy and Climate Plan (NECP) [16] the term EC encompasses both CEC and REC. In the case of REC, community members must reside in close proximity to the project, whereas for CEC there are no restrictions regarding distance [17]. Prior to the adoption of this strategic document, energy sharing among multiple consumers was only possible within residential communities.

In order to implement the principles of Directive (EU) 2018/2001 and to develop a legal framework for ECs in Denmark, an executive order was adopted concerning RECs, CECs, electricity trading companies, and collective electricity supply companies. This regulation defines that ECs may engage in activities such as energy production, supply, consumption, aggregation, storage, provision of energy efficiency services, electric vehicle charging, and other energy-related services. However, they are not permitted to own, establish, purchase, or lease distribution networks [18].

In accordance with the Executive Order, ECs must be treated equally to other market participants, whether they are companies or individual consumers. This enables them to access the electricity market, engage in energy trading, and operate as aggregators. Their operations should be conducted through transparent and straightforward procedures, with an obligation to assume financial responsibility for any disturbances they may cause in the distribution energy system [18].

Changes in legislation have led to a clear distinction between ECs and energy cooperatives. Unlike cooperatives, ECs have the ability to share the electricity they produce and own through a collective network, which obliges them to pay grid tariffs and taxes.

To mitigate the financial burden of electricity sharing and to incentivize cost reducing use of the local electricity grid, a local collective tariff for EC has been introduced by Cerius-Radius DSO and will be applied in their areas of their jurisdiction. This tariff applies when the community contributes to reducing grid load, provided that the produced energy is consumed locally within 15 minutes of generation. Such an approach encourages the involvement of various actors with diverse consumption patterns, thereby maximizing benefits, reducing costs, and generating positive effects on the electricity distribution system [19].

When it comes to the sharing of heat, the Danish Heat Supply Act [20] aims to promote solutions that are socio-economically and environmentally sustainable for end users. The Act also encourages the use of RES in the heating sector and ensures equal treatment of all participants. Companies engaged in district heating must have this activity as their core business function. Within a district heating EC, the produced energy may be distributed exclusively within the community, without the possibility of transfer beyond its boundaries.

Since the concept of electricity sharing within ECs in Denmark is still under development, it is essential to understand their position and role within specific energy frameworks. At the same time, when analyzing the overall electricity demand across all sectors [21], as shown in Figure 1.2, it becomes evident that potential members of ECs (households, public buildings, and small and medium-sized enterprises) represent significant end-users of electricity.

In this regard, the aim of this report is to analyze different types of ECs, providing an assessment of how different members contribute to reducing the need for electricity distribution companies to expand the grid. The study does not include an analysis of the local electricity grid or potential changes in grid-related costs. Instead, it focuses on how changes in electricity exchange between the ECs and the grid can be used to discuss how ECs might organize to reduce their reliance on the local grid in a simplified way.

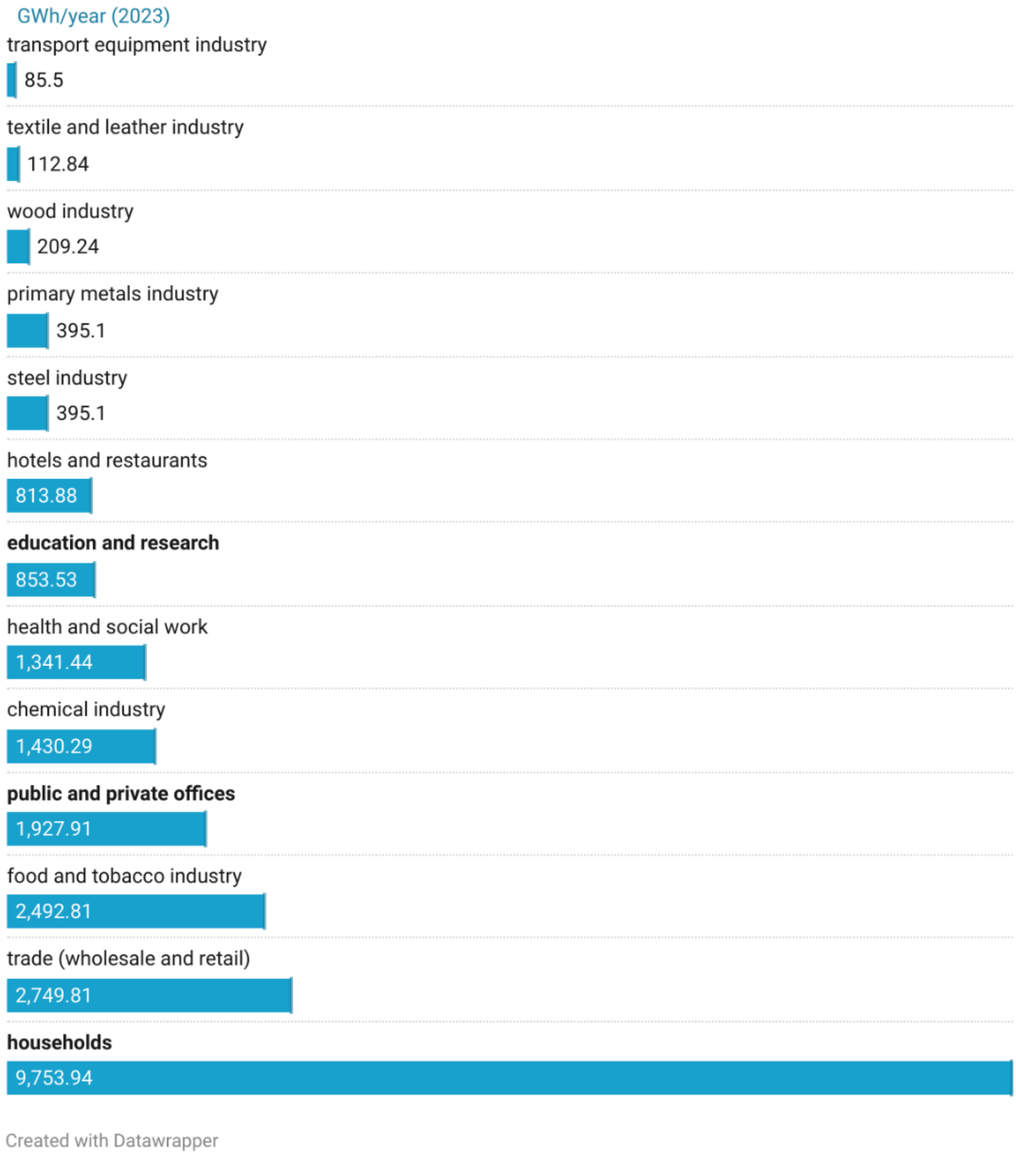

Figure 1.2. Electricity consumption in Denmark (For 2023-last year with all available data) [21]

2. METHODOLOGY

In this report, having different types of buildings into ECs was analysed under different technological setups. The study includes both urban ECs and rural ECs. This chapter outlines the methodology applied in the analysis of ECs. It presents the description of the key archetypes examined, the assumptions for modeling that was adopted, and the structure of the anticipated outcomes for each scenario. It should be noted that findings presented in this report are limited, since they dont include all aspects of establishing and operating ECs but should be seen as an indicator of ECs potential directions.

2.1. ANALYSED ARCHETYPES OF ENERGY COMMUNITIES

This analysis is based on archetypes of ECs which may be characteristic of rural and urban settlements in Denmark. The main difference in defining these archetypes is reflected in the type of consumer (a households in a rural environment and an apartment in an urban environment), as well as in the way energy is produced. To make the archtypes as comparable as possible, it is assumed that each archetype consists of 300 households/apartments (hh). In the other two archetypes an educational institution building (sch) and a public-purpose building (pb) is added. The technologies for electricity production used in rural archetypes include wind turbines and PV. On the other hand, in urban archetypes production technologies include only rooftop PV. For flexibility, different electricity consumption technologies are added: electric vehicles (EVs) and heat pumps (HPs). The HPs are only added in the rural system, as it is assumed that the urban system already have district heating (DH) and therefore do not include heating technologies. In reallity, such systems could of course exist in urban systems. The HPs are tested both in individual heating solutions with air-to-water HP in each building and with a central HP connected to a local DH system. Two scenarios for DH solutions has been included: One involves the analysis of air-to-water HPs, while the other focuses on the integration of ground-source HPs. In both, heat storage systems are included to allow flexibility in the HP operation.

Battery systems are also added in both rural and urban ECs, to investigate the effect of these in relation to local RES production and flexible consumption.

The analysed archetypes of ECs are shown in Figure 2.1.

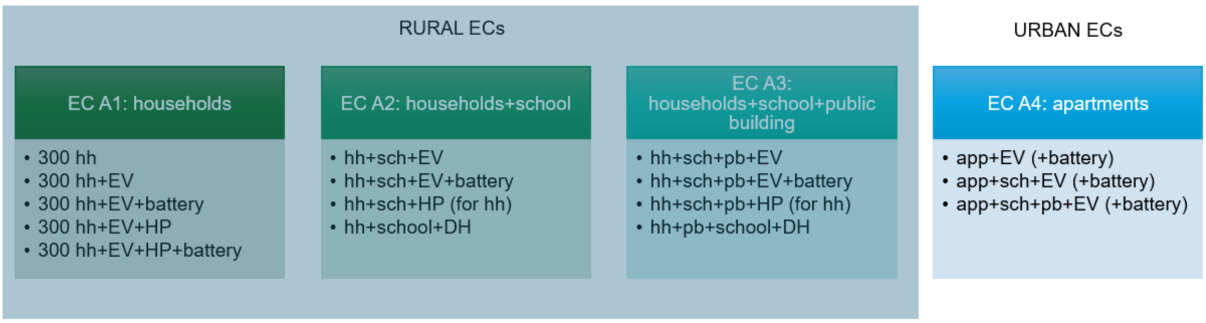

Figure 2.1. Analysed Archetypes of Energy Communities

Further details regarding the sizing of the aforementioned technologies are provided in Chapter 2.2.

2.2. INITIAL ASSUMPTIONS IN SCENARIO ANALYSIS

2.2.1 Defining Electricity Demand

The electricity demand profiles for each type of analyzed building were defined on the basis of data presented on the website of the Danish electricity distribution company Radius [22]. As the data on the official website contains indeterminacies, certain assumptions have been made. The available data include daily hourly variations in electricity demand for different building types, during average working days and weekends/non-working days throughout the year. The website also provides data on differences in electricity demand during the months over the year. Using data on the hourly distribution of energy demand during an average day throughout the year, as well as variations in average energy demands across different months, datasets were generated for a typical weekday and weekend day each month. These normalized datasets were then used to construct the hourly energy demand profile for the entire year. It should be noted that the reference year covers the period from May 2024 to May 2025, as the most recent period with available data, and that the analyzed data refer to detached houses and apartments, educational building, while building type „cultural acctivities“ was adopted as the representative of public institutions. When analyzing the data available on the website, the difference in consumption over the observed period and during the 12 months preceding it for detached households is observed. As these changes are assumed to be mainly due to the increased use of EVs, as the demand is mostly seen at night, the differences in consumption for these two periods have been ignored. The reason for this decision lies in the fact that the use of EVs has been taken into account as an additional electricity demand. The average daily electricity demand on a hourly basis for each type of analyzed consumer is shown in Figure 2.2

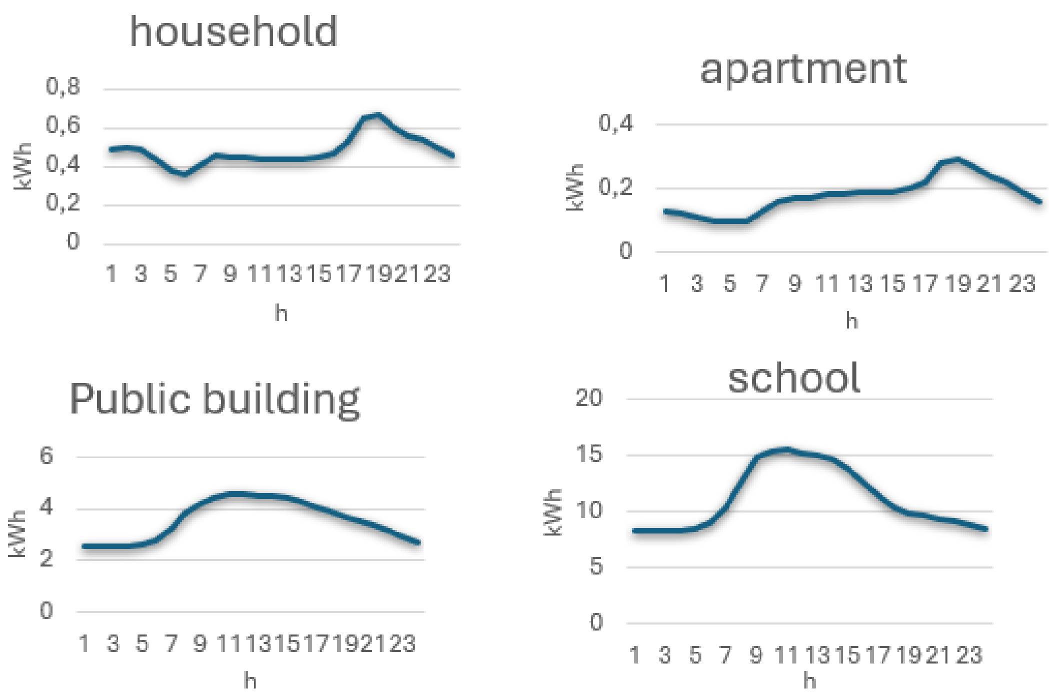

Figure 2.2. Daily electricity demand profile for analyzed types of buildings

2.2.2 Defining the Electricity Production Capacity of the Energy Community

When modeling rural archetypes of ECs, it was assumed that, small and already exsting wind turbines (characteristics shown in Table 2.1) and PV panels would be used for generation of electricity. This production can represent a group of wind turbines.

Table 2.1 Characteristic of wind turbines

Wind speed [m/s]	Power [kW]
3	0
4	132,6
5	304
6	560
7	914
8	1380
9	1956
10	2592
11	3196
12	3636
13	3870
14	3960
15	3990
16	3998
17	4000
18	4000
19	4000
20	4000
21	4000
22	4000
23	4000
24	4000
25	4000
26	0
Measure height	10 m
Hub Height	67 m

To maximize the utilization of the energy produced and reduce the load on the grid, the capacity of PV panels within the EC is determined based on the peak energy demand during summer daytime hours.

For comparison, when PV panels are installed in individual households outside of an EC, statistical data from Denmark indicate that the average installed capacity is 5 kW, whereas the average capacity installed on the rooftops of public buildings is approximately 100 kW [23]. The significance of ECs compared to individual electricity production, will be illustrated through the analysis of rural ECs using Archetype 1 as an example.

When analyzing the urban archetype of an EC, due to the nature of the urban area, usually it is not feasible to install a typical horizontal wind turbine. However, the approach to defining the PV production capacities of the ECs is based on the same assumptions as in the case of rural archetypes.

2.2.3 Defining heat demand and heat production capacity

The heat energy demand for the different buildings was defined based on data presented in the Danish Heat Atlas [24], [25] and reflects the average heat energy demand across all types of buildings analyzed within EC. This includes both the space heating and domestic hot water demands. The hourly profiles were defined based on external conditions and heating degree days (for Denmark heating treashold is set to 17°C), using hourly temperature profiles from the CFSR2 data. The average monthly outdoor temperature in the analized location is shown in Figure 2.3.

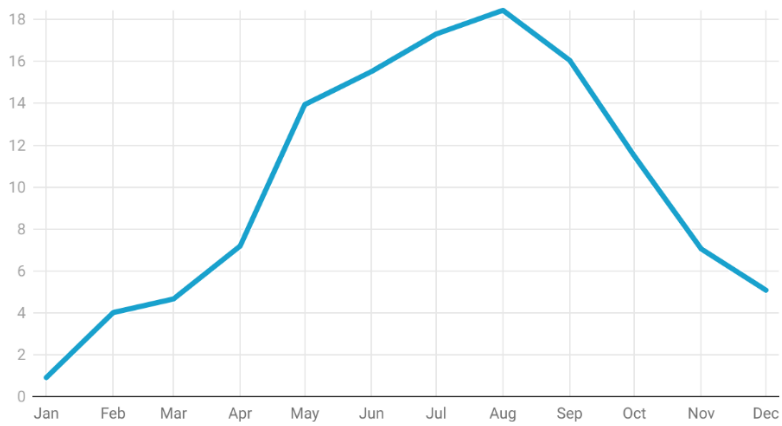

Figure 2.3. Average mounthly temperature variation in analized location (in °C)

The heating demand for water heating was determined through an analysis of statistical data available in the Odyssee-Mure database [21]. An analysis of the available data showes that, on average, 4,4 MWh of thermal energy is required for heating of hot water in average households in Denmark, annually. Based on the available database, the total heat demand for hot water in Denmark was determined, as well as its share in the overall energy demand for space heating, as 29%. The heating demand for water heating is considered constant throughout all hours of the year.

The heating demand for different types of buildings are shown in Table 2.2.

Table 2.2 Total annualy heat demand for analyzed type of buildings

Building type	*Annualy heating demand (MWh/year) per building*
Household space heating	15
School	35
Public building (sport facility)	75

Figure 2.4. Shows the resulting hourly district heating demand incl. grid loss of 20% profile fot the rural archetype that includes households and a public building.

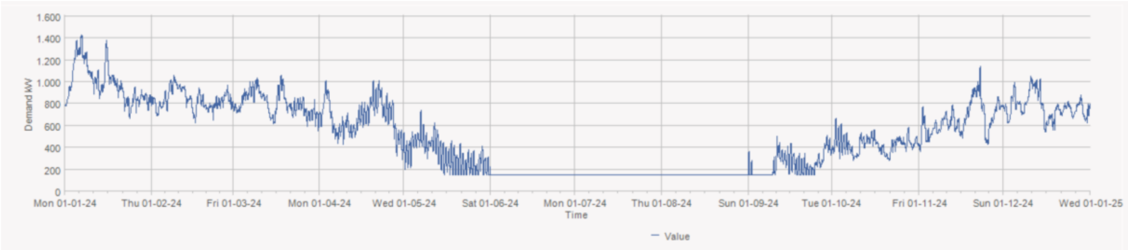

Figure 2.4. District Heating hourly heating demand for rural archetype that includes public building and 300 households

In the analysis of the DH system, it is assumed that the HP meets the average annual thermal load, while electric boilers are used to cover peak demand. The heat storage is dimensioned to meet 24 hours of average heat demand, based on the average daily heat requirement, including grid losses, that assumes to be 20% for DH with air-to-water HPs and 10% for for DH with ground source HP, since it can be expected that due lower water temperature in the grid, grid losses are also lower. In the scenario involving individual household HPs, and in scenarios with DH with ground source HP the heat storages is assumed to have a total capacity of 24 m^3, which corresponds to 80 liters of hot water per household.

When calculating the energy production using HPs, the Coefficient of Performance (COP) is calculated depending on the temperature of the outside air, where the required water temperature is assumed to be 60°C (Eq. 1) and a efficiency of the HP of 40%. The resulting hourly COP is shown in Figure 2.5.

$$COP \approx \frac{T_{hot}}{T_{hot}-T_{out}} \cdot 0{,}4 \qquad (1)$$

Where:

COP [-] – coefficient of Performance

Thot [K]– Temperature of heated water (60 °C)

Tout [K]– Temperature of outside air

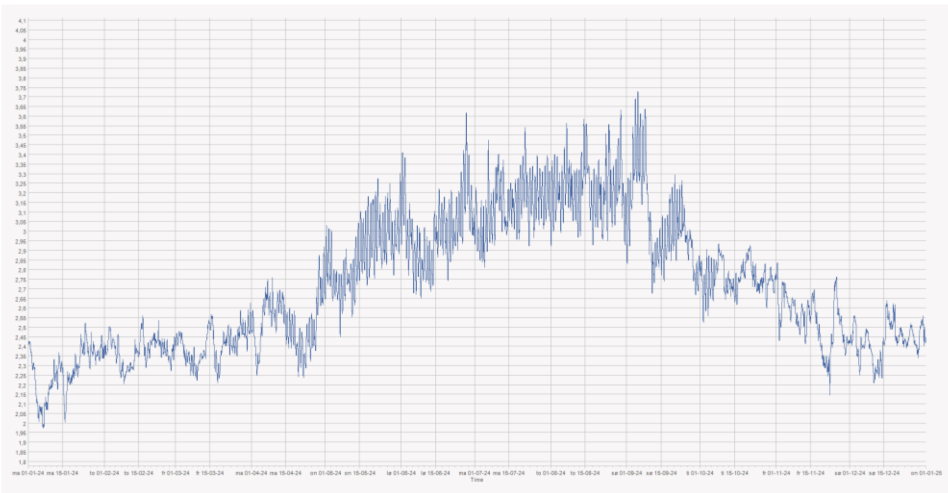

Figure 2.5. Annual variations in COP values for air-water heat pump

For the case of DH systems utilizing groundwater HPs, the COP is adopted from [23] and is set at 3,75 as a yearly average level.

2.2.4 The use of electric vehicles

The use of EVs in households was defined based on statistical data. According to available data, Denmark had an average of 2.1 residents per household in 2024 [26]. At the same time, Denmark reported 546 cars per 1.000 inhabitants [27]. An analysis of registered vehicles in 2024 revealed that EVs accounted for 16% of all household-registered vehicles [28]. Accordingly, it is assumed that within an EC consisting of 300 households, the number of electric vehicles is 60.

Annual hourly variations demand for EV charging were defined using the IDA Climate Response scenario [29]. Capacity of EV battery is set to be 3,6 MWh, and charging power as 0,66 MW with efficiency of 90%. It was defined that charging depends on driving demand- high driving demand-low charging and other way around. The EVs are modelled as one combined unit with average driving demand, and as such, flexibility of these can be overestimated in the modelling. Accordingly, the monthly demand associated with the adopted number of EVs is illustrated in Figure 2.6.

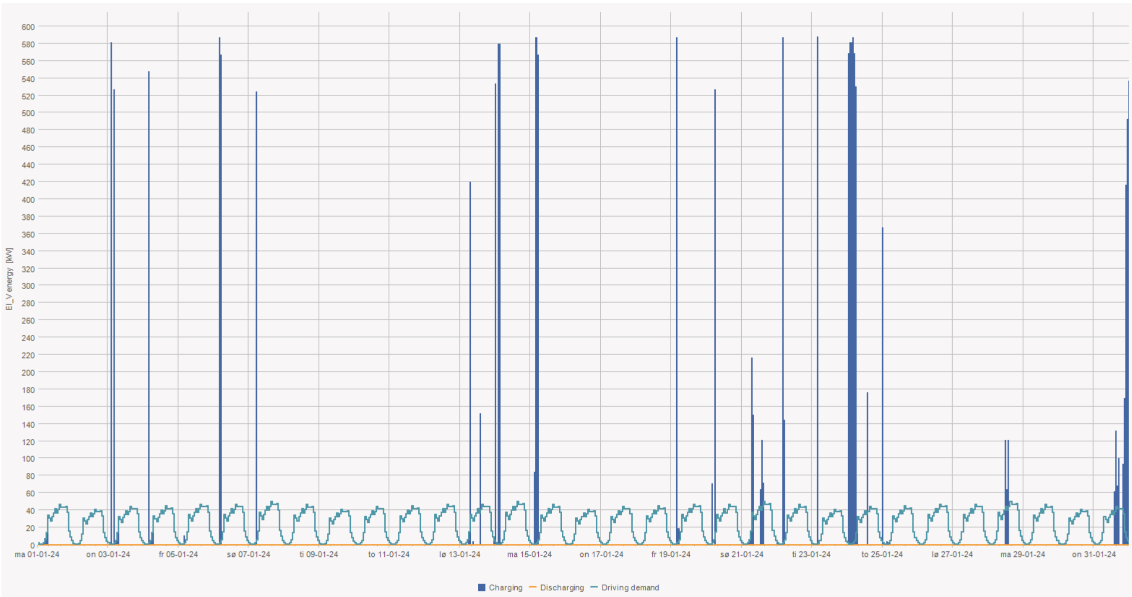

Figure 2.6. Electricity demand for EV on a monthly basis within the observed EC

2.2.5 Determining the cost of using electricity

The total costs associated with the purchase and sale of electricity were determined based on data from the Day-Ahead Spot Market of Nord Pool for 2024 in DK1 price area [30]. It should be noted that electricity prices differ from year to year (Figure 2.7.) and that this may affect overall results, because model allow PV and wind turbines to curtail, when the economic conditions make it optimal (during negative price hours).

