# Economic Impacts of Energy Communities – The Use of Separate Lines or DSO Networks in Connecting Shared Energy Resources

Juha Koskela, Kimmo Lummi, Pertti Järventausta
Electrical Engineering
Tampere University
Tampere, Finland
juha.j.koskela@tuni.fi

***Abstract*—Energy communities (ECs) are collectives in which multiple customers can utilize different energy resources (ERs), e.g., small-scale energy production and different flexibility resources, together. ECs enable the increase of local renewable energy production and flexibility in the grid, and the customer participation in producing cleaner energy. This paper studies the economic impacts of connecting different ERs to an EC either via a separate line or the distribution system operator (DSO) network. ECs can be profitable if its members, and the ERs, are situated within the same property boundary. However, there are also situations where it is better to connect the ERs to the EC by using separate line crossing the property boundary. These options have different impacts on the EC and different stakeholders. The paper shows that building a short separate line can be profitable, and that the present DSO tariff do not encourage ECs to use a DSO network.**

***Index Terms*—Batteries, Energy management, Load modeling, Power system economics, Solar energy.**

## I. Introduction

The change in progress regarding the electrification of the energy system because it enables using renewable energy sources in consumption. Consequently, there is an increasing need to add renewable energy production into the generation mix. High amount of weather-dependent renewable production requires a lot of flexibility from the power system. To answer these needs, small-scale customers can take an active role and start to produce electricity, thus offering flexibility to the energy system. The European Union has a goal of making compulsory rooftop solar energy systems in public and commercial buildings and all new residential buildings in the future [1]. In many situations, the solar energy rooftop installations are not profitable or reasonable for individual small-scale customers, e.g., a building's roof is tilted to the wrong direction or shades block the solar radiation from reaching the rooftop solar panel. However, groups of customers can form energy communities (ECs), where different energy resources (ERs), e.g., solar panels or batteries, are utilized by all the participants in the ECs. The EC can install common ERs in the best possible locations. This paper focuses on Finland's situation, and the studied cases are based on the Finnish electricity market and legislation.

There are situations, where the establishment of ECs would be an option to consider. For instance, in apartment buildings, the self-production (e.g., rooftop solar panels) can be utilized only for self-consumption for the common loads of the housing company. In that situation, each apartment has a contract with both the energy retailer and the distribution system operator (DSO). Self-production could also be utilized in the apartments if the owners of the apartments and the housing company together form an EC in which the apartment building acts like an individual customer from the perspective of the DSO and energy retailer [2]. For the apartment owners or the tenants, the EC model is practically the only option available for them to utilize their own ERs.

In detached houses, the owners may be able to utilize their own ERs profitably in many cases [3]. However, there are still cases where investing into personal ERs is less profitable than investing into common ERs as a part of an EC. For instance, the shading conditions on a property can impair photovoltaic (PV) production, or the customer load profile can make the investment unprofitable. In these situations, forming an EC that includes several detached houses can be a reasonable option. In the typical situation, each detached house has its own single property, which means that the connections of the EC exceed the property boundaries. In Finland, the DSOs have a monopoly position over the electricity energy distribution between properties, which means that members of an EC must pay distribution fees to the DSO if they are situated on separate properties. Additionally, electricity taxes are based on the amount of transmitted electrical energy to the property if energy production on the property is small-scale. These fees can be avoided if the members of an EC are situated on the same property. If the distribution fees and taxes make the forming an EC unprofitable, this may lead to a development direction where the cities and municipalities may zone the areas into larger properties, which can fit multiple detached houses, such that those living there can form an EC together. This development direction can also lead to a similar situation in city centers, where multiple apartment buildings are situated on the same property.

Regardless of how an EC is formed, there can be situations, in which installing a shared ER outside of a property border is more profitable when compared to installing the ER on the inside of the property, e.g., due to lower shading conditions. A shared ER on the outside a property can be connected to the EC by using a DSO network. The current Electricity Market Act in Finland also allows connecting an ER to one property by a using separate line [4]. The research question of this paper is as follows. What would the economic impacts be if the ERs are connected to the EC by using a separate line?

This paper consists of six sections. Section II presents the options for connection between shared ERs and ECs. Components of electricity costs for customers and stakeholders that are affected by forming ECs are introduced in Section III. Study cases and initial data are presented in Section IV and the results of the study in Section V. Section VI include the discussion and conclusions.