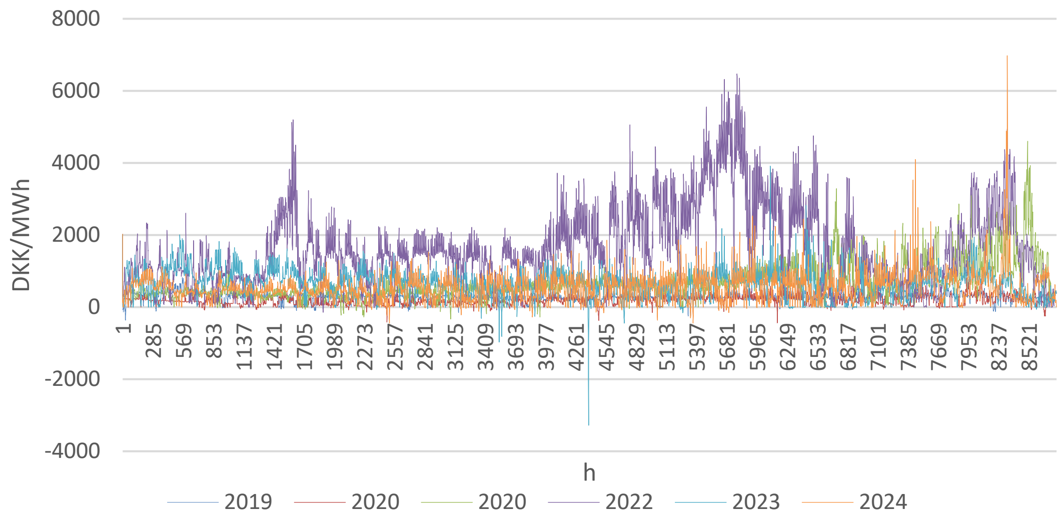

Figure 2.7. Day-Ahead Spot Market of Nord Pool electricity prices from 2019-2024

Also, transmission system operator (TSO) grid tariffs [31], DSO grid tariffs [32], and electricity taxation applicable in Denmark were taken into account in the simulation of the operation. The potential to participate in electricity balancing and reserve markets are not investigated in this study.

The billing of electricity and related taxes within ECs is complex and depends on agreements among community members. When the members are households equipped with PV panels, the electricity generated is first consumed within the household when needed. No tariffs and taxes are applied to this self-consumed energy. Any surplus electricity is then transferred to the EC, where other members can purchase it at a price lower than the market price outside the community. To this amount of shared electricity, taxes and tariffs are applied. In cases where the EC owns shared generation capacities (such as wind turbines or PV panels installed on public surfaces), the produced electricity is primarily consumed within the community, while any excess is sold to the grid. It should be noted that in this case, the use of generated electricity is subject to taxation.

For the sake of model simplification in this report, it is assumed that all generation capacities are located on shared surfaces.

For the electricity exported to the grid and sold, as well as for the electricity purchased, costs are defined based on the day-ahead market. Conversely, costs related to DSO and TSO charges, as well as balancing costs and feed-in tariffs (both TSO and DSO), are defined based on [33].

Fluctuations in costs over the months, including minimum, maximum and average values in the day ahead market, as well as in DSO taxes, are shown in Figure 2.8.

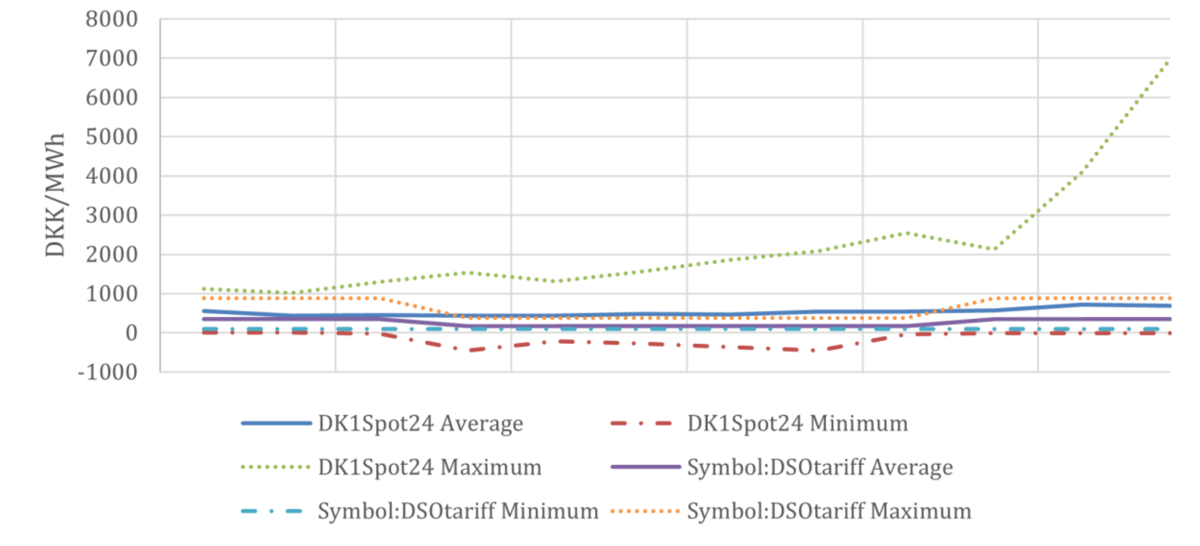

Figure 2.8. Mounthly differences in electricity price and tariffs

When comparing the role of ECs with energy cooperatives in terms of energy production and consumption, the geographical location of technologies plays a crucial role in RES electricity generation and payment structures. Specifically, self-consumption of PV electricity is permitted only when both production and consumption occur simultaneously on the same parcel, ensuring optimal utilization of generated energy. Accordingly, wind power generation is assumed not to be located or connected to any parcel with electricity demand; therefore, all electricity produced by wind turbines is considered to be sold directly to the grid.

It should be noted that, in both scenarios, the prices presented exclude sales taxes.

2.2.6 Structure of the results

The scenario analysis for the proposed EC archetypes was conducted using the energyPRO software package developed by EMD International A/S [34]. energyPRO is an advanced tool for modeling, simulation, and optimization of complex energy systems, with a focus on techno-economic analysis of projects involving electricity and heat production and consumption. The tool focuses on the optimization of the operation using the flows of energy and potentially mass. The tool is used to simulate one year of operation on an hourly basis. It does this with perfect forecast for the simulated year, and therefore the results show the best possible case for flexible units and energy storages.

The software operates based on advanced mathematical algorithms, including mixed-integer linear programming (MILP), enabling users to model different scenarios and optimize system operation in accordance with external factors such as weather conditions, market energy prices, and consumption demands. energyPRO features a modular structure that allows flexible use tailored to specific user needs, including modules for system design, financial analysis, operational optimization, market simulation, scenario comparison, and component sizing. Through the generation of detailed reports on greenhouse gas emissions, cash flows, and investment indicators, energyPRO supports informed decision-making in the planning and management of energy projects, thereby contributing significantly to the transition toward sustainable and efficient energy solutions [34].

The energy models developed in this study will focus on the following results:

- Yearly electricity production and consumption;
- Yearly peak electricity import and export. For selected scenarios, more detailed insights will be provided, such as monthly peaks or duration curves showing hourly import and export values;
- Net payments, disaggregated into electricity purchase costs (including balancing tariffs), DSO tariffs and TSO tariffs.

It should be noted that, due to the complexity of the billing system for electricity sales and purchases within the EC, as well as the individual characteristics of each EC, the net payment data are intended solely for scenario comparison and should not be considered as final values for practical application. Likewise, investment costs for technologies in the EC and cost effects on the local electricity grid is not included in the study, and the results can therefore not be used for making investment decisions nor show cost effects on the surrounding energy system.

3. RESULTS AND DISCUSSIONS

3.1. ARCHETYPE 1A: HOUSEHOLDS

A schematic representation of Archetype 1 of rural-type ECs is shown in Figure 3.1.

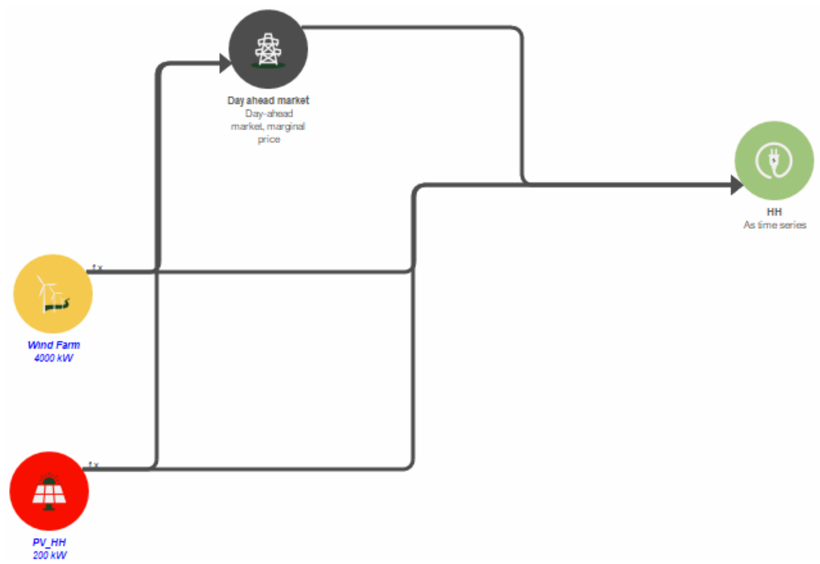

Figure 3.1. Archetype 1a of Rural Energy Communities (EC A1a): Households

For the analysis of this archetype, it is assumed that the EC has 4 MW of installed wind capacity and 200 kW of PV capacity. Since the generated electricity is first consumed within the EC and subsequently delivered to the grid, it is subject to electricity tax, as well as DSO and TSO charges.

The monthly electricity demand of this EC archetype is presented in Figure 3.2.

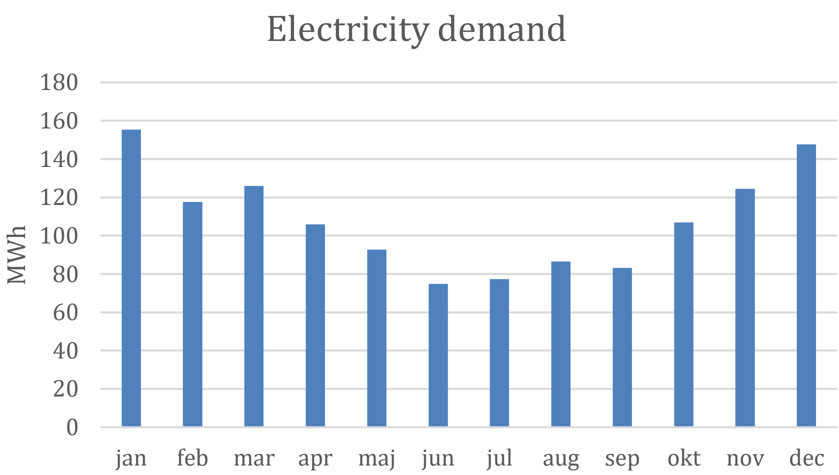

Figure 3.2. Electricity demand on a monthly level EC 1a

Monthly fluctuations in electricity production from installed capacities and electricity demand are presented in Figure 3.3. As illustrated in the figure, during the winter months, the majority of electricity is generated from wind power capacities, whereas the potential for utilizing electricity produced by PV is significantly higher during the summer months. It should be noted that the electricity demand in this scenario is assumed to be non-flexible.

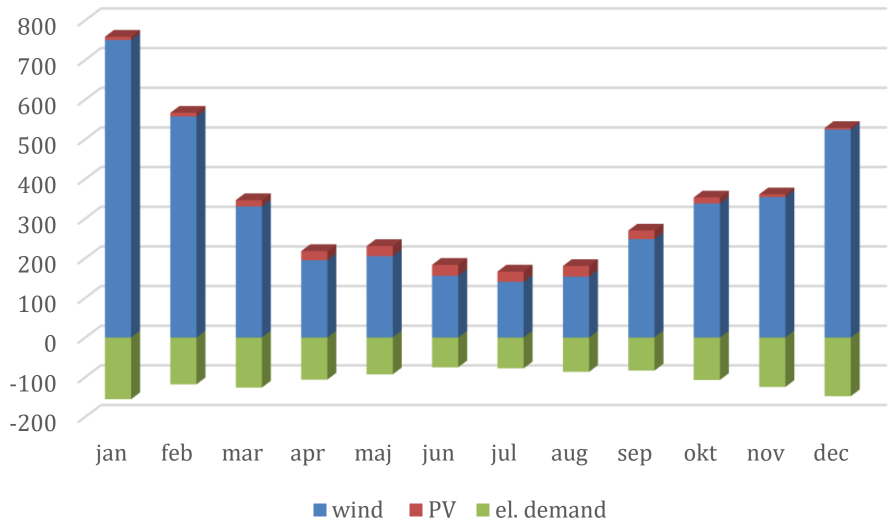

Figure 3.3. Montrly electricity demand and prodiction for EC A1a

The monthly PV production is lower than the total energy demand within this archetype. However, when considering the ratio between production and energy demand on a daily basis during summer months, it becomes evident that the capacities are dimensioned to ensure that most of the generated electricity is consumed within the community, thereby avoiding exports and additional stress on the grid (Figure 3.4).

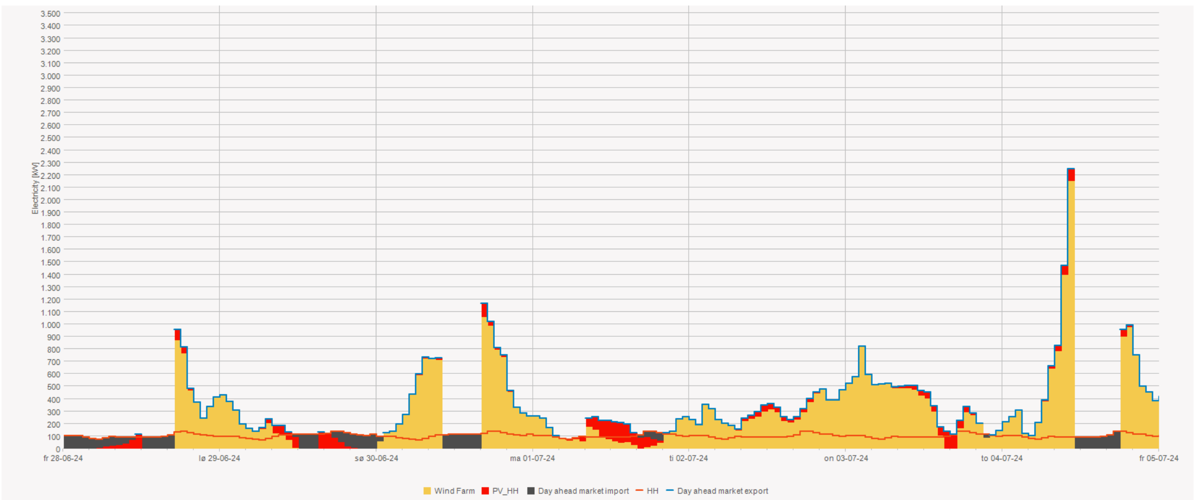

Figure 3.4. Import and export of energy during the summer months for EC A1a

Furthermore, considering the nature of electricity generation from PV, which is limited to daylight hours, and the fact that household electricity consumption occurs throughout the day (Figure 3.5), it can be concluded that the system requires both electricity import and export to maintain balance.

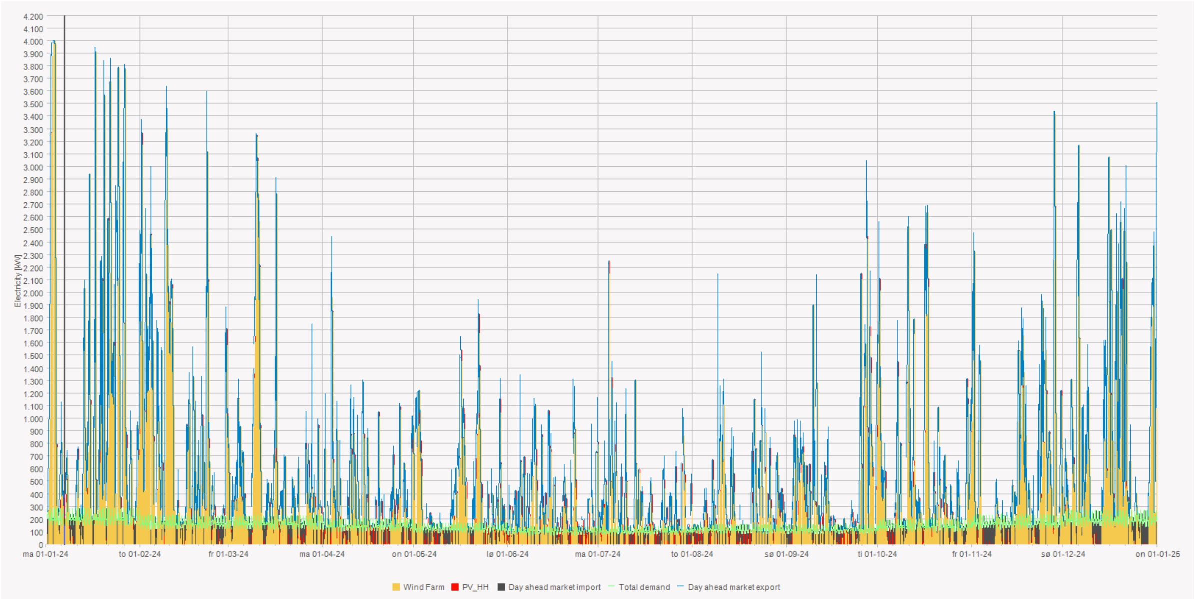

Figure 3.5. Electricity production, demand and import and export of the system on an hourly basis EC A1a

In such a system, the monthly peaks in electricity export and import are shown in Figure 3.6.

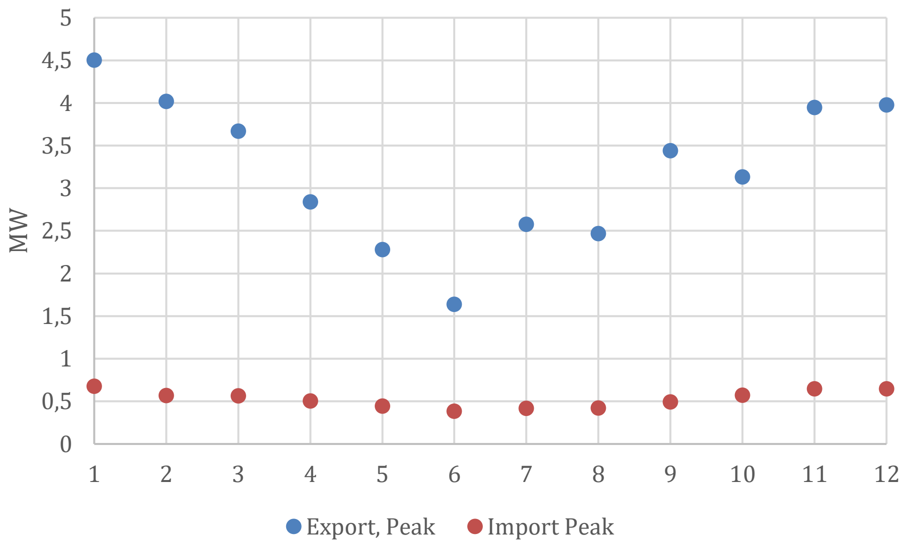

Figure 3.6. Monthly differences in Imported and Exported Peaks for EC A1

In a system dimensioned in this way, consisting of wind turbines and PV panels, the highest electricity exports occur during the winter months, while the lowest are observed in July.

If energy exchange within the EC were not possible, and the surplus electricity that cannot be consumed immediately were sold at the established day-ahead price, then in a system where the total PV capacity is the same as in the EC example (assuming each household has an equal share of the installed capacity), the comparison of export and import peaks relative to the EC is presented in Figure 3.7.

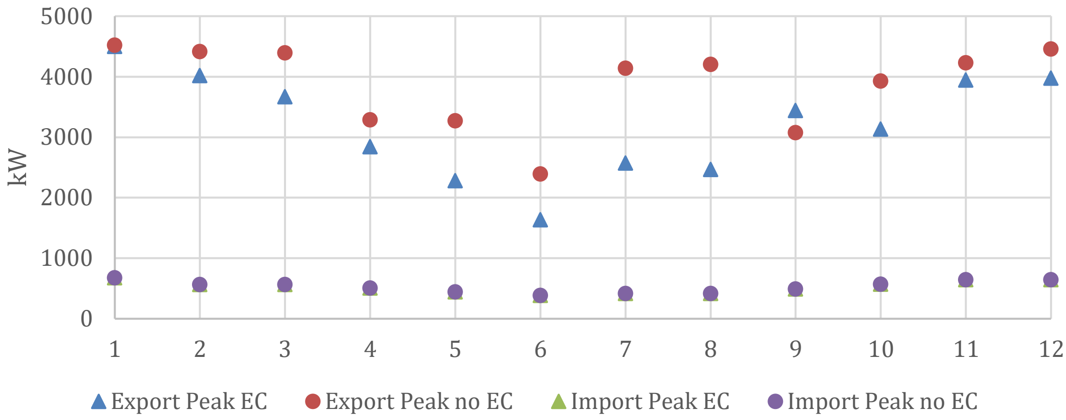

Figure 3.7. Electricity import and export peaks for the cases when sharing of electricit is possible and not

Although the average installed capacity of PV in households in Denmark is 5 kW for households with PV, even with significantly smaller capacities, the export peaks during summer months are considerably higher compared to a system where energy sharing is possible.

A schematic representation of archetype 1b of rural-type ECs, that includes, beside households, also EVs is shown in Figure 3.8. The EVs are expected to be able to be charged flexible limited by the driving demand of the users, and therefore adding EVs introduces a flexible electricity demand to the model.

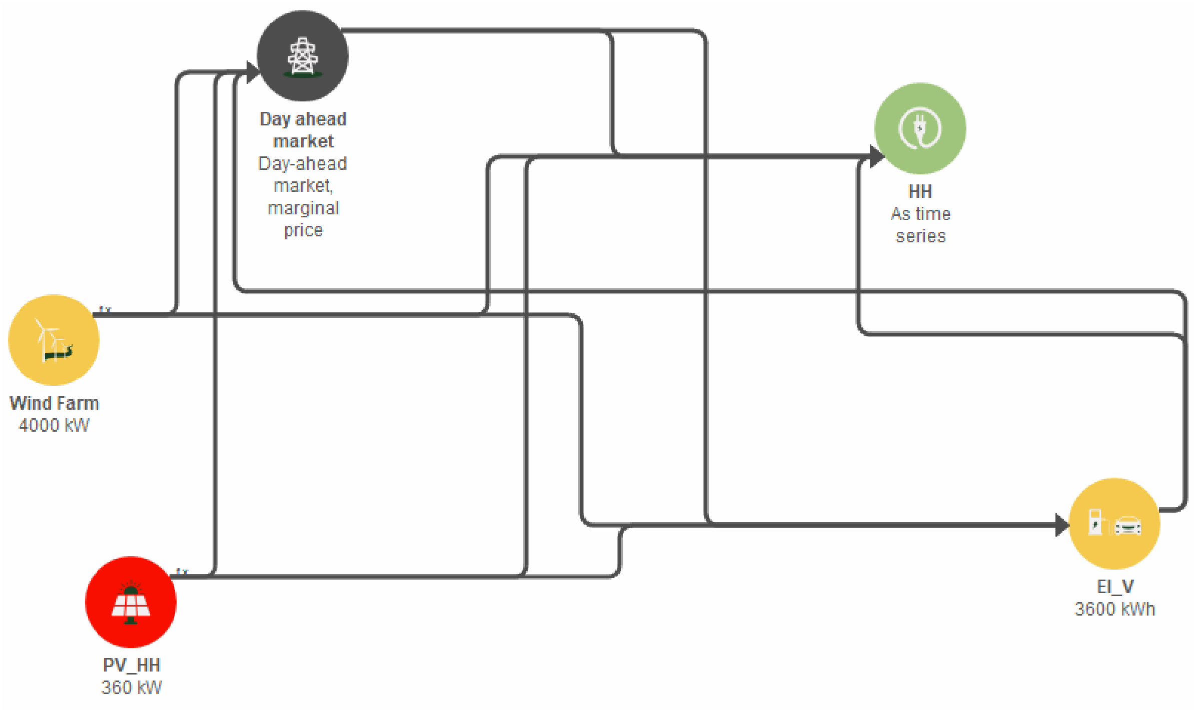

Figure 3.8. Archetype 1b of Rural Energy Communities (EC A1b): Households and EVs

Unlike EC A1a, the PV capacity in this archetype is 360 kW. It should be noted that EVs increase electricity demand (and consequently peak load), but these peaks occur during nighttime hours. Therefore, when determining the PV capacity, the increased daytime electricity demand was considered (Figure 3.9).

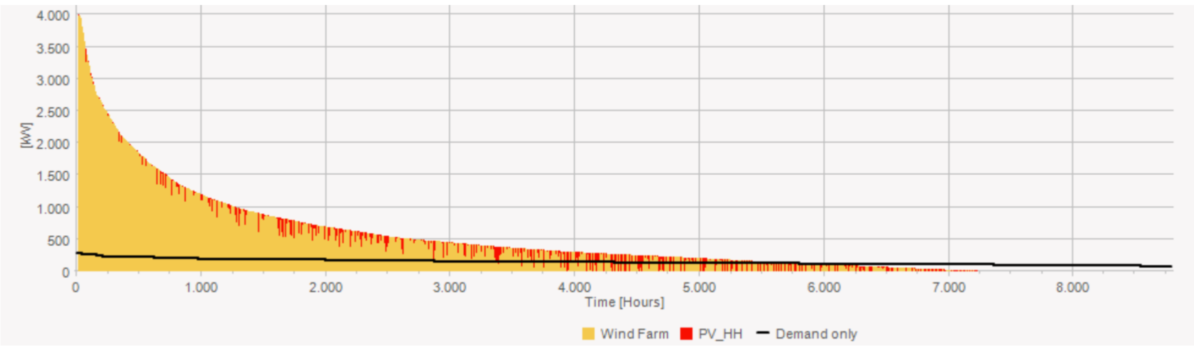

Figure 3.9. Duration curve for electricity demand (EC A1b)

Monthly fluctuations in electricity production from installed capacities and electricity demand are presented in Figure 3.10. As illustrated in the figure, during the winter months, the majority of electricity is generated from wind power capacities, whereas the potential for utilizing electricity produced by PV is significantly higher during the summer months.

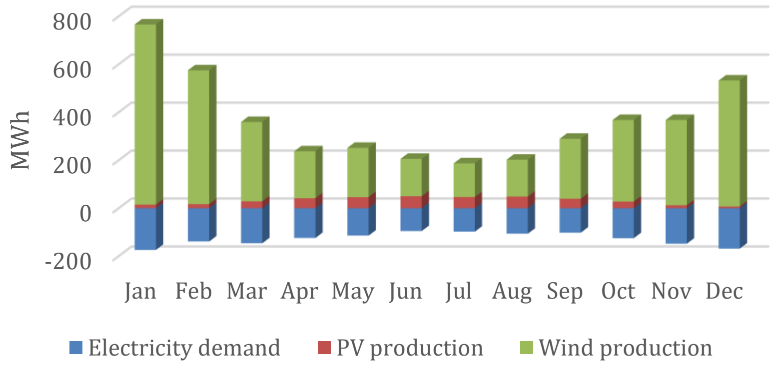

Figure 3.10. Monthly electricity demands and production in EC A1b

As shown in the figure, the highest electricity generation from wind capacities occurs during the winter months. During the summer months, electricity demand is significantly met by PV production. However, considering the variability of these sources, as illustrated in Figure 3.11, even in summer months the system imports certain amounts of electricity at times when production does not coincide with energy demand.

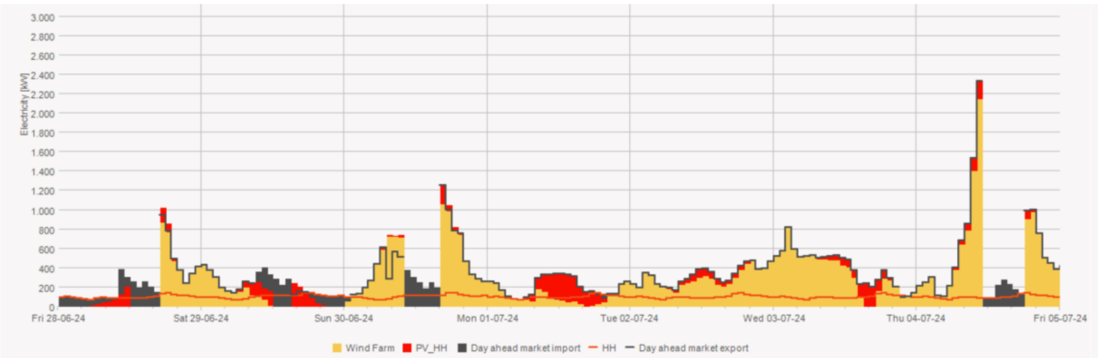

Figure 3.11. Import and export of energy during the week in the summer months for EC A1b

The annual balance of electricity import and export for the EC A1b system is shown in Figure 3.12.

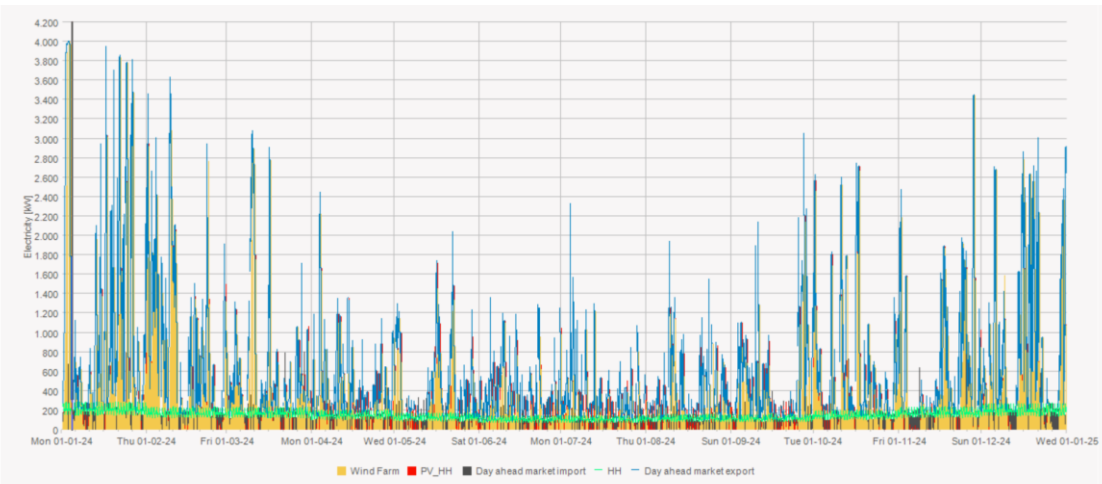

Figure 3.12. Electricity production, demand and import of the system on an hourly basis EC A1b

In such a system, the monthly peaks in electricity export and import are shown in Figure 3.13.

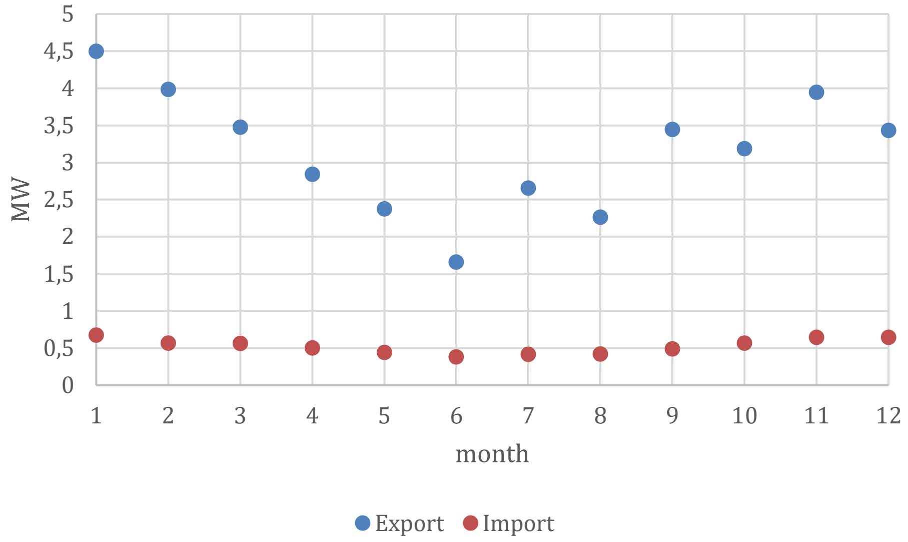

Figure 3.13. Monthly differences in Imported and Exported Peaks for EC A1b

As shown in the figure, the highest electricity export from the system occur during the winter months and around July. However, export is not only driven by PV panel production but by increased generation from wind capacities (Figure 3.14).

When comparing export peaks between EC A1a and EC A1b, the use of EVs in this EC results in reduced energy export during August, October, and December, while causing an increase in the peak during May. On the other hand, there is almost no difference in the peaks of energy import. This can be explained by the fact that EVs are mostly charged in periods of RES production and outside the normal peak demand periods, thus not contributing to an increase in existing peaks.

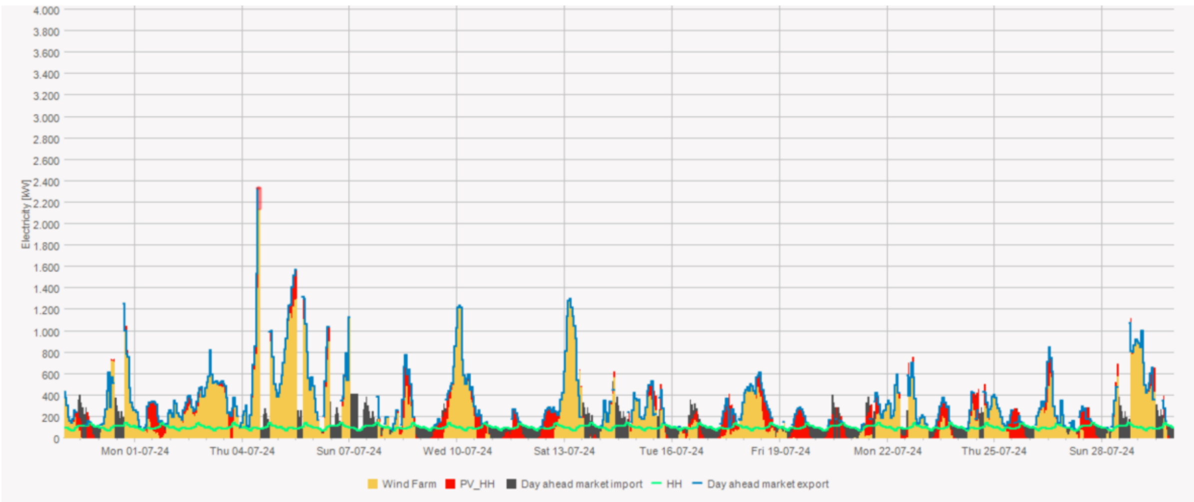

Figure 3.14. Peak of electricity import duing July (4th of July at 9:57am)

When battery storage is added to such a system (EC A1c, Figure 3.15), changes in electricity import and export can be expected, as the battery allows for charging in high RES production periods and discharge in low RES production periods. Though as the battery has a loss in the charging and discharging cycles it also introduces an extra energy demand to utilise the batteries.

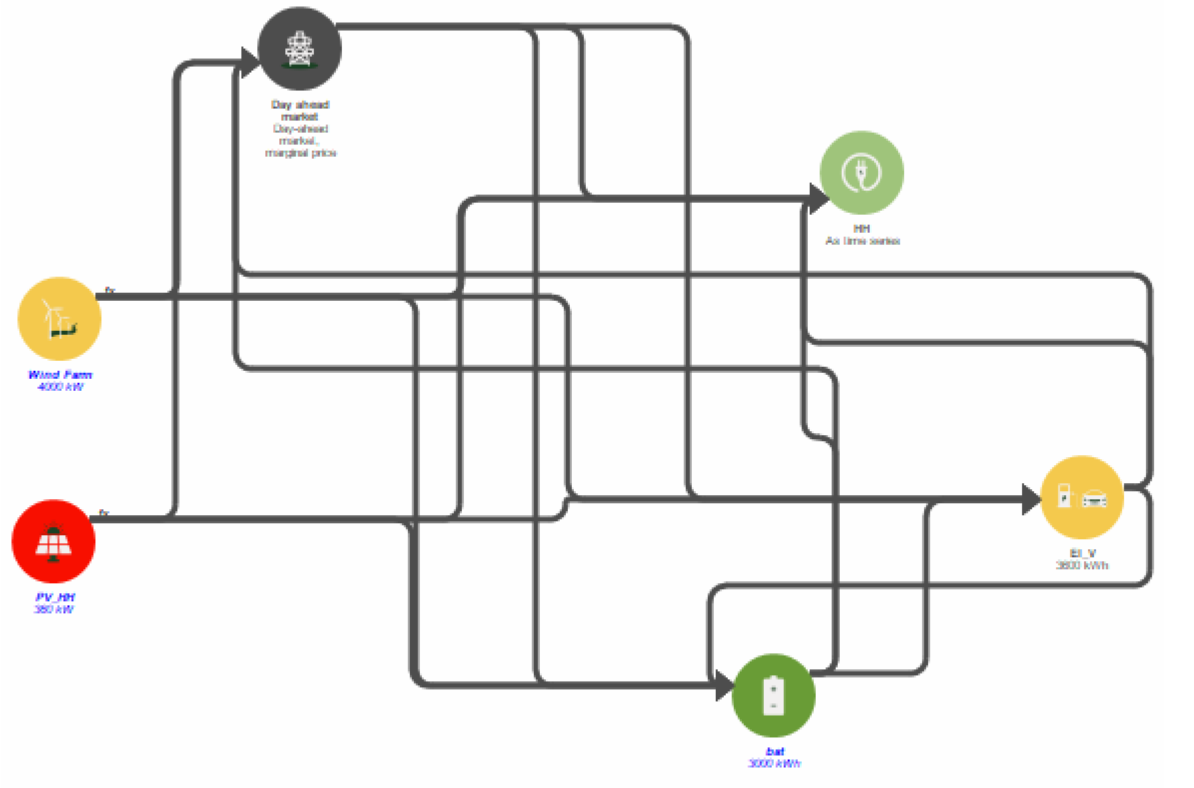

Figure 3.15. Archetype EC A1c: Households, EVs and battery

The monthly peaks of electricity import and export from this system, compared to the EC A1b system, are shown in Figure 3.16.

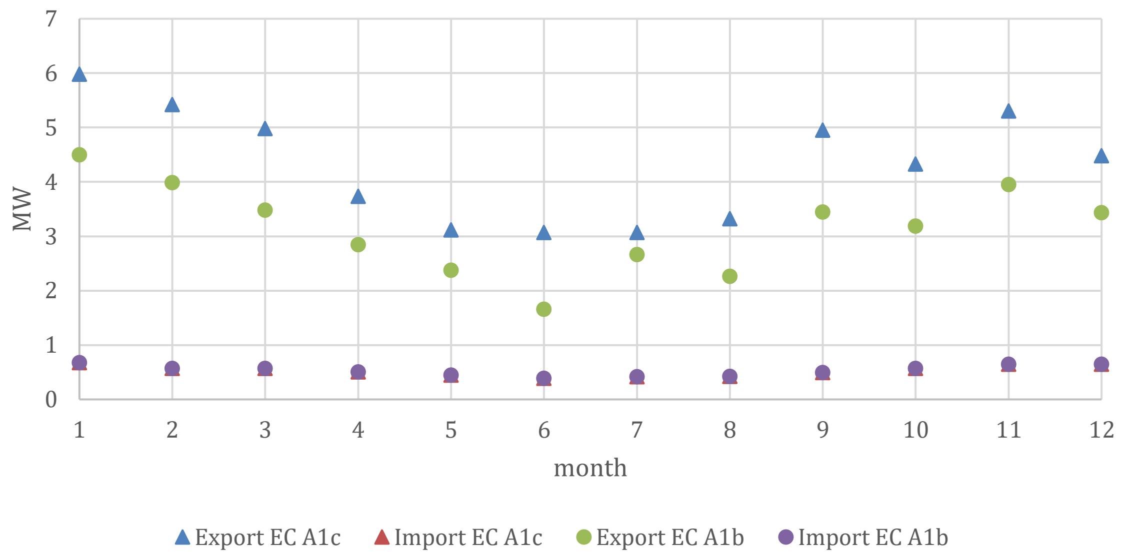

Figure 3.16. Comparison of electricity import and export for EC A1b and ECA1c

As illustrated in Figure 3.17, the introduction of battery storage into the system increases the monthly peaks of energy export. However, it is important to note that the system will import electricity when prices are lowest and export it when prices are highest, so this increase comes due to variations in electricity market prices and not due to local conditions. The battery is operated to reduce the operation costs of the system, and therefore can choose to be operated this way if the variations in electricity market prices makes it economic feasible to do.

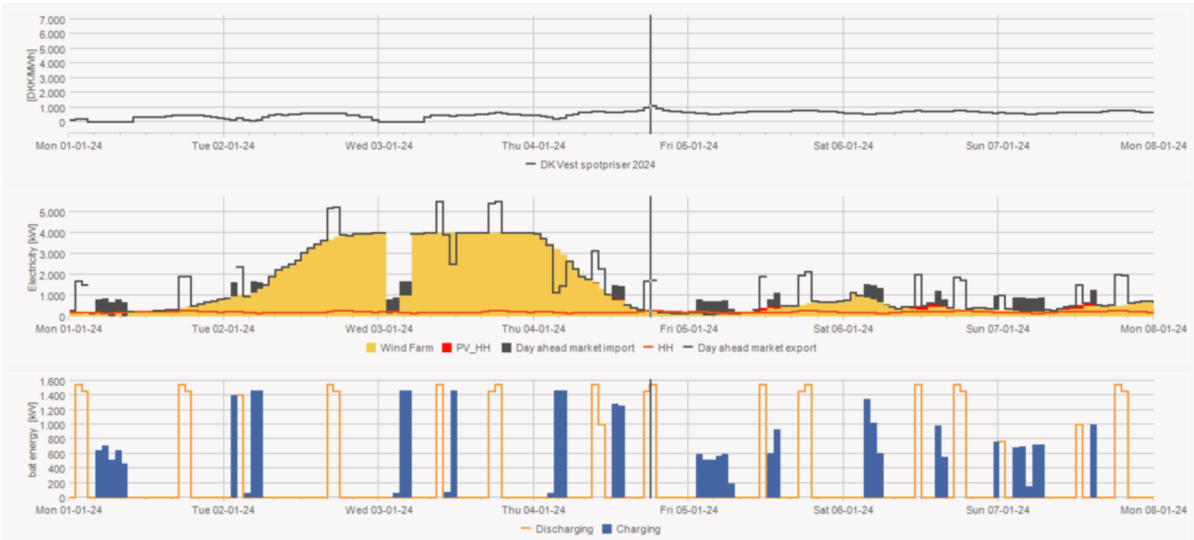

Figure 3.17. Impact of energy prices on electricity import and export when the energy community includes battery storage

If all households in this EC archetype were to use HPs to meet heat demand (EC A1d, Figure 3.18), the system would include a PV capacity of 1000 kW, as adding HPs increases the electricity demand of the system. As this EC includes heat storage, it is assumed that the HP can be operated flexible using the heat storage to make sure that the heat demand is fulfilled during all ours of the year.

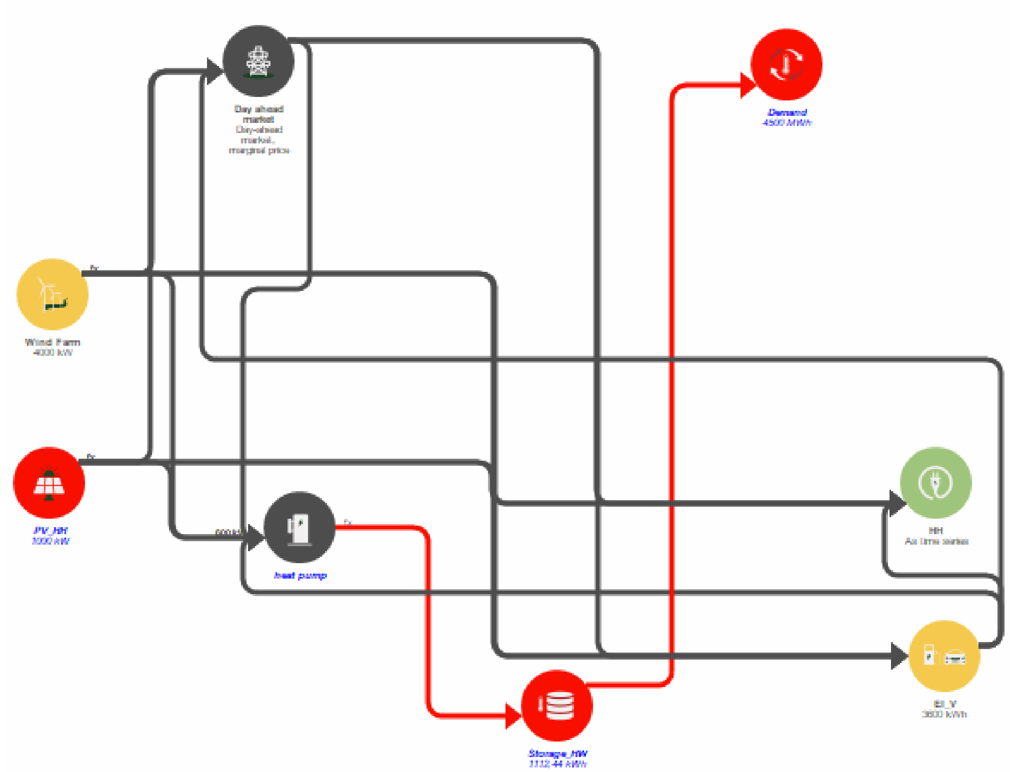

Figure 3.18. Archetype EC A1d: Households, EVs and heat pump

The monthly heat demand in such a system is shown in Figure 3.19, along with the electricity demand for operating HPs and the amount of energy produced in EC.

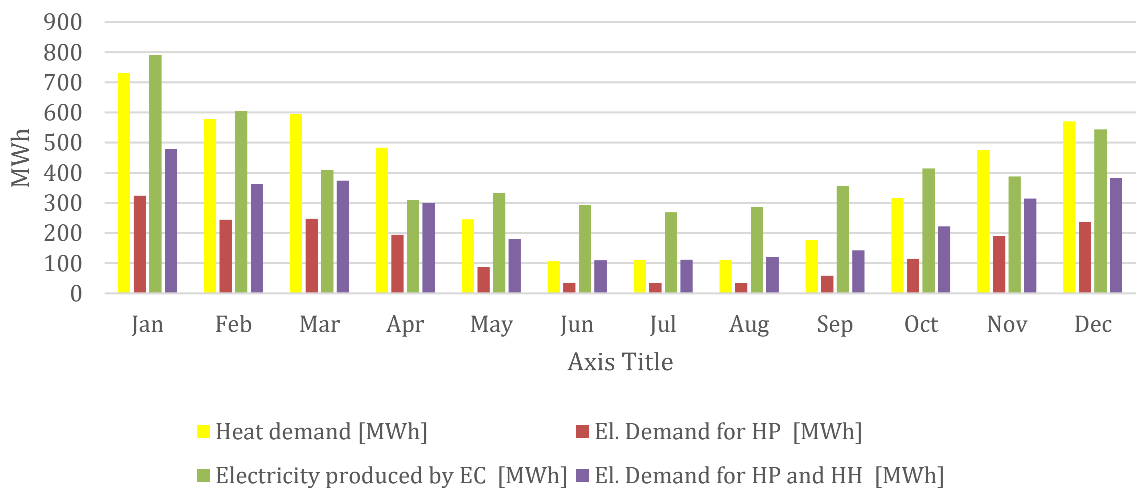

Figure 3.19. Heat and electricity demand, and electricity generation in EC A1d.

As shown in the figure, electricity generation within the EC exceeds total electricity demand in almost all months.

Such a system results in changes in the monthly peaks of electricity export and import compared to a system without HPs, as illustrated in Figure 3.20.

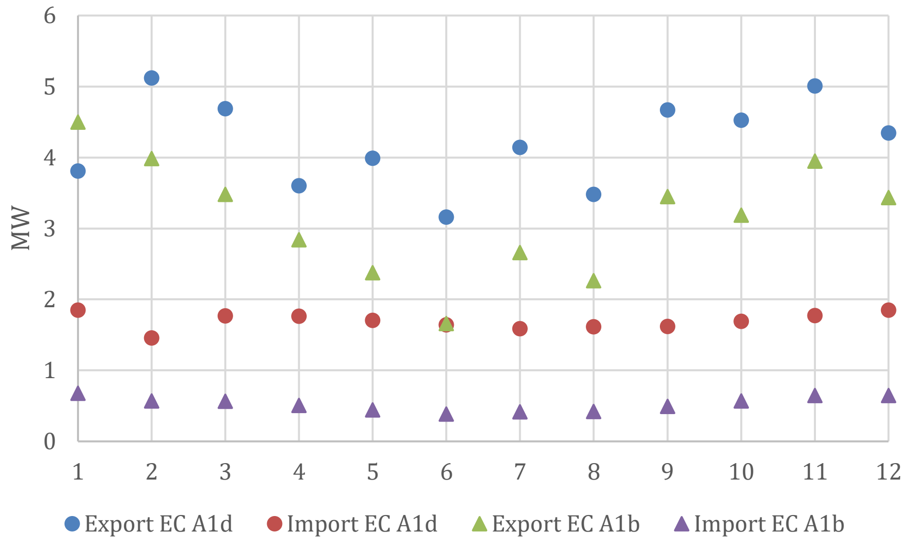

Figure 3.20. Changes in electricity import and export in systems with (EC A1d) and without (EC A1b) heat pumps.

The use of HPs significantly affects electricity import and export from the EC. The only month in which the export peak is lower in this system is January, which is also the coldest month with the highest heat demand. On the other hand, if battery storage were added to such a system (EC A1e), the comparison of electricity import and export is shown in Figure 3.21.

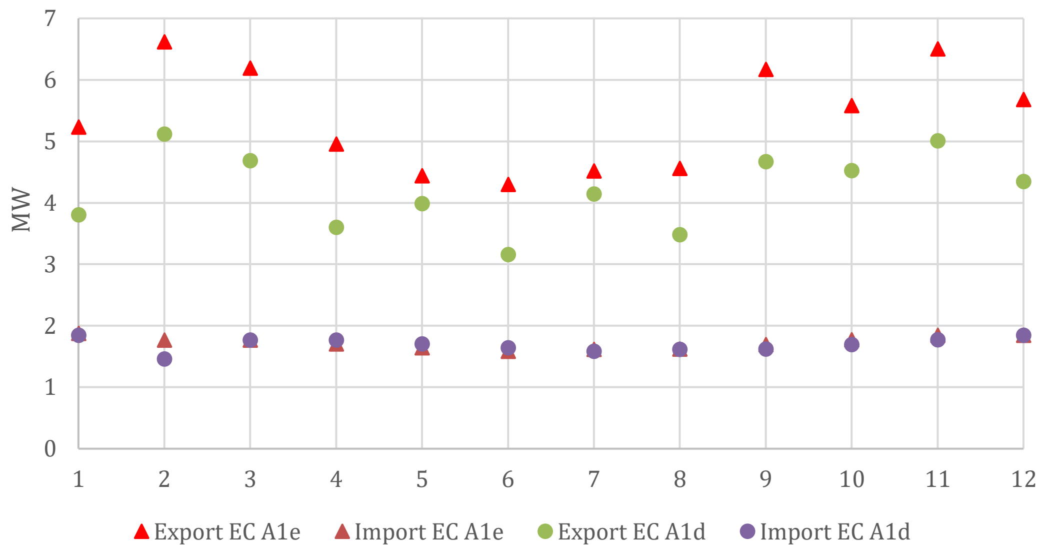

Figure 3.21. Comparison of electricity imports and exports in systems with (EC A1e) and without (EC A1d) battery storage

As shown in the figure, energy export in the system with battery storage are more pronounced during the winter months and also in June, while energy import differ only slightly. This can be explained by variations in electricity prices, with the system exporting and selling electricity when prices are highest (Figure 3.22).

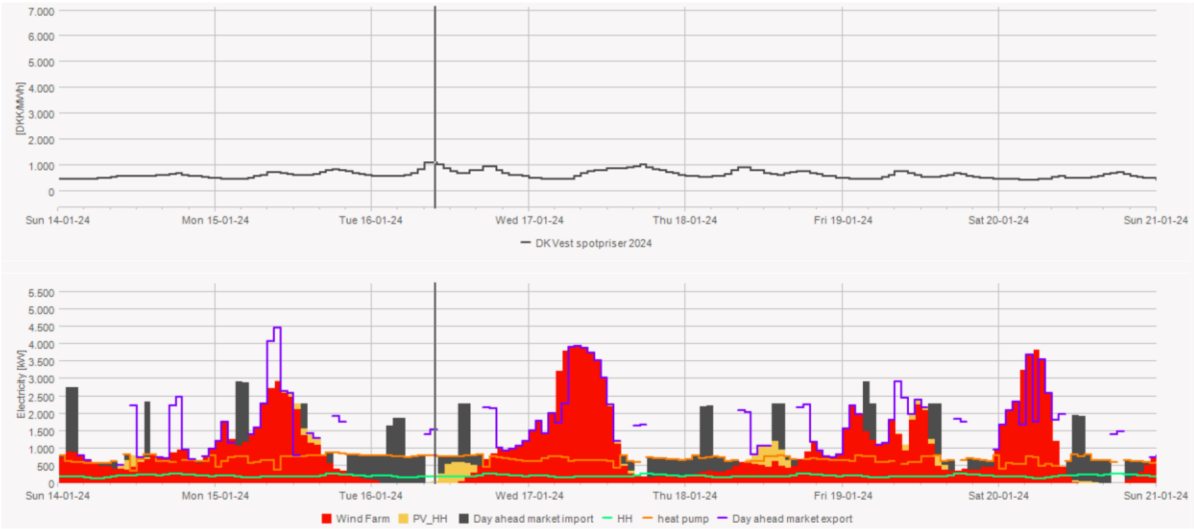

Figure 3.22. Impact of electricity prices on electricity import and export in the EC A1e system

3.1.2. Comparison of revenues and expenditures across all scenarios for Archetype 1 energy communities

Table 3.1 presents a comparative overview of operational income and costs within all analyzed scenarios for Archetype 1. Based on the data provided, the presence of battery storage within the EC can contribute to achieving significant operational financial gains for the community. It should be noted that those costs refer exclusively to electricity. Accordingly, when all households within the EC are equipped with HPs (without battery storage), the annual operating costs for electricity and heating amount to less than 6.000 DKK per household. Note that this does not include investment costs and associated costs related to loans etc. These costs can therefore not be used to identify total costs for the consumer, and the costs shown here are only for the purposes of comparing between the five scenarios analysed.

Table 3.1 Comparison of Revenues and Costs for Electricity in the case of EC A1 (kDKK/year)

	EC A1a	**EC A1b**	**EC A1c**	**EC A1d**	**EC A1e**
Sale of Electricity	1.189,78	1.211,24	1.354,85	1.090,82	1.403,67
Purchase of electricity	251,10	233,04	133,69	721,89	705,01
TSO_consumption	175,28	207,68	207,68	451,25	451,25
TSO_subscription fee	54,60	54,60	54,60	54,60	54,60
TSO_feed in	46,18	49,15	52,52	54,18	57,49
DSO_consumption tariffs	319,85	329,94	330,70	674,32	674,38
DSO_feed_in	18,88	20,09	21,46	22,14	23,49
Balancig cost	40,16	42,74	45,67	47,11	49,99
DSO and TSO Tariffs total	***654,95***	***704,18***	***712,63***	***1.303,60***	***1.311,20***

3.1.3. Comparison of all scenarios of the EC A1 archetype

Table 3.2 provides a comparative overview of data related to all scenarios within the analyzed archetype. The data include monthly electricity demand, energy production, import and export of electricity, and monthly peak values.

Table 3.2 Comparative overview of the analyzed scenarios in the EC A1 archetype

		jan	feb	mar	apr	maj	jun	jul	aug	sep	okt	nov	dec	TOTAL
Electricity produced (MWh)	EC A1a	758,50	566,75	346,44	217,92	230,72	183,31	166,25	180,43	269,85	353,22	361,10	528,50	4162,99
	EC A1b	765,83	574,54	359,02	237,10	251,17	205,47	186,82	201,91	289,22	367,49	367,40	532,01	4337,97
	EC A1c	771,79	577,60	365,13	244,91	275,69	223,79	203,04	218,87	306,69	374,98	370,46	533,67	4466,62
	EC A1d	791,67	604,02	409,33	309,99	332,95	293,88	269,11	287,38	357,27	414,00	388,35	544,10	5002,04
	EC A1e	796,43	610,23	416,84	321,85	347,98	309,37	284,29	301,16	371,50	422,40	391,42	546,04	5119,51
Import electicity (MWh)	EC A1a	28,77	26,84	32,44	33,77	34,31	21,57	27,17	30,31	22,57	28,03	41,90	40,43	368,12
	EC A1b	32,00	29,84	37,21	41,00	46,15	31,08	36,82	39,09	28,54	34,11	45,81	42,34	443,98
	EC A1c	113,37	108,90	149,25	153,73	134,05	123,09	139,45	147,38	139,70	148,40	150,02	131,32	1638,65
	EC A1d	169,57	124,14	155,56	139,04	86,72	42,25	48,50	50,83	56,01	82,82	148,87	159,49	1263,80
	EC A1e	273,35	238,38	310,14	297,96	223,60	192,00	202,27	211,57	201,63	229,52	288,44	291,47	2960,33
Export electricity (MWh)	EC A1a	631,95	475,94	252,90	145,80	172,41	130,01	116,05	124,27	209,27	274,31	278,58	421,24	3232,72
	EC A1b	624,19	465,77	250,21	154,16	183,31	141,33	126,00	134,77	215,83	276,61	265,48	405,91	3243,56
	EC A1c	703,39	541,30	361,13	266,32	288,72	242,80	236,94	252,10	335,10	389,16	364,31	484,94	4466,21
	EC A1d	463,22	344,81	170,85	130,67	218,61	205,51	185,00	198,02	252,23	256,60	199,44	299,01	2923,97
	EC A1e	563,53	458,80	325,03	292,05	361,83	361,52	344,89	362,58	402,63	402,21	333,12	420,56	4628,76
Peak import electicity (MW)	EC A1a	0,68	0,57	0,57	0,51	0,44	0,39	0,42	0,42	0,49	0,57	0,65	0,65	0,68
	EC A1b	0,68	0,57	0,57	0,51	0,44	0,39	0,42	0,42	0,49	0,57	0,65	0,65	0,68
	EC A1c	0,68	0,57	0,57	0,51	0,44	0,39	0,42	0,42	0,49	0,57	0,65	0,65	0,68
	EC A1d	1,46	1,77	1,77	1,71	1,64	1,59	1,62	1,62	1,69	1,77	1,85	1,85	1,85
	EC A1e	1,88	1,77	1,77	1,71	1,64	1,59	1,62	1,62	1,69	1,77	1,85	1,85	1,88
Peak export electricity (MW)	EC A1a	4,50	4,02	3,67	2,84	2,28	1,64	2,58	2,47	3,44	3,13	3,95	3,98	4,50
	EC A1b	4,50	3,99	3,48	2,84	2,38	1,66	2,66	2,26	3,45	3,19	3,95	3,44	4,50
	EC A1c	5,98	5,42	4,98	3,73	3,12	3,07	3,07	3,32	4,95	4,32	5,31	4,48	5,98
	EC A1d	3,81	5,12	4,69	3,60	3,99	3,16	4,14	3,48	4,67	4,52	5,01	4,34	5,12
	EC A1e	5,23	6,62	6,19	4,96	4,44	4,30	4,52	4,56	6,17	5,58	6,51	5,68	6,62

3.2. ARCHETYPE 2A: HOUSEHOLDS AND EDUCATIONAL INSTITUTION

When the member of EC are not only households but also an educational institution (Figure 3.23), the installed capacity of solar panels is 400 kW. The EVs are the only electricity demand that is assumed to be flexible in this scenario A2a.

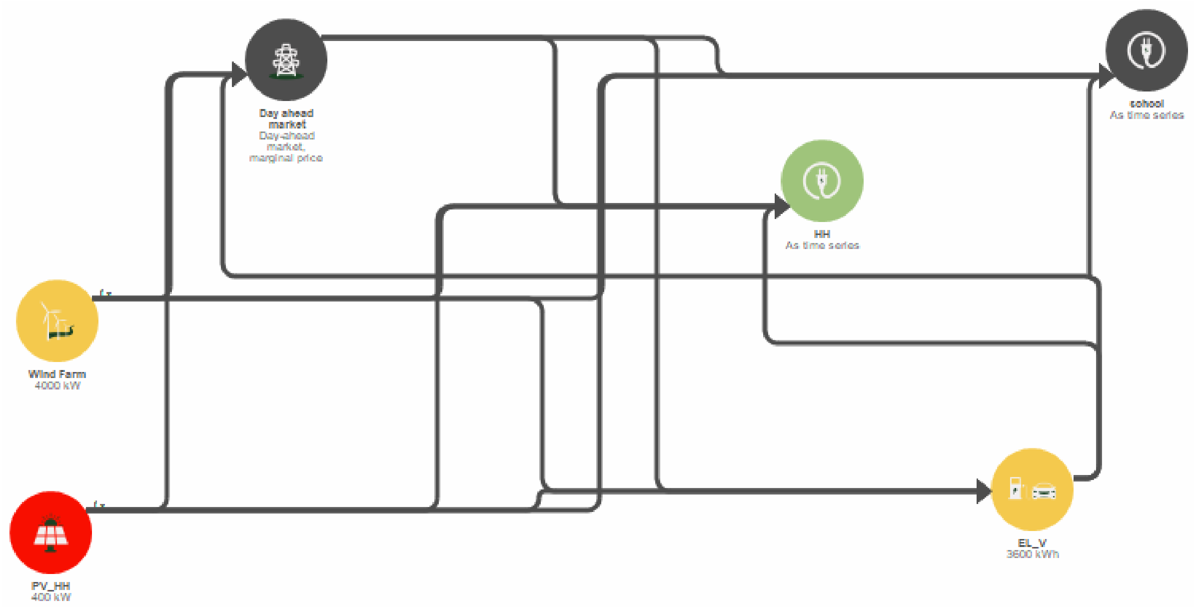

Figure 3.23. Archetype EC A2a: Households, educational building and EVs

Energy production within the community and its monthly energy demand is illustrated in Figure 3.24.

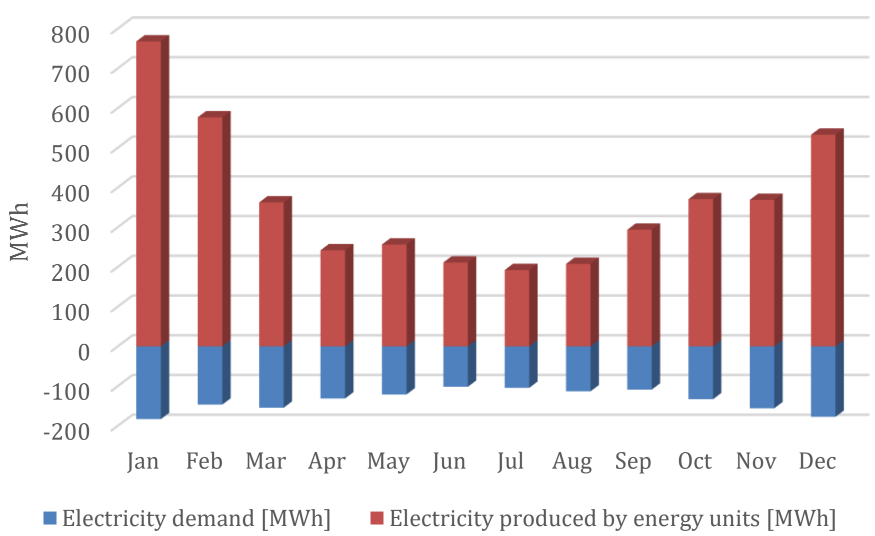

Figure 3.24. Ratio of electricity produced and required on a monthly basis within EC A2a

Although electricity generation exceeds consumption in all months, the system annually exports a total of 3.2 GWh of electricity while importing 470 MWh. The highest energy export occurs in January (618 MWh), whereas the highest import is recorded in November (49 MWh). These energy exchanges are reflected in the monthly peaks shown in Figure 3.25.

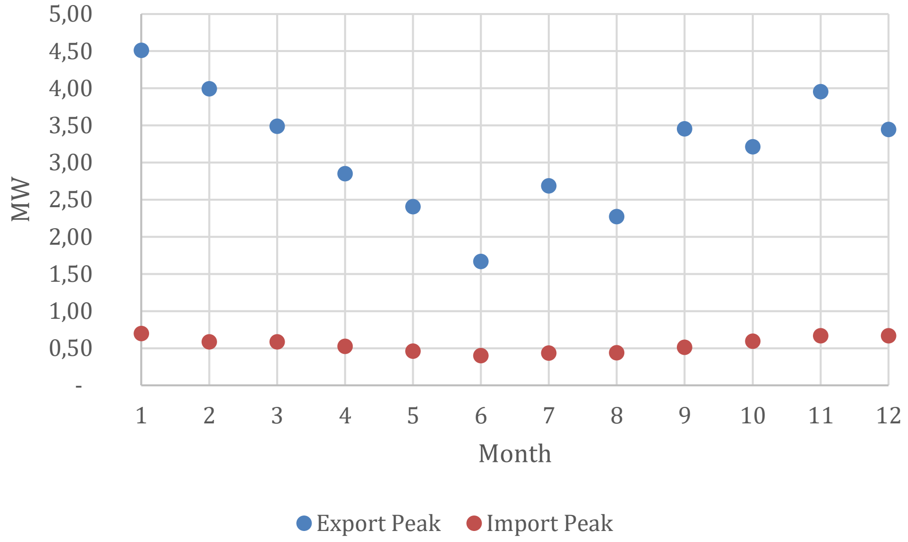

Figure 3.25. Peaks of import and export of energy (EC A2a)

Although Figure 3.25 might suggest that energy export in July exceed those in August, Figure 3.26 indicates that peak values are not necessarily determined by the amount of energy exported during a given month. For instance, in August, the system exports more energy compared to April, yet the peak in August is lower than the peak observed in April.

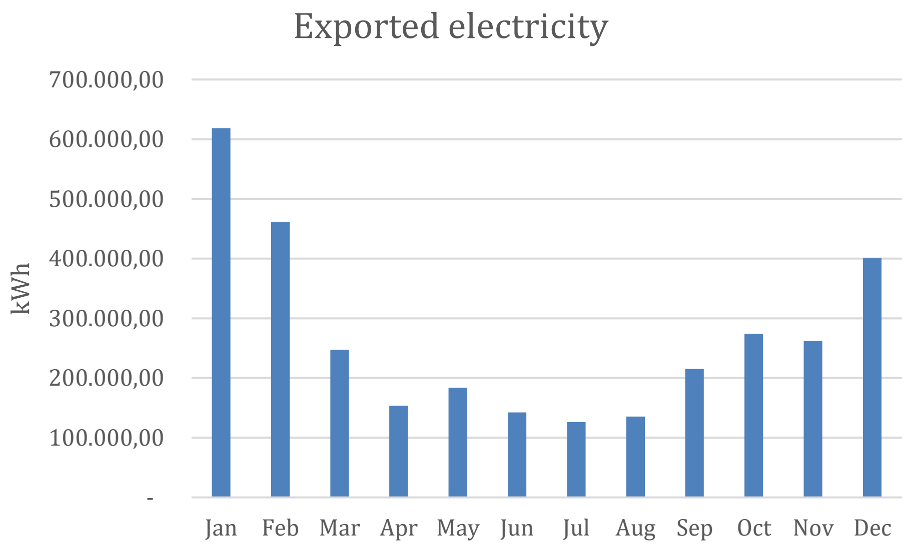

Figure 3.26. Amount of energy exported from the system on a monthly basis from EC A2a

If batteries were added to this system (EC A2b), energy import would not differ significantly compared to the configuration without battery storage. However, a substantial difference occurs in energy export during the winter months as well as in June (Figure 3.27).

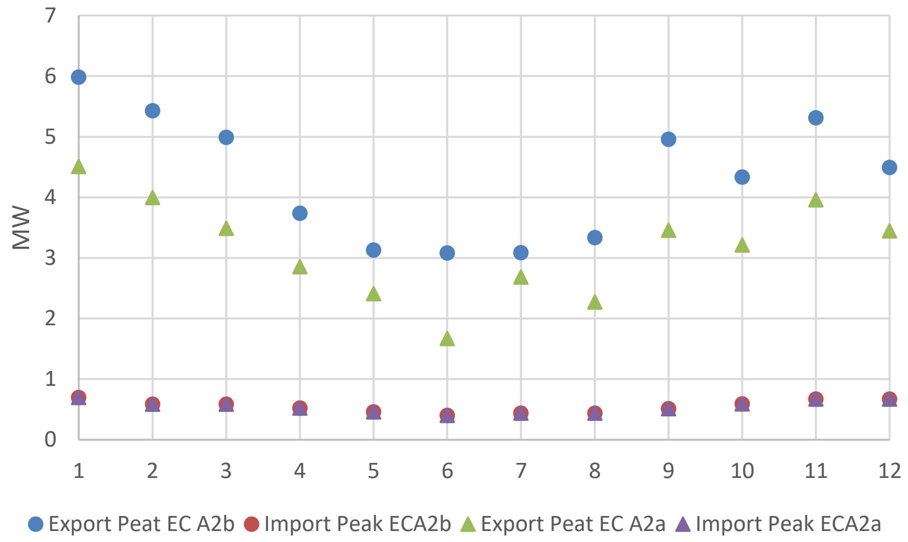

Figure 3.27. Comparison of energy import and export peaks in systems with (EC A2b) and without (EC A2a) batteries

When an educational building is part of an EC whose members are households with HPs (EC A2c), the installed PV capacity reaches 1.100 kW. Such a system annually exports 2,96 GWh of electricity and imports 1,3 GWh (Figure 3.28).

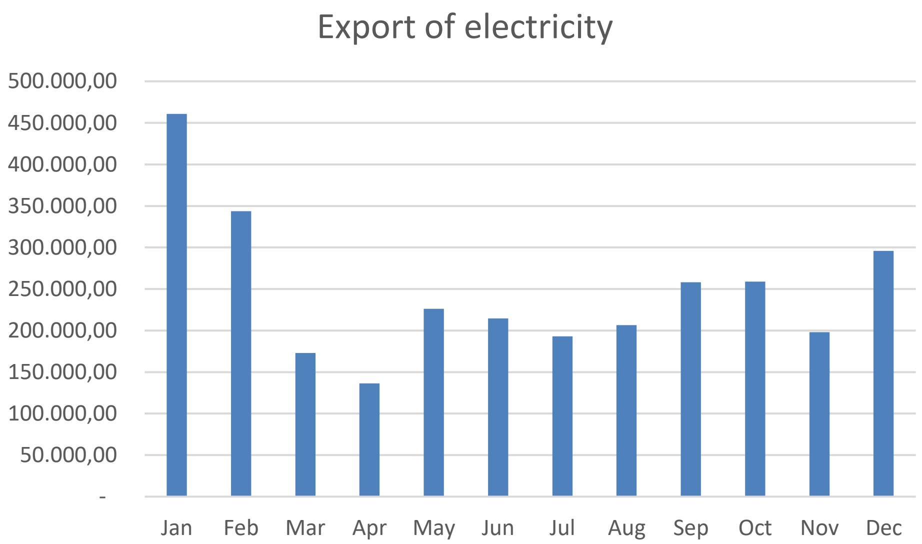

Figure 3.28. Electricity exports on a monthly basis (EC A2C)

Although the highest amount of electricity is exported in January, higher export peaks are recorded in February and March. Furthermore, in July, despite the total exported energy being greater compared to June, the peak in this month is 1 MW lower than in July, as shown in Figure 3.29.

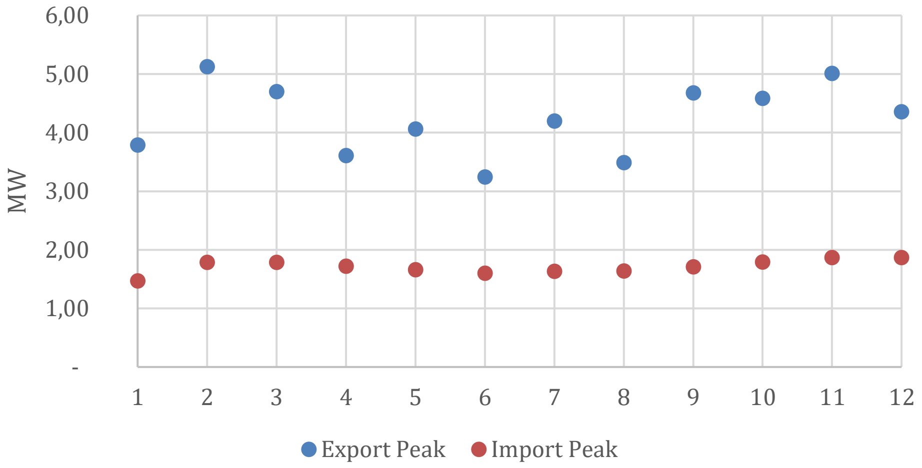

Figure 3.29. Monthly peaks of energy export and import (EC A2c)

The possibility of supplying heat through a DH system, including the heating demands of, not only households, but also the school, was analyzed across three scenarios:

- EC A2d – district heating system without heat storage,
- EC A2e – district heating system with heat storage,
- EC A2f – district heating system with both heat and electricity storage (Figure 3.30).

For comparison purposes, all systems in which heating options are analyzed assuming an installed PV capacity of 1.100 kW.

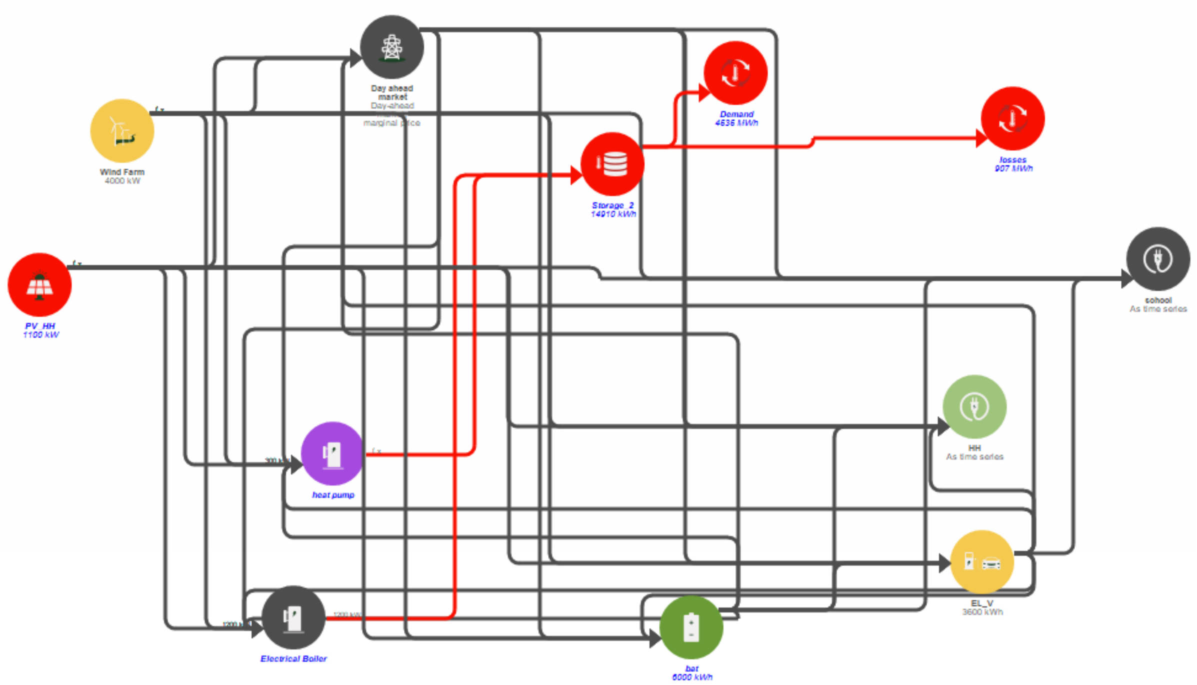

Figure 3.30. Archetype EC A2f: Households and school with district heating

Monthly fluctuations in heat demand within this system are presented in Figure 3.31.

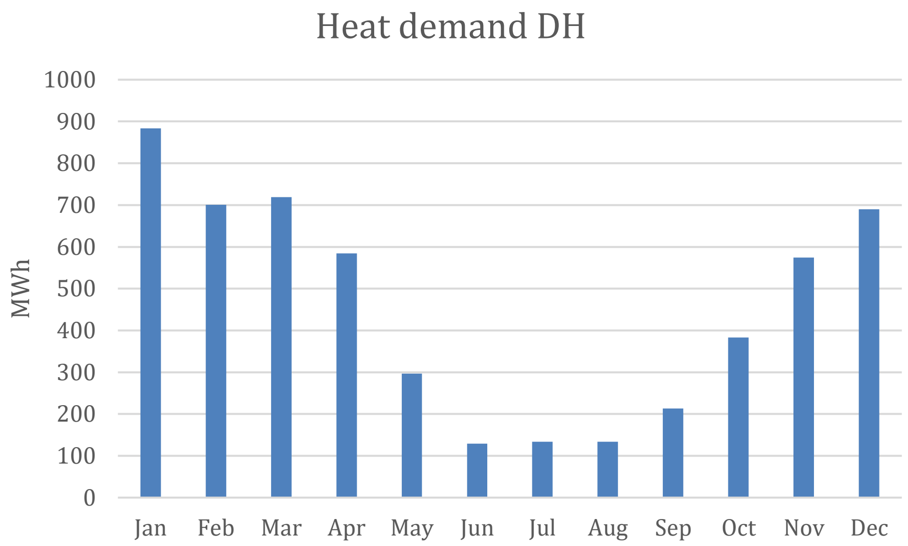

Figure 3.31. Heat energy demand in EC A2

A comparative overeview of energy export from the system for all three analyzed scenarios is shown in Figure 3.32.

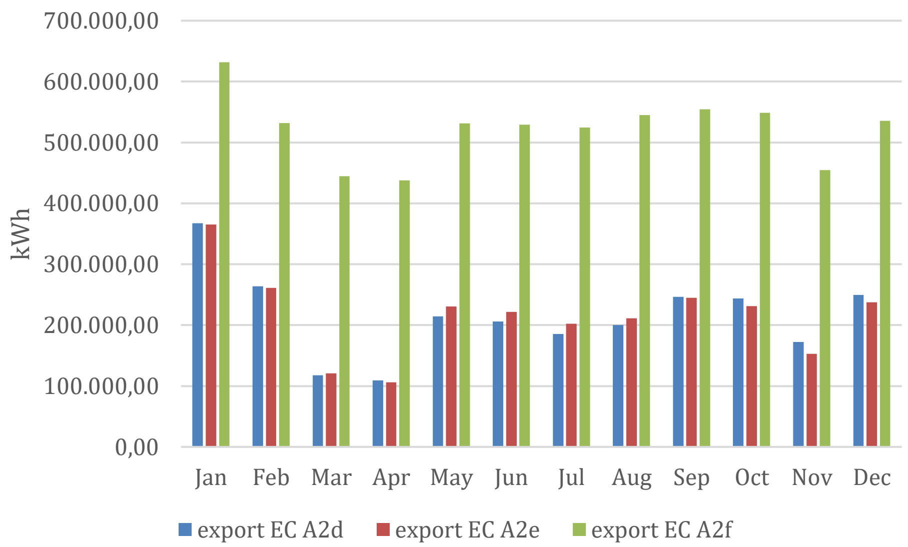

Figure 3.32. Export of electricity on a monthly basis for EC A2 d-f

As observed in the figure, the highest energy export occur in the system that has both battery and heat storage, which can be explained by the export of electricity when market prices are favorable. In contrast, the system without heat storage records higher energy export from October to November. On the other hand, this system imports less energy on a monthly basis during the summer months, as illustrated in Figure 3.33.

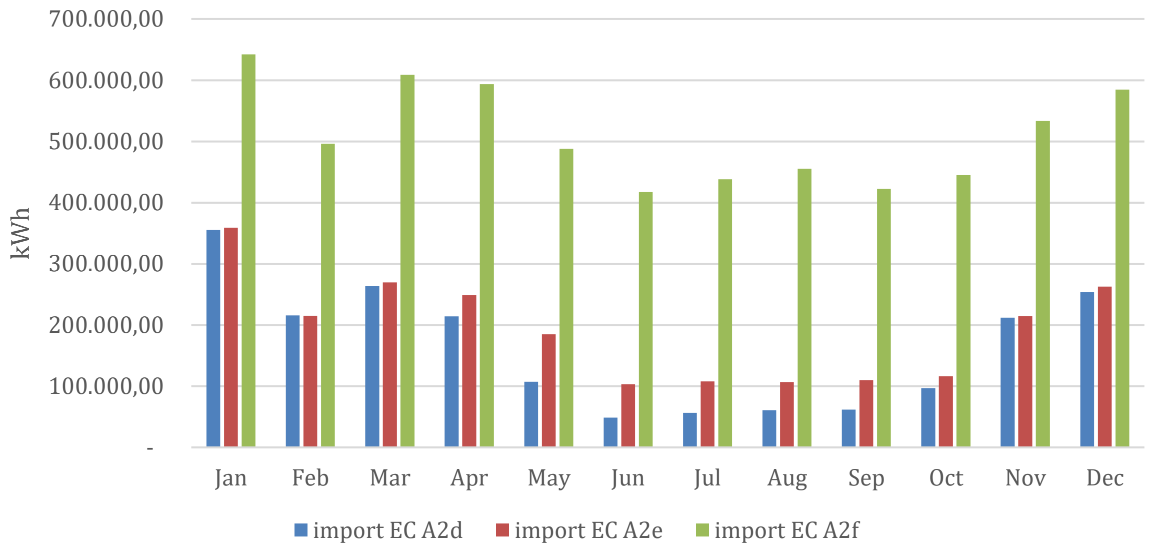

Figure 3.33. Comparative overview of electricity exports from EC A2d-f

A comparison of monthly peaks in exported and imported energy is provided in Figure 3.34

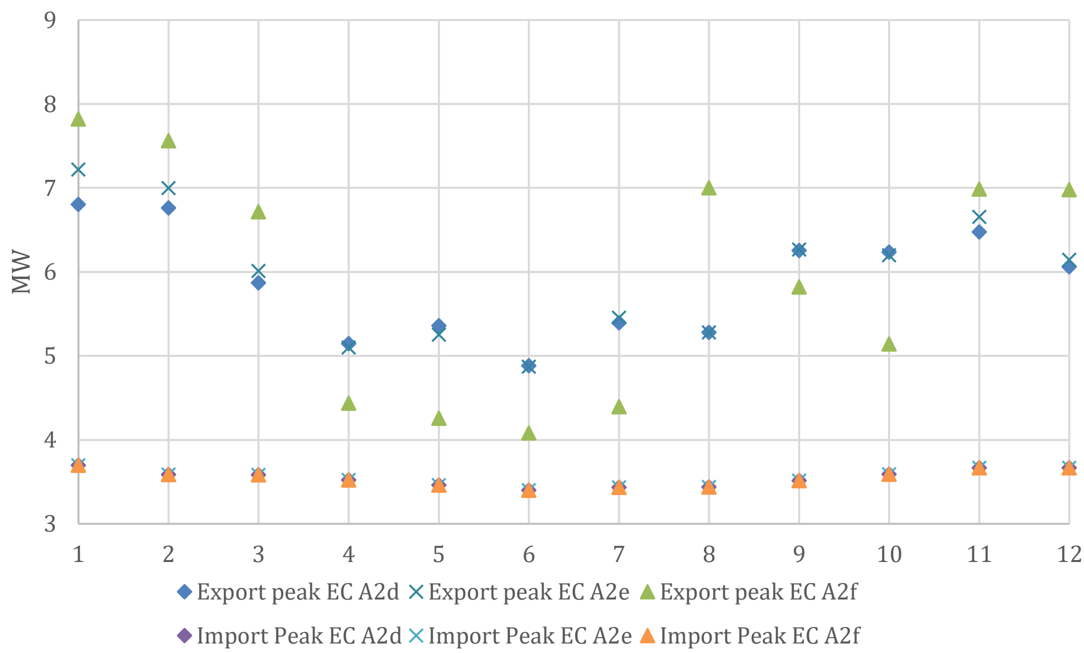

Figure 3.34. Comparative overview of peaks of import and export of electricity from the EC A2 d-f system

As shown in the figure, the highest export peaks for system EC A2f occur during the winter months, while the lowest are observed in summer. The system without heat storage has lower peaks in winter compared to the configuration with heat storage. However, across the analyzed systems, there is almost no difference in the peaks of imported electricity.

If the DH system analyzed in scenarios EC A2d-f were replaced with DH system where a ground source HP is used instead of an air-to-water HP, the feasibility of implementing this system was examined through two scenarios:

- EC A2g – without battery storage
- EC A2h – with battery storage.

This system results in changes of electricity export peaks. Specifically, the system with battery storage exports more energy compared to the system without battery storage during the winter months, whereas the opposite occurs in summer. With the used economic assumptions, battery storage does not affect energy import into the system (Figure 3.35).

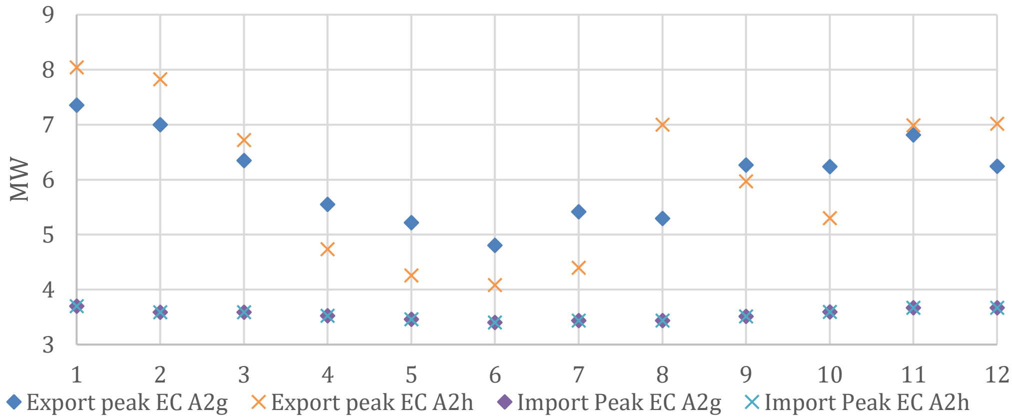

Figure 3.35. Comparative overview of energy import and export in EC A2g-h

In the system without battery storage (EC A2g), the use of electric boilers is higher compared to the system with battery storage (EC A2h), as shown in Figure 3.36. This result demonstrates that electricity storage not only enables better balancing of electricity production but also facilitates greater utilization of efficient devices within the analyzed system.

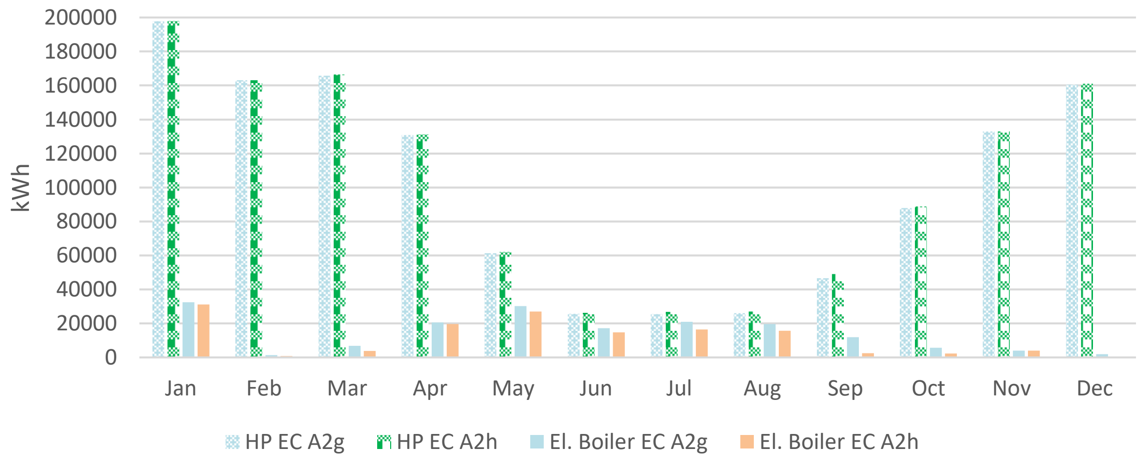

Figure 3.36. Comparative overview of the use of technologies for the production of heat in the EC A2g-h system

3.2.2. Comparison of revenues and expenditures across all scenarios for Archetype 2 EC

A comparative overview of the operational income and expenses of all scenarios of the analyzed EC A2 archetype is shown in Table 3.3. In the table, the purple color refers to tariffs, where the last column represents their sum. Note that this does not include investment costs and associated costs related to loans etc. These costs can therefore not be used to identify total costs for the consumer, and the costs shown here are only for the purposes of comparing between the 8 scenarios analysed.

Table 3.3. Comparative overview of operational costs and revenues in the EC A2 energy community (kDKK)

	EC A2a	EC A2b	EC A2c	EC A2d	EC A2e	EC A2f	EC A2g	EC A2h
sale of electricity	1.198,15	1.339,29	1.101,15	896,25	822,13	1.135,74	1.132,59	1.454,06
Purchase of electricity	251,03	145,61	733,37	1.231,27	790,64	685,36	518,96	355,83
TSO_consumption	219,95	219,95	219,95	597,55	605,75	603,37	394,47	394,47
TSP_subscription fee	54,78	54,78	54,78	54,78	54,78	54,78	54,78	54,78
TSO_feed in	49,67	53,11	55,30	55,30	60,83	65,75	58,58	65,34
DSO_consumption tariffs	350,39	351,18	349,30	1.033,01	820,95	824,41	605,07	605,34
DSO_feed in	20,30	21,71	22,60	22,60	24,86	26,87	23,94	26,71
balancing cost	43,19	46,18	48,09	48,09	52,90	57,18	50,94	56,82
TSO and TSO tariffs TOTAL	***738,28***	***746,91***	***750,03***	***1.811,34***	***1.620,07***	***1.632,36***	***1.187,80***	***1.203,47***

In a system that, in addition to households, includes an educational institution, the role of energy storage proves to be multifaceted. First, the impact of battery storage is evident, as it positively contributes to reducing the overall operational costs of the energy community in both scenarios, whether individual heating systems or district heating are applied, though at the same time it also increases the peak usages of the electricity grid potentially adding a need for electricity grid expansion. On the other hand, the results highlight the critical importance of heat storages. Not only does it enable more efficient utilization and integration of RES, but a system without heat storage has is almost twice as high net operational costs compared to one where heat storage is possible. As already mentioned, these results do not include investment costs, and therefore cannot be used for investment decisions, nor to identify what the lowest total cost system would be.

3.2.1. Comparison of all scenarios of the EC A2 archetype

Table 3.4 provides a comparative overview of data related to all scenarios within the analyzed archetype. The data include yearly electricity and heat demand, energy production, import and export of electricity as well as their peaks.

Table 3.4 Comparative overview of all the scenarios of the EC A2 archetype

	EC A2a	EC A2b	EC A2c	EC A2d	EC A2e	EC A2f	EC A2g	EC A2h
Heat demand (MWh/year)	-	-	4.500,00	5.442,00	5.442,00	5.442,00	4.762,00	4.762,00
Electricity consumed (MWh/year)	1.629,27	1.389,21	1.389,21	1.389,21	1.389,21	1.389,21	1.389,21	1.389,21
Electricity produced (MWh/year)	4.333,29	4.333,29	4.333,29	4.333,29	4.333,29	4.333,29	4.333,29	4.333,29
Exported electricity (MWh/year)	3.016,30	3.030,40	2.798,88	2.412,84	2.105,21	2.167,40	2.899,11	2.964,24
Peak export (MW)	3,80	3,80	5,13	6,77	3,52	3,53	3,70	3,70
Imported electricity Day ahead market (MWh)	312,28	230,18	1.422,75	2.031,25	1.284,33	1.221,61	716,45	589,78
Peak import (MW)	0,67	0,67	1,87	3,70	2,33	3,67	1,72	3,67

3.3. ARCHETYPE 3: HOUSEHOLDS, EDUCATIONAL INSTITUTION AND PUBLIC BUILDING

When the energy community EC comprises not only households and educational institution but also another public building (Figure 3.37), the installed capacity of PV amounts to 440 kW.

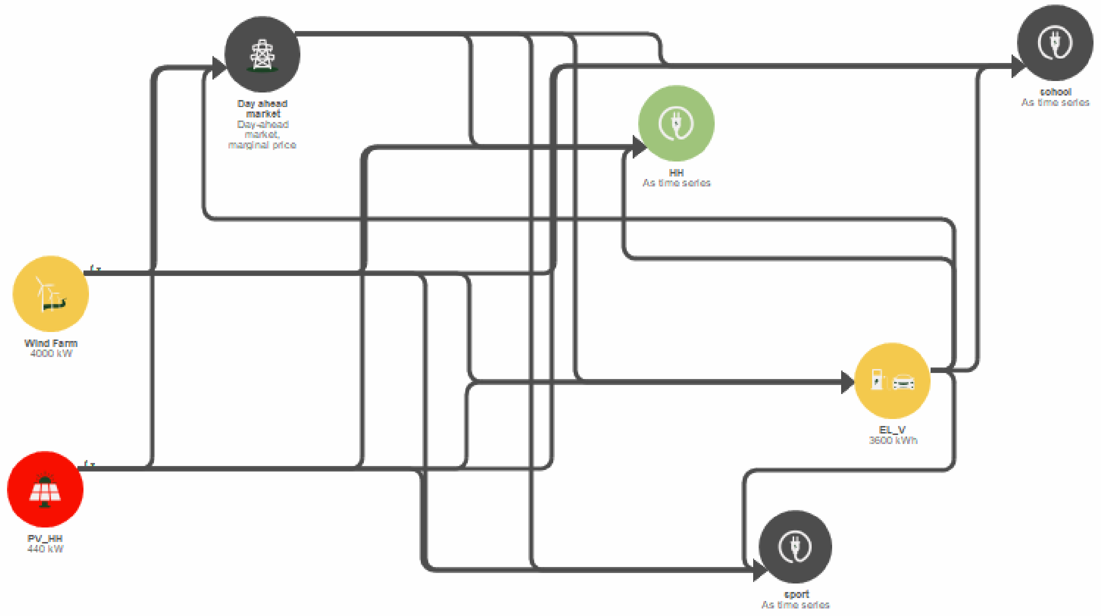

Figure 3.37. Archetype EC A3a: Households, educational and public building and EV

Energy production within the community and its monthly energy demand is illustrated in Figure 3.38.

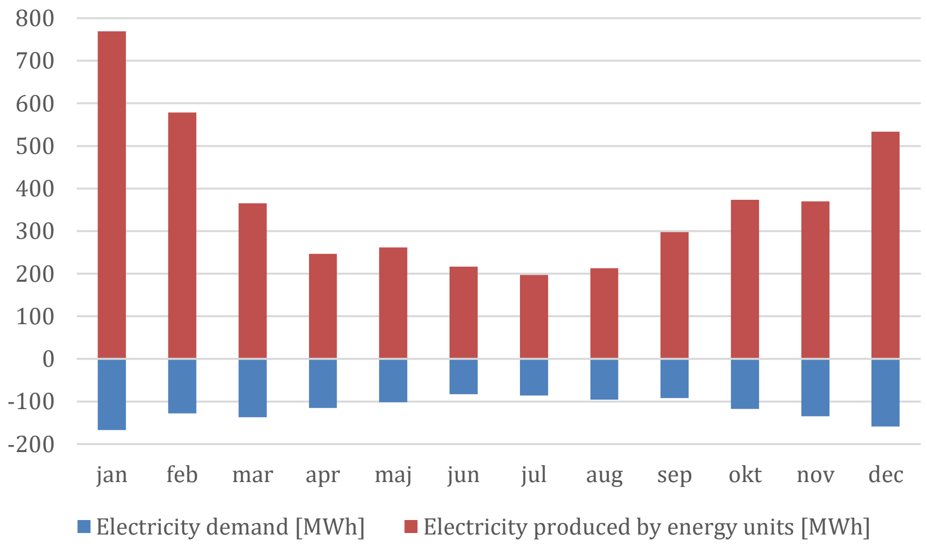

Figure 3.38. Ratio of electricity produced and required on a monthly basis within EC A3a

Although electricity generation exceeds consumption in all months, the system annually exports a total of 3.24 GWh of electricity while importing 475,5 MWh. The highest energy export occurs in January (618 MWh), whereas the highest import is recorded in November (49,7 MWh). These energy exchanges are reflected in the monthly peaks shown in Figure 3.39.

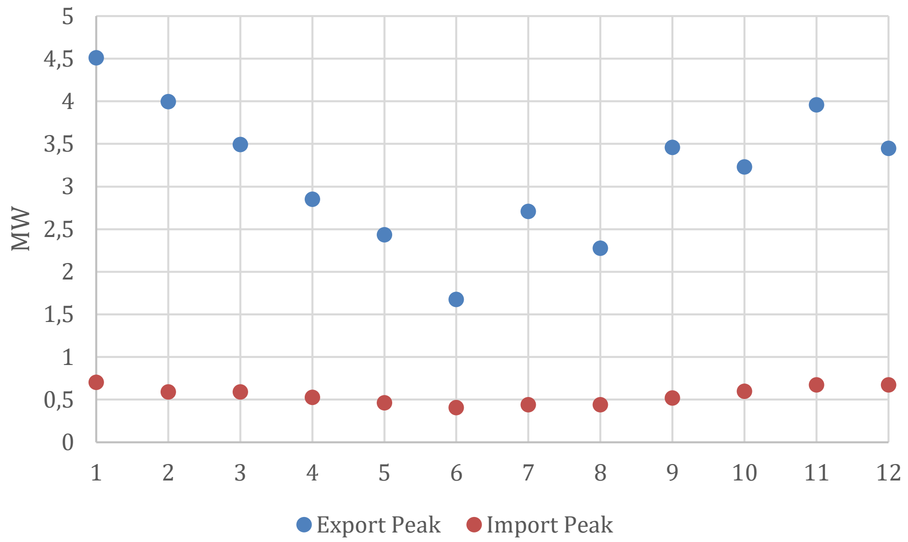

Figure 3.39. Peaks of import and export of energy (EC A3a)

Figures 3.39 and 3.40 indicate that peak values are not necessarily determined by the amount of energy exported during a given month. For instance, the system exports more energy in May compared to April, yet the peak in May is lower than the peak observed in April.

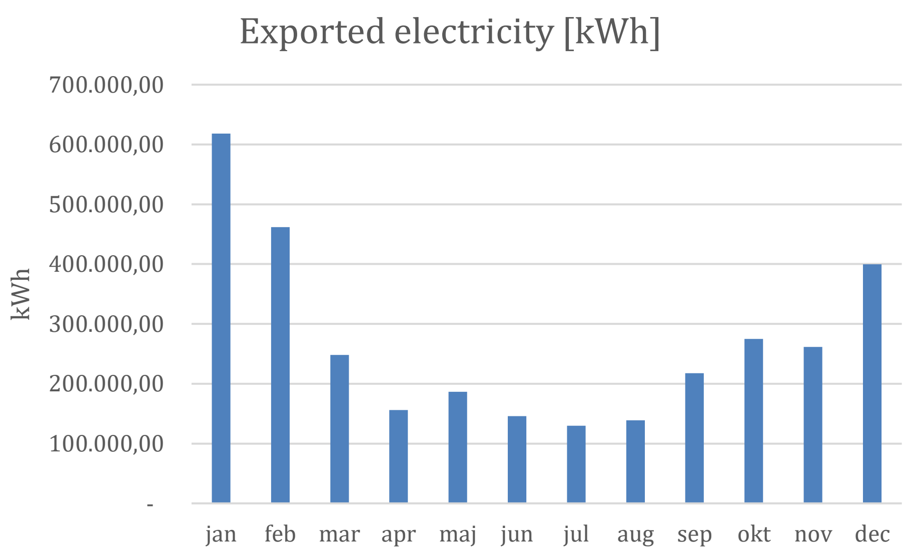

Figure 3.40. Amount of energy exported from the system on a monthly basis from EC A3a

If electricity storage were added to this system (EC A3b), energy import would not differ significantly compared to the configuration without battery storage. However, a substantial difference occurs in energy export during the winter months as well as in June (Figure 3.41).

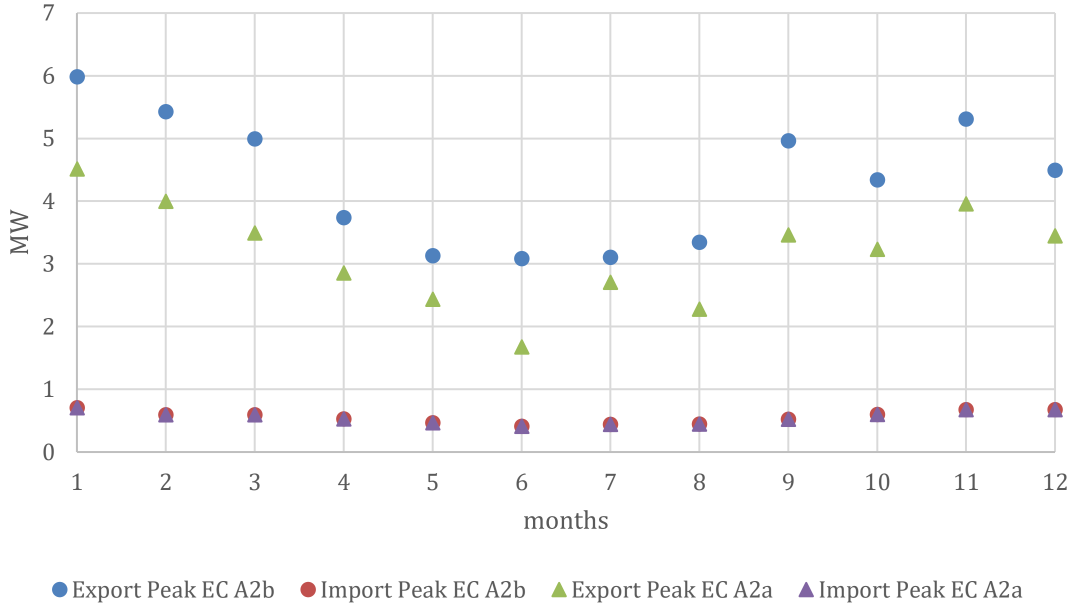

Figure 3.41. Comparison of energy import and export peaks in systems with (EC A3b) and without (EC A3a) batteries

When an educational building is part of an EC whose members are households equipped with HPs (EC A3c), the installed PV capacity reaches 1.230 kW. Such system annually exports 3,1 GWh of electricity and imports 1,3 GWh (Figure 3.42).

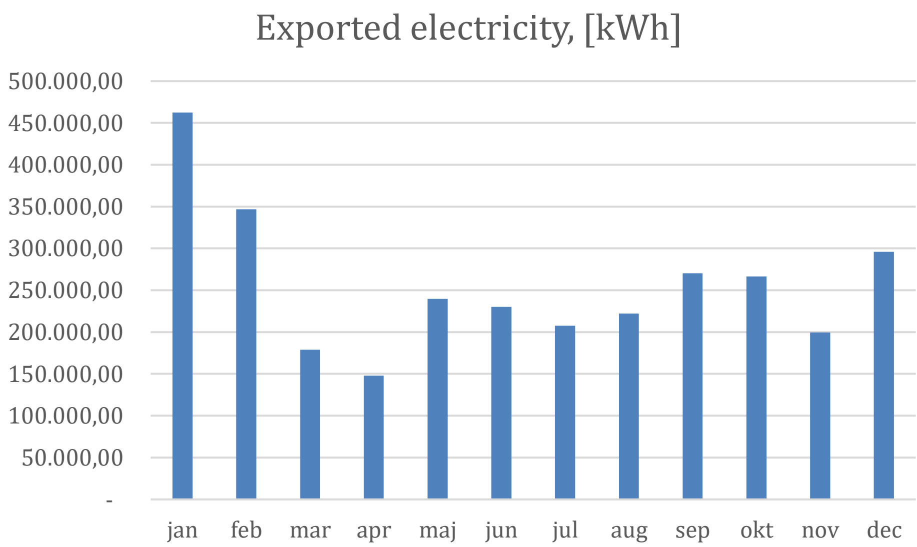

Figure 3.42. Electricity export on a monthly basis (EC A3C)

Although the highest amount of electricity is exported in January, export peaks are recorded in February and March. Furthermore, in July, despite the total exported energy being greater compared to June, the peak in this month is 1 MW lower than in July (Figure 3.43).

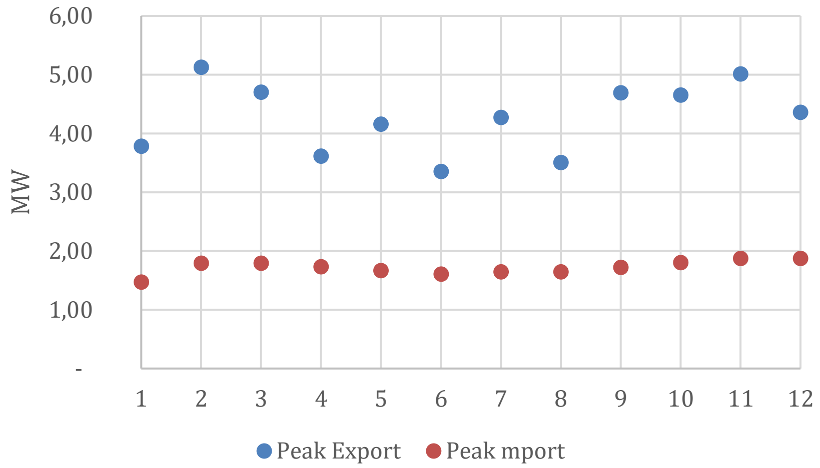

Figure 3.43. Monthly peaks of energy export and import (EC A3c)

The possibility of supplying heat through a district heating system, including the energy demand of not only households and educational building, but also public building was analyzed across three scenarios:

- EC A3d – district heating system without heat storage
- EC A3e – district heating system with heat storage
- EC A3f – district heating system with both heat and electricity storage (Figure 3.44).

For comparison purposes, all systems in which heating options are analyzed have an installed PV capacity of 1.230 kW.

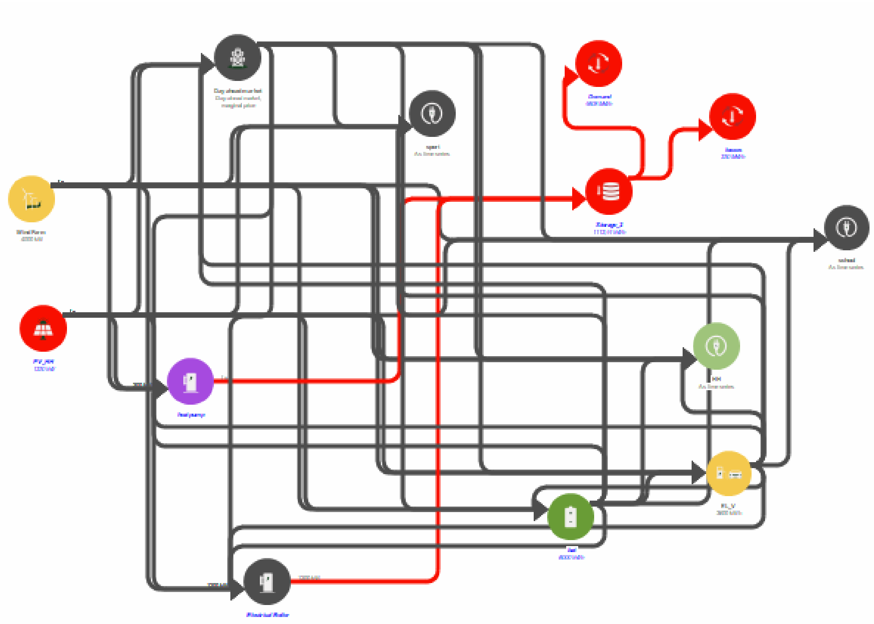

Figure 3.44. Archetype EC A3f: Households, educational and public building with district heating

Monthly fluctuations in heat demand within this system are presented in Figure 3.45.

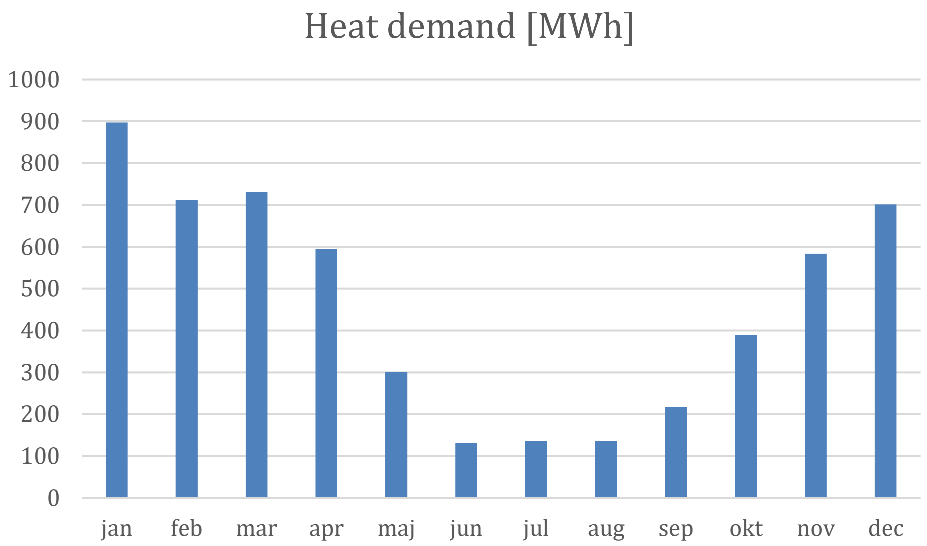

Figure 3.45. Heat energy demand in EC A3

A comparative overview of energy export from the system for all three analyzed scenarios is shown in Figure 3.46.

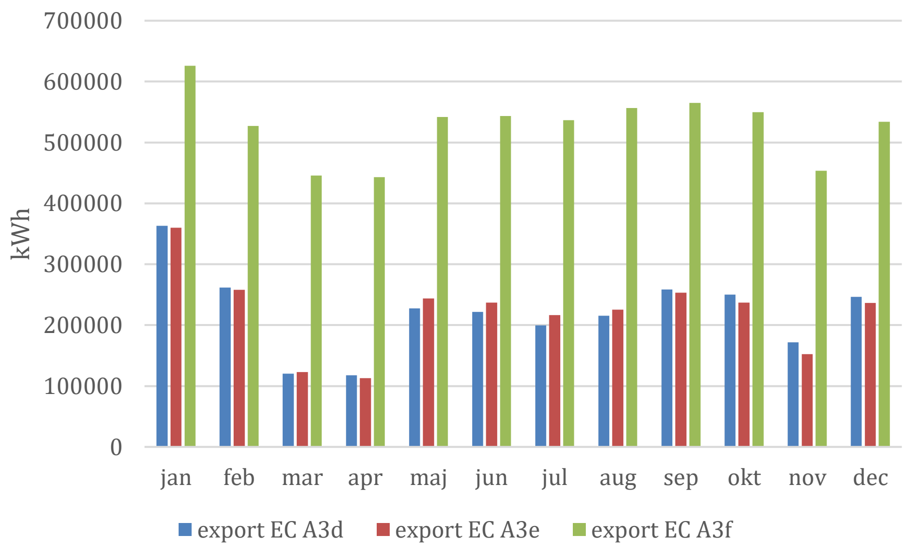

Figure 3.46. Export of electricity on a monthly basis for EC A3 d-f

As observed in the figure, the highest energy export occur in the system with battery and thermal storage, which can be explained by the export of electricity when market prices are favorable, as in all pervious scenarios. In contrast, the system without heat storage has higher energy export from October to November. As in EC A2e-f, this system imports less energy on a monthly basis from may till October.

A comparison of monthly peaks in exported and imported energy is provided in Figure 3.47

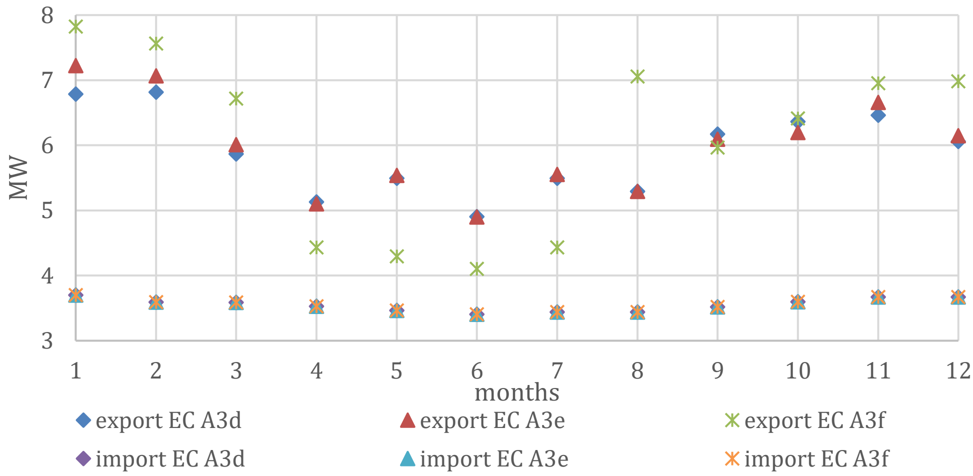

Figure 3.47. Comparative overview of peaks of import and export of electricity from the EC A3 d-f system

As shown in the figure, the highest export peak for system EC A3f is occuring in January, while the lowest are observed in summer. On the other side, the system without heat storage has lower export peaks in winter compared to the configuration with heat storage. However, across the analyzed systems, there is almost no difference in the peaks of imported electricity.

If the DH system analyzed in scenarios EC A3d-f were replaced with a DH system, where a ground source HP is used instead of an air-to-water HP, the feasibility of implementing this system was examined through two scenarios:

- EC A3g – without battery storage,
- EC A3h – with battery storage.

The hourly electricity demand-supply for EC A3h is shown in Figure 3.48.

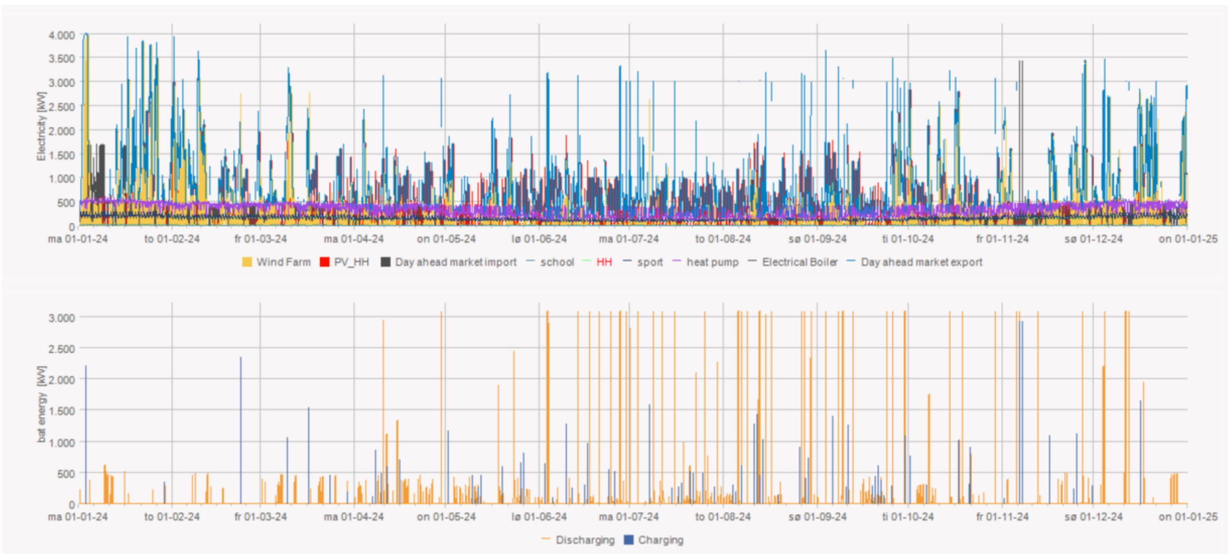

Figure 3.48. Energy balance on hourly level for EC A3h

This system results in changes to the peaks of electricity export. Specifically, the system with battery storage exports more energy compared to the system without battery storage during the winter months, whereas the difference in summer months is not significant. Also, battery storage will increase import of electricity in the system (Figure 3.49).

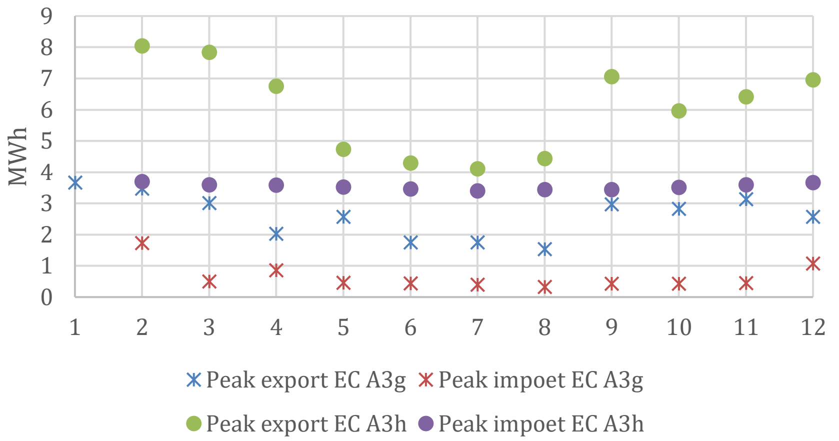

Figure 3.49. Comparative overview of energy import and export in EC A2g-h

3.3.2. Comparison of revenues and expenditures across all scenarios for Archetype 2 EC

A comparative overview of the operational income and expenses of all scenarios of the analyzed EC A3 archetype is shown in Table 3.5. Note that this Table does not include investment costs and associated costs related to loans etc. These costs can therefore not be used to identify total costs for the consumer, and the costs shown here are only for the purposes of comparing between the 8 scenarios analysed.

Table 3.5 Comparative overview of operational costs and revenues in the EC A3 energy community (kDKK)

	EC A3a	EC A3b	EC A3c	EC A3d	EC A3e	EC A3f	EC A3g	EC A3h
sale of electricity	1.204,26	1.345,76	1.141,74	906,02	848,89	1.168,96	1.169,64	1.497,34
Purchase of electricity	254,70	146,22	731,23	1.246,38	805,08	701,07	526,72	359,31
TSO_consumption	223,95	223,95	223,95	610,94	614,92	616,64	401,64	401,64
TSP_subscription fee	54,96	54,96	54,96	54,96	54,96	54,96	54,96	54,96
TSO_feed in	50,16	53,67	56,76	60,16	62,38	67,45	60,09	67,06
DSO_consumption tariffs	357,28	358,20	356,05	1.064,56	835,32	843,77	617,50	617,84
DSO_feed in	20,50	21,93	23,20	24,59	25,50	27,57	24,56	27,41
balancing cost	43,61	46,67	49,36	52,32	54,25	58,65	52,25	58,31
TSO and DSO tariffs TOTAL	750,46	759,38	764,28	1.867,53	1.647,33	1.669,04	1.211,00	1.227,22

3.3.3. Comparison of all scenarios of the EC A3 archetype

Table 3.6 provides a comparative overview of data related to all scenarios within the analyzed archetype. The data include yearly electricity and heat demand, energy production, imports and exports of electricity as well as their peaks.

Table 3.6 Comparative overview of all the scenarios of the EC A3 archetype

	EC A3a	EC A3b	EC A3c	EC A3d	EC A3e	EC A3f	EC A3h	EC A3g
Heat demand (MWh/year)	0,00	0,00	4500	5530	5530	5530,00	4838,00	4838,00
Electricity consumed (MWh/year)	1658,86	1658,86	3462,30	4529,19	4653,67	4607,40	2983,45	2981,52
Electricity produced (MWh/year)	4375,49	4482,44	4935,88	5246,57	5511,63	5616,16	5243,66	5461,40
Exported electricity (MWh/year)	3033,22	3045,18	2894,77	2429,70	2165,79	2230,49	2987,15	3055,34
Imported electricity (MWh/year)	316,58	230,43	1421,19	1712,33	1307,83	1235,13	726,95	592,97
Export Peak (MW)	3,80	3,80	5,13	3,23	3,52	3,53	3,66	3,66
Eimport Peak (MW)	0,67	0,67	1,87	1,64	2,33	3,67	1,73	3,67

3.4. COMPARISON OF RURAL EC THAT PRODUCE ONLY ELECTRICITY

When considering all analyzed scenarios in which only electricity is produced, a comparative overview of energy import into the system is presented in Figure 3.50.

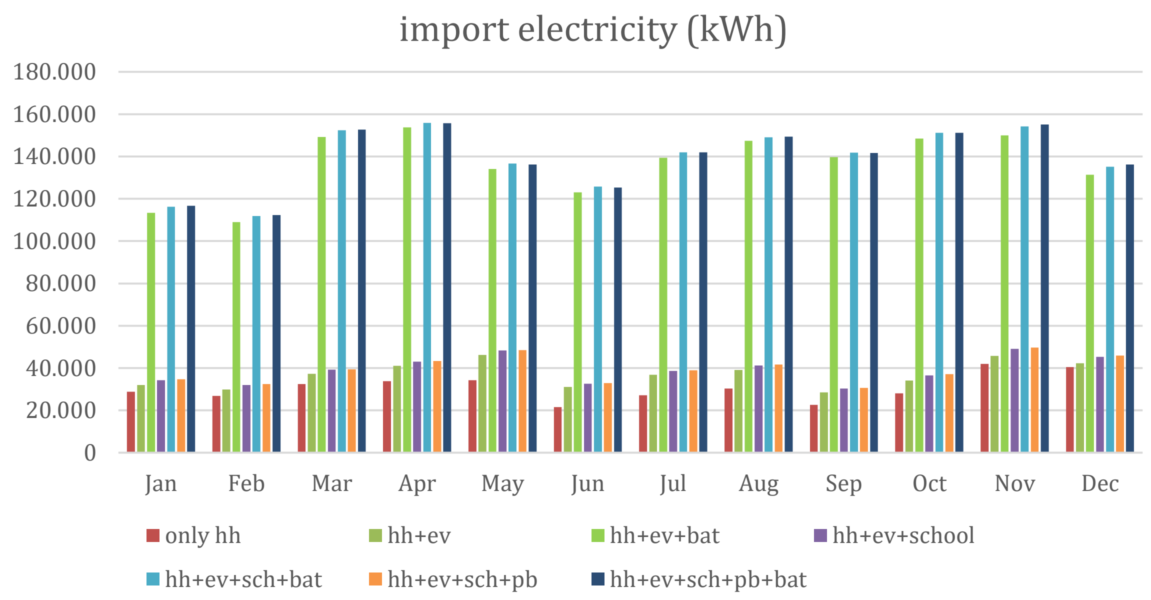

Figure 3.50. Comparative overview of energy imports for electricity-only scenarios for EC A1-3

As illustrated in Figure 3.50, the inclusion of EVs in the ECs affects the total monthly import of electricity. Conversely, when comparing systems that already incorporate EVs, adding new members has almost no impact on the total monthly electricity import, except during the winter months, when higher import are observed for EC A2 and EC A3.

Regarding electricity export, a comparative overview is presented in Figure 3.51.

When comparing archetypes of ECs that include EVs, the figure indicates that adding new types of buildings have no effect on increasing of total electricity export on a monthly level to the local system. On the contrary, comparing the scenario analyzing only households, with the scnarios that include new types of consumers (EVs and public buildings), it can be seen that during the summer months electricity export is higher, while during the winter months energy export is lower, respectively.

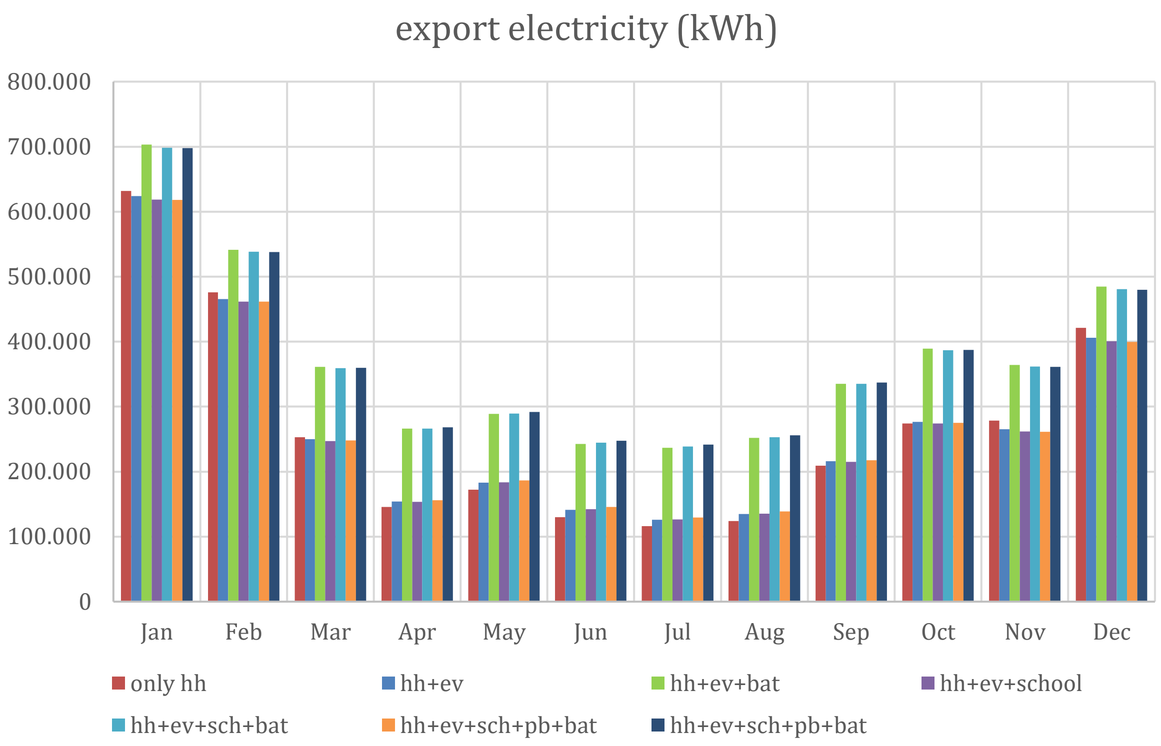

Figure 3.51. Comparative overview of energy export into the EC for all analyzed EC A1-3 scenarios

In such systems, the peaks of electricity export remain almost identical for configurations without battery storage. The same observation applies to export peaks in systems equipped with battery (Figure 3.52).

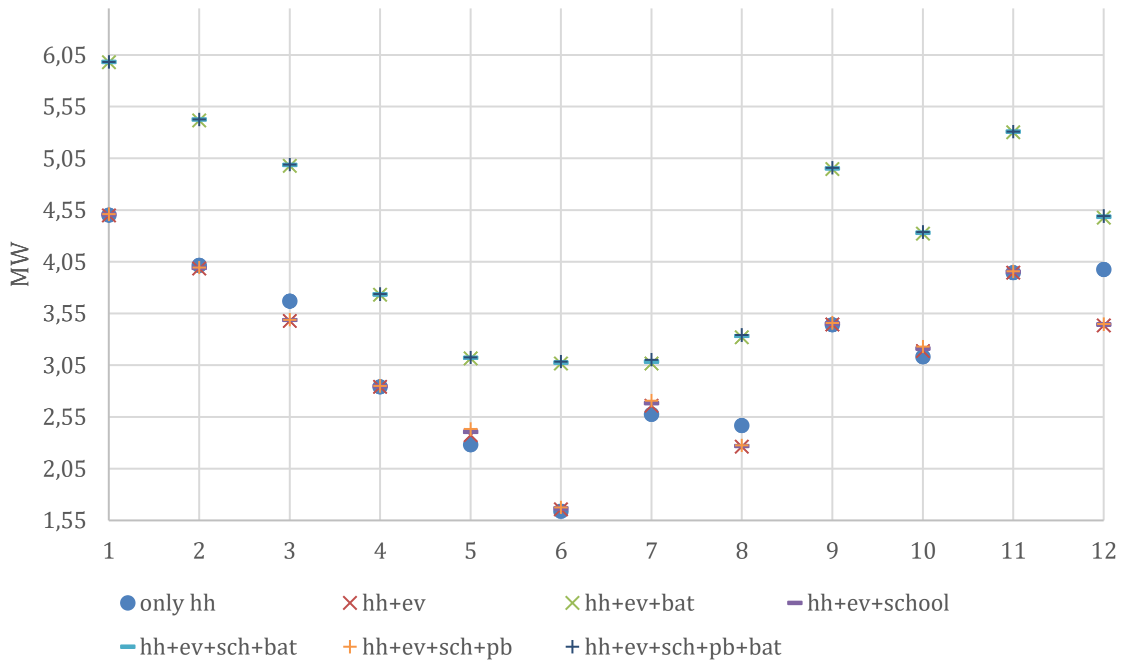

Figure 3.52. Comparison of peaks in export of electricity from theECs in which only electricity is produced (EC A1-3)

As previously explained in the context of techno-economic optimization, the integration of batteries can influence the potential for increased electricity import and export. However, it should be noted that this effect is primarily driven by market electricity prices, allowing the system to import low-cost electricity and export and sell electricity at higher prices.

This comparison is particularly relevant from the perspective of ECs members, as it demonstrates the potential for leveraging local RES at the community level.

These results are not intended to assess the impact of the ECs on the local distribution system, but rather to highlight the potential of ECs and the importance of matching different energy consumption profiles.

Table 3.7 presents, for all analyzed scenarios, the revenues from electricity sales as well as the costs associated with electricity purchases and TSO/DSO tariffs.

Table 3.7 Comparative overview of operational costs and revenues of ECs where only electricity is produced (kDKK)

	sale of electricity	purchase of electricity	DSO and TSO tariffs
only hh	1.189,78	251,10	654,95
hh+ev	1.211,24	233,04	704,18
hh+ev+bat	1.354,85	133,69	712,63
hh+ev+school	1.198,15	251,03	738,28
hh+ev+sch+bat	1.339,29	145,61	746,91
hh+ev+sch+pb	1.204,26	254,70	750,46
hh+ev+sch+pb+bat	1.345,76	146,22	759,38

As shown in the table, the electricity purchase costs for scenarios where production profiles are paired (for example household + school) are almost identical to those in scenarios that include only households. On the other hand, in such scenarios, tariffs are higher due to the increased demand for energy as well as its production.

Conversely, when the system includes a battery, the costs of purchasing electricity are significantly lower, while revenues from energy sales are higher compared to a system without a battery.

However, it is important to emphasize that this study does not account for investment costs, which can be expected to be substantially higher in systems with battery storage compared to those without it and therefore cannot be used in decision of implementation feasibility.

3.5. COMPARISON OF HEATING SOLUTION IN ANALIZED RURAL ARCHETYPES OF EC

In the case of EC that produce not only electricity but also heat, two scenarios are compared:

- Scenarios where HPs are used for generating heat in households;
- Scenarios where heat demands, (for households, the school, and the public building) are met through a district heating system.

When air-to-water HPs are present in households, electricity import are shown in Figure 3.53.

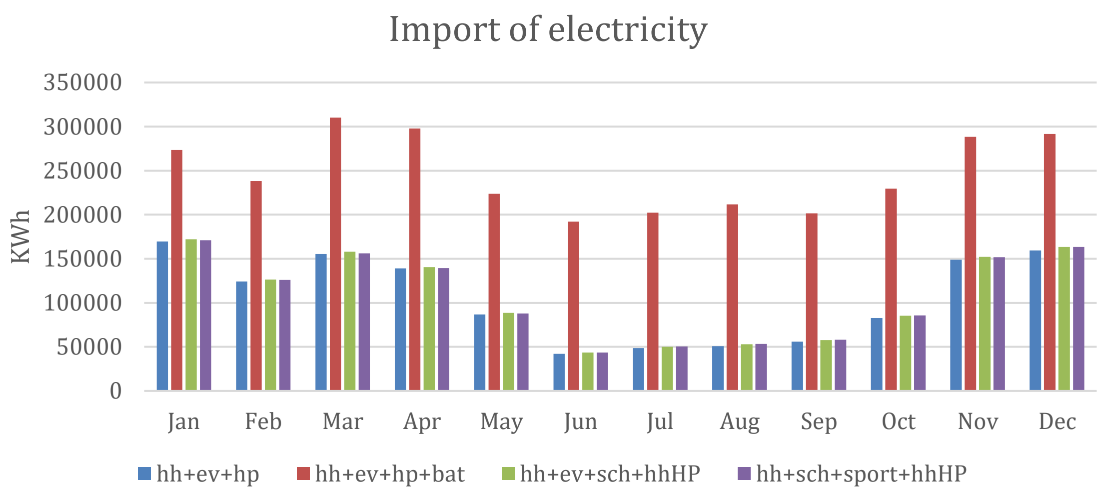

Figure 3.53. A comprehensive overview of electricity import in scenarios in which HPs are used in households

In such a system, the total monthly electricity export are shown in Figure 3.54.

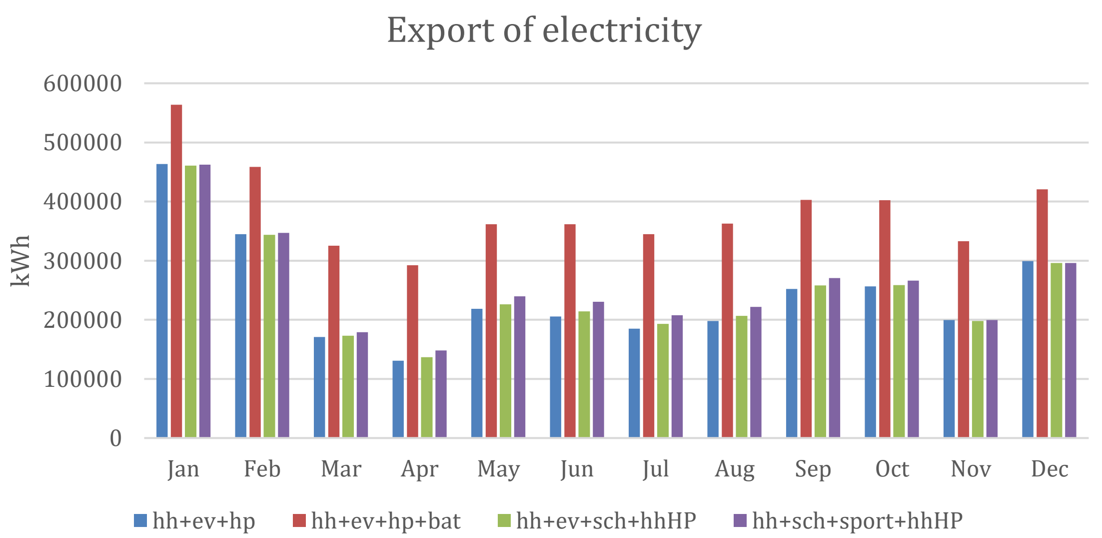

Figure 3.54. Comparative view of energy export for scenarios in which HPS are used to heat households

The figures indicate that, in the case of household heating with HPs, adding new members can cause a slight increase in energy import, particularly during the summer months. Conversely, the inclusion of a public building leads to an increase in electricity export. The inclusion of public buildings in an ECs where HPs are used for heating, energy export peaks increase during the summer months, while they are almost unchanged in the winter months, as shown in Figure 3.55.

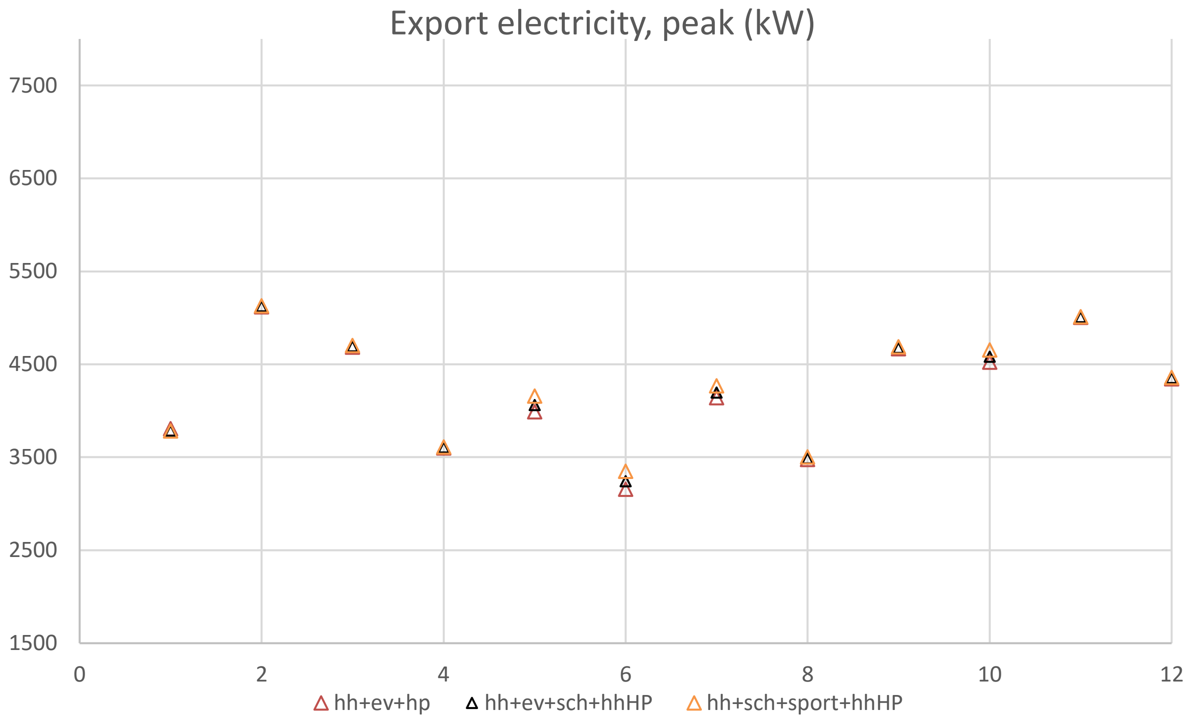

Figure 3.55. Comparative overview of energy export peaks in systems using heat pumps

When considering system operational costs and revenues, it can be observed (Table 3.8) that revenues from electricity sales are higher in systems with different profiles of electricity demand. However, in such systems, electricity purchases are also more expensive.

Table 3.8 Comparative overview of operating costs and revenues of ECs in which heat pumps are used (kDKK)

	sale of electricity	Purchase of electricity	TSO and DSO tariffs
hh+ev+hp	1.090,82	721,89	1.303,60
hh+ev+hp+bat	1.403,67	705,01	1.311,20
hh+ev+sch+hhHP	1.101,15	733,37	750,03
hh+sch+sport+hhHP	1.141,74	731,23	764,28

When analyzing the potential of DH, Figure 3.56 shows that these systems import significantly more energy compared to scenarios that consider only the use of HPs. However, it should be noted that in scenarios with HPs, only household heating demand is taken into account, whereas in other analyzed archetypes, the heat demands of the school and the public building are also included. Furthermore, in DH systems with lower grid loss, electricity import is lower compared to less efficient DH solutions.

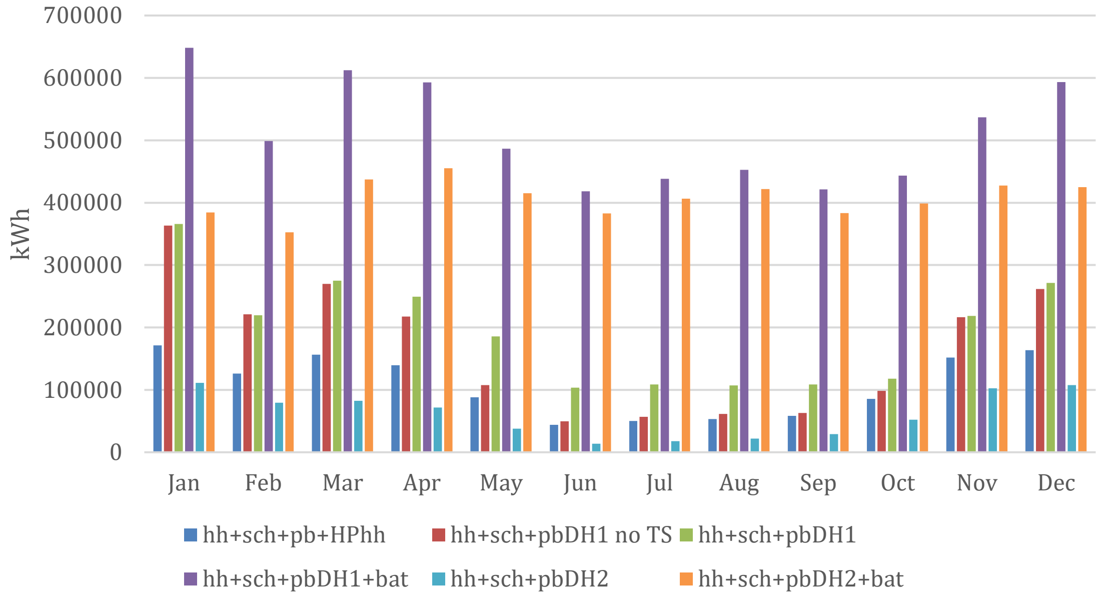

Figure 3.56. Comparative overview of energy import in scenarios where DH exists

When it comes to electricity export (Figure 3.57), systems that rely solely on HPs export more energy compared to those using DH. Unlike energy import, systems with more efficient heating configurations export a greater amount of energy on a monthly basis compared to systems using air-to-water HPs. Furthermore, it is worth noting the case of systems without heat storage: these systems export less energy than those equipped with heat storage.

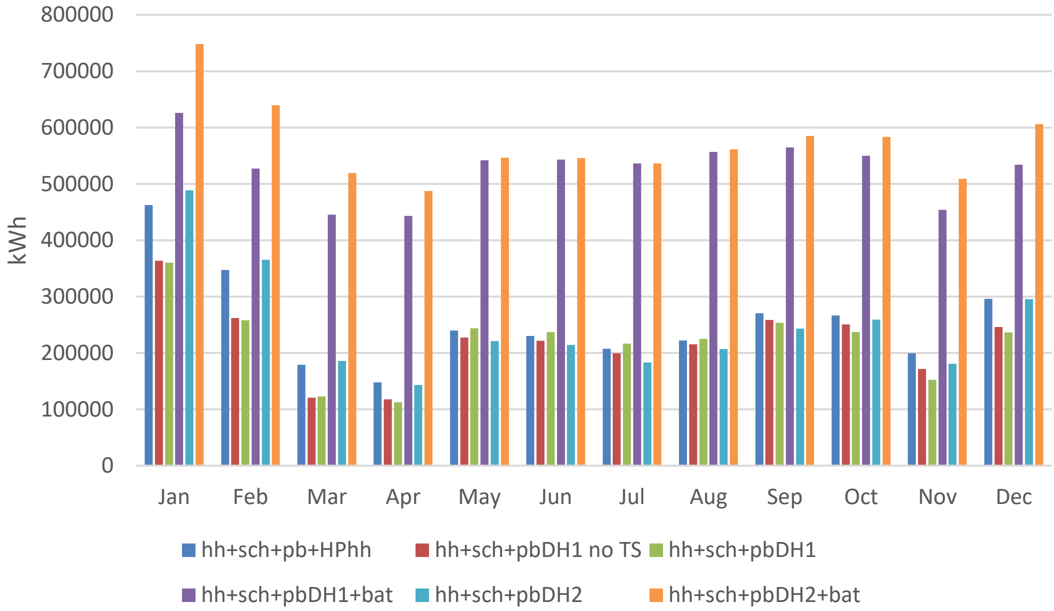

Figure 3.57. Comparative overview of energy export in scenarios where DH exists

However, when examining the amount of energy purchased or sold to the grid (table 3.9), it becomes evident that a system without heat storage has significantly higher costs compared to a system equipped with storage.

Table 3.9 Comparative overview of operational cost and revenues in scenarios where DH exists (kDKK)

	Sale of electricity	Purchase of electricity	Grid tariffs
hh+sch+pb+HPhh	1141,74	731,23	764,28
hh+sch+pbDH1 no TS	906,02	1246,38	1867,53
hh+sch+pbDH1	848,89	805,08	1647,33
hh+sch+pbDH1+bat	1168,96	701,07	1669,04
hh+sch+pbDH2	1169,64	526,72	1211,00
hh+sch+pbDH2+bat	1497,34	359,31	1227,22

3.6. URBAN ARCHETYPE OF EC

In the analysis of urban energy districts, the following scenarios were considered:

- EC A4a: apartments and electric vehicles,
- EC A4b: apartments, electric vehicles, and an educational institution,
- EC A4c: 300 apartments, electric vehicles, an educational institution, and a public building
- EC A4d: apartments, electric vehicles, and battery storage,
- EC A4e: apartments, electric vehicles, an educational institution, and battery storage,
- EC A4f: apartments, electric vehicles, an educational institution, a public building, and battery storage.

The main difference between this archetype and the previous ones lies in the fact that all generation capacities within this archetype are based exclusively on solar panels. In all archetypes, the PV capacity is 700 kW, except in the case of the EC consisting only of households, where the generation capacity is 650 kW.

A schematic representation of archetype EC A4f is shown in Figure 3.58.

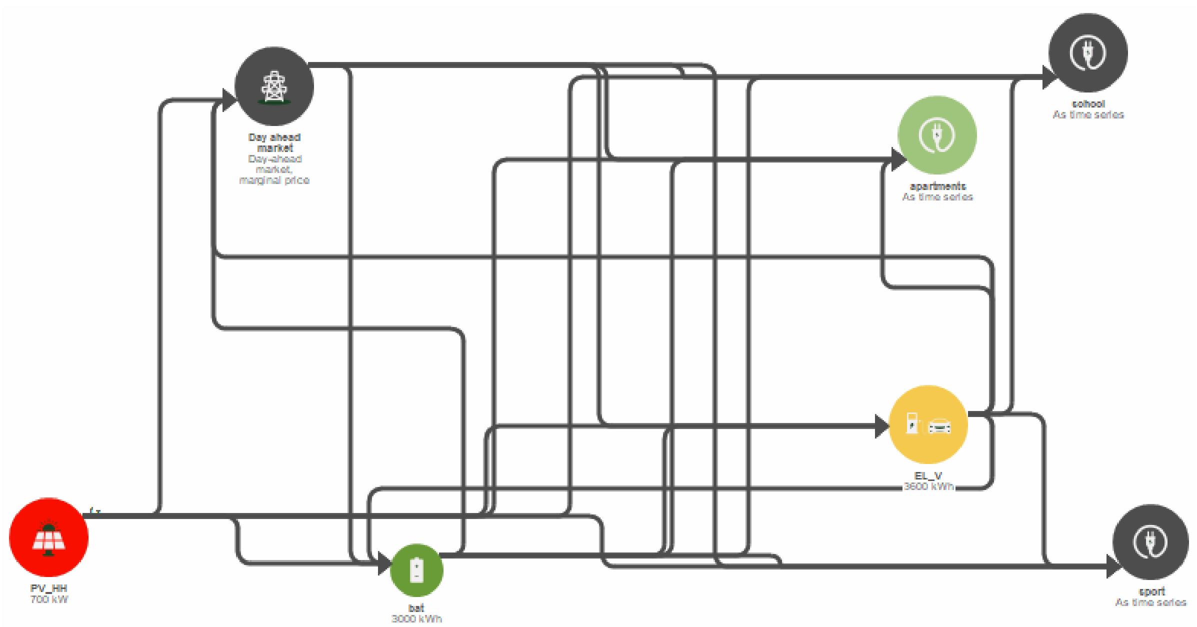

Figure 3.58. Archetype EC A4g: apartments, electric vehicles, an educational institution, a public building, and battery storage.

Unlike archetypes that include wind generation capacities, in EC A4 import are most pronounced during the winter months. This can be explained by the nature of PV production. Furthermore, when comparing scenarios, it becomes evident that electricity import are higher in scenarios that include public buildings and apartments compared to those with apartments only. In contrast to all previous models (EC A 1-3), where electricity import were more significant in systems with battery storage, in cases where generation relies exclusively on PV, import is reduced in systems with batteries, particularly during the summer months (Figure 3.59).

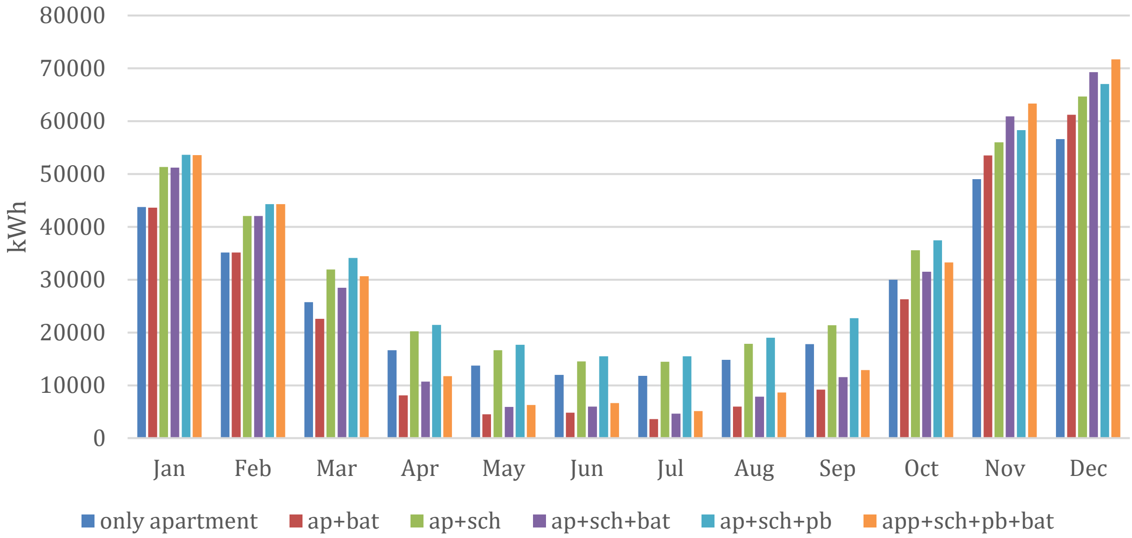

Figure 3.59. Comparative overview of energy import in EC A4

This can be explained by the low electricity prices during daytime in the summer months, and the ability to store energy when prices are low, as illustrated in Figure 3.60.

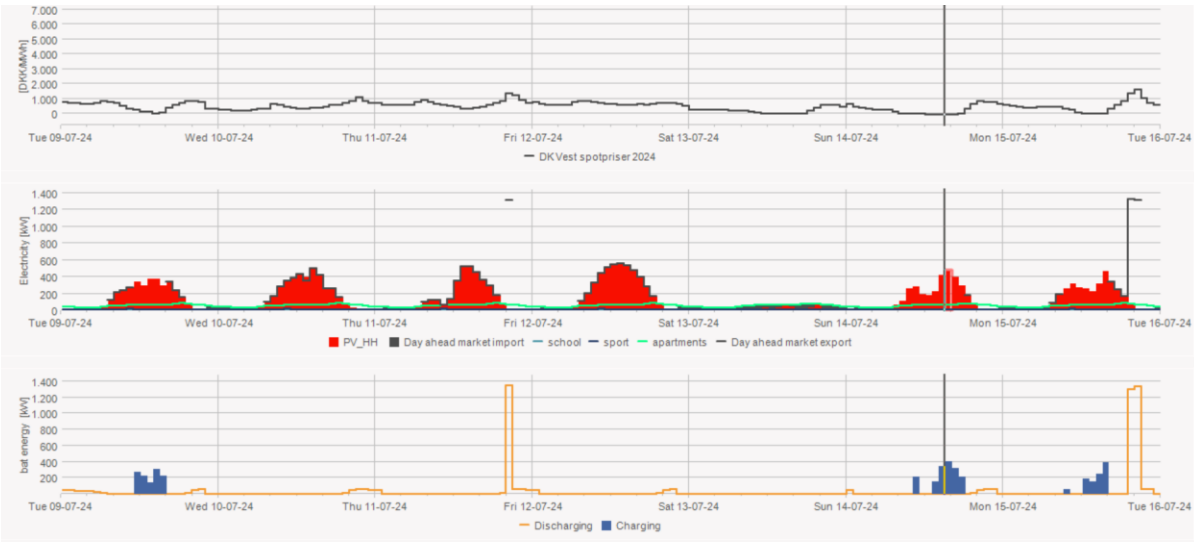

Figure 3.60. Comparative overview of electricity prices, import and export of energy, and battery storage utilization from the EC A4g system

On the other hand, electricity export are most pronounced during the summer months (Fig. 3.61), when PV generation reaches its peak. The system that exports the largest amount of energy is the one consisting solely of apartments, while systems with combined consumption patterns (including schools and public buildings) export less. Additionally, the presence of battery increases energy exports. It is important to note that energy is exported during periods when prices are most favorable (for example, at night, as shown in Figure 3.60). At the same time, during January and February, there is almost no difference in energy export between systems with and without batteries, and the difference is even smaller when the system includes, in addition to apartments, a school or a public building. This example demonstrates that load matching is of critical importance for maximizing the utilization of solar potential.

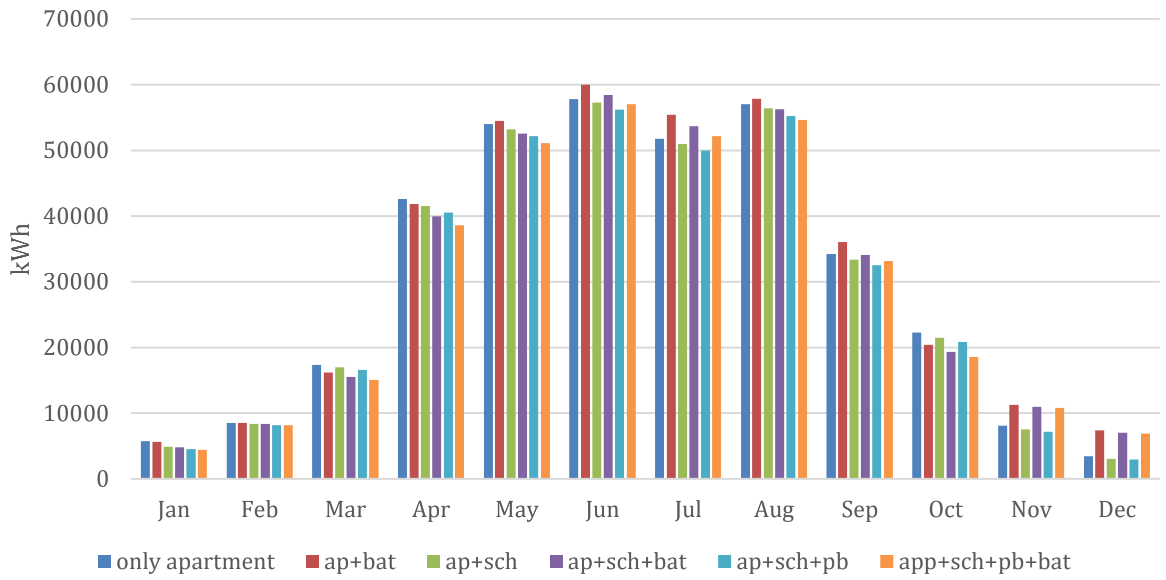

Figure 3.61. Comparative overview of energy export in EC A4

Conversely, when considering electricity export peaks (Fig 3.62), in systems without batteries they remain almost identical throughout the year, except in January, when the highest peaks are recorded in ECs that rely solely on solar panels.

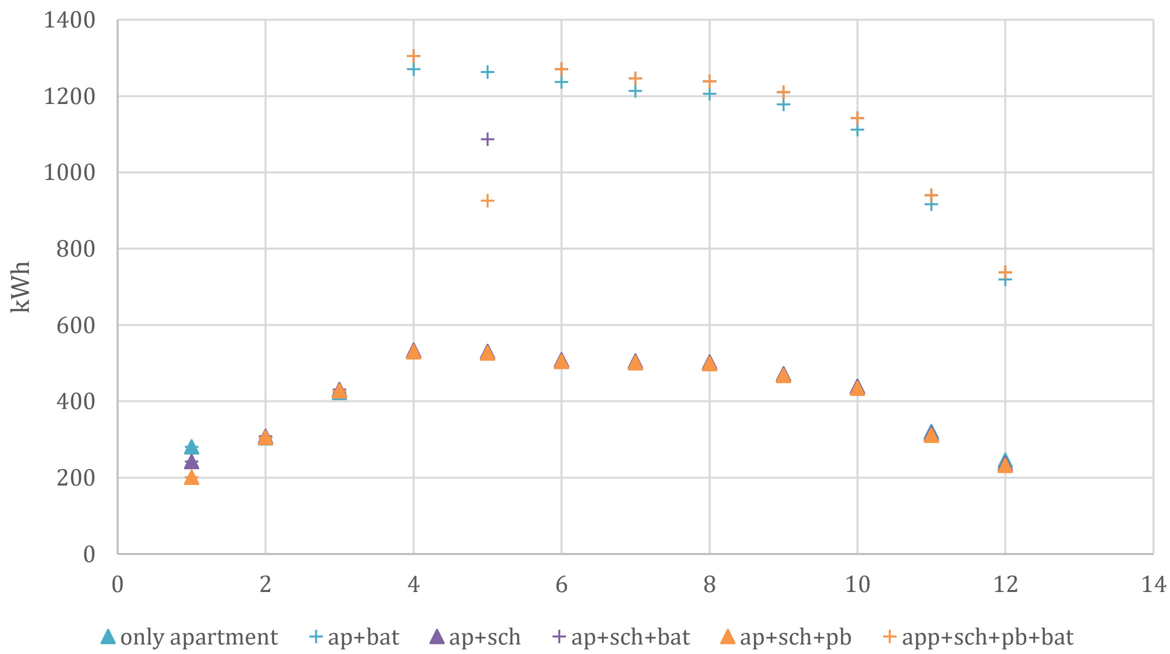

Figure 3.62. Comparative overview of electricity export peaks in EC A4

The overview of operational costs and revenues for all scenarios of EC A4 is shown in Table 3.10.

Table 3.10 Comparative overview of operational cost and revenues in scenarios where DH exists (kDKK)

	EC A4a	EC A4b	EC A4c	EC A4d	EC A4e	EC A4f
sale of electricity	172,358	166,705	162,42	288,263	280,075	273,615
Purchase of electricity	176,027	209,976	221,475	122,86	148,067	156,949
TSO_consumption	96,924	109,185	113,18	96,924	109,185	113,18
TSP_subscription fee	54,964	54,964	54,964	54,964	54,964	54,964
TSO_feed in	8,67	8,939	8,954	10,908	11,297	11,321
DSO_consumption tariffs	164,267	183,825	190,271	163,811	183,378	189,842
DSO_feed in	3,543	3,653	3,66	4,458	4,617	4,627
balancing cost	7,539	7,773	7,786	9,485	9,824	9,845
TSO and DSO tariffs TOTAL	335,907	368,339	378,815	340,55	373,265	383,779

4. CONCLUSIONS

Energy communities are becoming a part of the energy transition allowing citizens and local institutions to work together in producing, sharing, and using renewable energy. Instead of relying only on large centralized systems, ECs are ment to create local solutions that can reduce costs, improve flexibility, and strengthen social ties. They can also help facilitate local integration of renewable sources such as solar and wind, which are essential for reducing carbon emissions and achieving climate goals.

This report analyzed how different archetypes of ECs in Denmark can perform from both technical and operational economic perspectives. The study looked at different scenarios, starting with households only and then adding electric vehicles, public and educational buildings, battery storage, and heating systems. The results show that communities with a mix of different users and technologies have a higher self consumption compering with only households. Batteries can play a key role in EC potential because they allow energy to be stored when prices are low and sold when prices are high, which reduces costs and increases income, though this also results in increased peak import from and export to the local electricity grid, potentially resulting in grid expansion needs to allow for such battery operation. Heat storage and smart heating systems also help by lowering energy use during expensive periods and making the system more flexible.

However, the study's scope was limited to operational techno-economics and did not include investment costs nor detailed grid impact assessments. Future research should address these gaps by incorporating capital expenditure analyses, grid studies, and distributional effects to ensure fair benefit allocation. Expanding the archetypes to include industrial loads and flexible commercial actors could unlock additional synergies and resilience benefits.

The most robust outcomes arise when communities integrate diverse consumption profiles, battery and heat storage, and coordinated sector coupling across electricity, heat, and mobility. With supportive regulatory frameworks, clear sharing rules, and targeted financial incentives, ECs can scale as trusted, citizen-led institutions that provide measurable technical benefits to the grid and meaningful economic and social advantages to local communities.

5. REFERENCE

[1] "Clean energy for all Europeans package," European Commission. [Online]. Available: https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en

[2] "European Green Deal," European Commission.

[3] "Q&A: What are 'citizen' and 'renewable' energy communities?," REScoop. [Online]. Available: https://www.rescoop.eu/uploads/rescoop/downloads/QA-What-are-citizens-energy-communities-renewable-energy-communities-in-the-CEP.pdf

[4] "The 7 cooperative principles with examples from energy cooperatives," REScoop. [Online]. Available: https://www.rescoop.eu/toolbox/the-7-cooperative-principles-with-examples-from-energy-cooperatives

[5] M. M. Sokołowski, M. Taylor, and I. Buller, "Seven pillars of energy cooperation: an energy justice-driven framework for energy communities and energy cooperatives," *J. Energy Nat. Resour. Law*, vol. 43, no. 3, pp. 287–309, Jul. 2025, doi: 10.1080/02646811.2025.2455853.

[6] Dimitris Kitsikopoulos and Christos Vrettos, *The social impact of energy communities in Greece*. Thessaloniki: Heinrich Böll Foundation Greece and ELECTRA Energy cooperative, 2023. [Online]. Available: https://www.rescoop.eu/toolbox/the-social-impact-of-energy-communities-in-greece

[7] S. Soeiro and M. Ferreira Dias, "Community renewable energy: Benefits and drivers," *Energy Rep.*, vol. 6, pp. 134–140, Dec. 2020, doi: 10.1016/j.egyr.2020.11.087.

[8] "Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)." Official Journal of the European Union, Dec. 11, 2018. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG

[9] "Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast)." Official Journal of the European Union, Jun. 05, 2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019L0944

[10] "Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast) (Text with EEA relevance)." Official Journal of the European Union, Sep. 13, 2023. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AJOL_2023_231_R_0001&qid=1695186598766

[11] "Commission adopts guidance to EU countries on implementing the revised directives on renewable energy and on energy efficiency," European Commission. [Online]. Available: https://energy.ec.europa.eu/news/commission-adopts-guidance-eu-countries-implementing-revised-directives-renewable-energy-and-energy-2024-09-02_en

[12] "COMMUNICATION FROM THE COMMISSION Guidance on Article 20a on sector integration of renewable electricity of Directive (EU) 2018/2001 on the

promotion of energy from renewable sources, as amended by Directive (EU) 2023/2413." European Comission, Feb. 09, 2024.
[13] "EU Energy Communities legislation 2.0: an upwards trend." [Online]. Available: https://sustainable-energy-week.ec.europa.eu/news/eu-energy-communities-legislation-20-upwards-trend-2024-03-14_en
[14] H. Bo Madsen, "Danish Experience with Community Owned Energy," presented at the International Conference on Renewable Energy Cooperatives, Turkey, Apr. 27, 2022. [Online]. Available: https://www.inforse.org/europe/pdfs/S_22_Conf_POWER_Turkey_VE_CommunityOwnedEnergy_Denmark_27.04.2022.pdf
[15] R. C. Krabsen and G. Verschuur, "Cooperative district heating in the making," *Hot Cool, Danish Board of Disttict Heating*, vol. 1, pp. 13–15, 2023.
[16] "Denmark's draft update of the National Energy and Climate Plan (NECP) for the period 2021-2030." Danish Ministry of Climate, Energy and Utilities. [Online]. Available: https://ens.dk/en/our-responsibilities/energy-climate-politics/eu-energy-union-denmarks-national-energy-and-climate
[17] "Denmark overview of the policy framework," Energy Communities Repository, Nov. 2023. [Online]. Available: https://energy-communities-repository.ec.europa.eu/document/download/a6d4833e-ab2c-491a-8591-742e95328510_en?filename=ECR_MSfiche_Denmark_clean.pdf
[18] Danish Ministry of Climate, Energy and Utilities, "Bekendtgørelse om VE-fællesskaber og borgerenergifællesskaber og forholdet mellem VE-fællesskaber og borgerenergifællesskaber og elhandelsvirksomheder og kollektive elforsyningsvirksomheder." Journalnummer: Klima-, Energi- og Forsyningsmin., Energistyrelsen, j.nr. 2020-4295, May 30, 2021.
[19] "Analyse af geografisk differentierede forbrugstariffer og direkte linje," Energistyrelsen, Dec. 2021. [Online]. Available: https://ens.dk/sites/ens.dk/files/El/analyse_af_geografisk_differentierede_forbrugstariffer_og_direkte_linjer.pdf
[20] "Bekendtgørelse af lov om varmeforsyning." Ministerium: Klima-, Energi- og Forsyningsministeriet, Nov. 16, 2021. [Online]. Available: https://www.retsinformation.dk/eli/lta/2021/2068
[21] "Odyssee database, The EU database on energy efficiency data and indicators," Enerdata. [Online]. Available: https://odyssee.enerdata.net
[22] Radius, "Vi deler viden om elnettet." [Online]. Available: https://radiuselnet.dk/om-elnettet/dyk-ned-i-elforbruget/
[23] "Technology Catalogues," Energistyrelsen. [Online]. Available: https://ens.dk/en/analyses-and-statistics/technology-catalogues
[24] Vurderings Stzrelsen, "Bzgnings-og Boligregistret," BBR. [Online]. Available: https://bbr.dk/forside
[25] "The Danish Heat Atlas," EnergzMaps. [Online]. Available: https://energymaps.eu/?page_id=33
[26] "People," Statistics Denmark. [Online]. Available: https://www.dst.dk/en/Statistik/emner/borgere
[27] "Cars by Country 2025," World Population Review. [Online]. Available: https://worldpopulationreview.com/country-rankings/cars-by-country

[28] "New registrations and used cars," Statistics Denmark.

[29] H. Lund *et al.*, *IDAs Klimasvar 2045: Sådan bliver vi klimaneutrale*. AAlborg: The Danish Society of Engineers (IDA), 2021. [Online]. Available: https://vbn.aau.dk/da/publications/idas-klimasvar-2045-s%C3%A5dan-bliver-vi-klimaneutrale

[30] "Day-Ahead Market Data," Nord Pool. [Online]. Available: https://www.nordpoolgroup.com/en/services/power-market-data-services/day-ahead-market-data/

[31] "Aktuelle Tariffer," EnergyNet. [Online]. Available: https://energinet.dk/el/elmarkedet/tariffer/aktuelle-tariffer/

[32] "Tariffer og netabonnement," radius. [Online]. Available: https://radiuselnet.dk/elnetkunder/tariffer-og-netabonnement/

[33] "Tariffs and fees," EnergiNet. [Online]. Available: https://en.energinet.dk/Electricity/Tariffs/

[34] "EnergyPRO," EMD international. [Online]. Available: https://www.emd-international.com/software/energypro