## II. Connecting Shared Energy Resources to Energy Communities

Regarding different ERs, the locational conditions vary and there are situations where the local conditions are not optimal, e.g., for energy production with PV panels. However, there might be areas close to the EC where the conditions are much better for producing electricity, e.g., an open field without excess shading, especially on the south-side, from different physical obstacles. The issue is that, if this area is on a different property or the properties are owned by different participants, then the connection to the EC must be done by using a DSO network. Hence, for every ER, a new connection must be built that incurs extra costs for the EC. In Finland, the price of a new connection depends on the DSO, distance from the nearest existing transformer and the connection size. Every DSO has its own prices and conditions for selling a new connection. For this study, a sample of 9 Finnish DSOs (altogether, there are from a total of 77 different DSOs as of 2023) was used. The price of a new 3x25A connection with 400 m connection distance from an existing transformer, ranges from 1 705 € to 3 937 €. For a 3x63A connection, the price ranges from 3 500 € to 9 970 €. Only one of the nine DSOs has a separate connection contract type for small-scale energy production, and its price is significantly lower than those of a regular connection (558 €). New connections also are followed by running costs (a monthly fixed charge and possible volumetric charges, if the ERs has any consumption, e.g., charging of an energy storage).

Another option to connect shared ERs to the EC over a property boundary is to use a separate line. This means that ECs must build a new line to connect the ER to the EC. The line construction and maintenance incur costs for the EC, but the EC can save money by avoiding the distribution fees and taxes. The building costs of an electricity line can be difficult to approximate, e.g., because of operating conditions and changing prices of different cost components. Here, the building costs are approximated by using the unit prices of network components defined by the Finnish regulator, Energy Authority [5]. Costs of a separate lines include the costs of cable and the cable trench. In the case of a medium-voltage connection, the investment costs of a transformer must also be accounted for.

The costs of a separate lines are studied in two different digging conditions (regular and difficult) with three different line lengths (100 m, 500 m, and 1 000 m). The sizing of lines was done for two power levels: 40 kVA, which is used to study the apartment building ECs and the ECs consisting of several small-scale customers, and 300 kVA, which is used to study several apartment buildings together as an EC. The costs of a separate line in different cable trench conditions and with different line lengths are presented in Table I.

TABLE I. Approximate costs of building a separate line [5]

| **Cable trench digging conditions: Regular** | | | |
|---|---|---|---|
| ***Line length*** | ***100 m*** | ***500 m*** | ***1000 m*** |
| 40 kVA | 2 900 € | 14 500 € | 29 000 € |
| 300 kVA | 6 960 € | 34 800 € | 69 100 € |
| **Cable trench digging conditions: Difficult** | | | |
| 40 kVA | 7 200 € | 36 000 € | 72 000 € |
| 300 kVA | 30 110 € | 66 550 € | 112 100 € |

## III. Electricity Pricing and Stakeholders

The main goal for individual customers is the pursuit of economic benefits when they form an EC. Additionally, they can try to fulfill the requirements of rooftop solar system installations or participate in local clean energy production. There are many stakeholders affected by the establishment of the EC. The three main stakeholders considered here are (1) the DSO as the grid owner, (2) the energy retailer, and (3) the state as the tax collector. This paper studies the economic impacts of ECs on those stakeholders. There are also two other stakeholder groups (electricity producers and other customers) that are indirectly affected by forming of an EC. Simply put, if the excess production of the EC is sold to the energy retailer, then it must purchase less energy from the energy markets. This can lower the price of electricity in the wholesale market, the electricity producers might receive smaller income from the produced energy, and the price of electricity for other customers might also decrease. The impact can be negligible, if the ECs are small and in low numbers, but if there are many ECs, then the impacts can be significant.

In this paper, it is assumed that a customer (i.e., the EC or an individual customer) has a single contract with an energy retailer that entails a fixed charge (3.04 €/month, VAT 0%) and a market price-based volumetric charge (market price + margin 0.36 c/kWh, VAT 0%.) The energy retailers purchase all the sold electricity from the electricity market, so the income of the energy retailer is formed by the fixed charges and the margin. If the EC cannot consume all its self-produced energy, then the EC can sell the surplus energy to the energy retailer at the market price. The energy retailer can then sell that energy to other customers with a margin.

Tariffs of DSOs vary significantly and, to study the economic impacts, distribution tariffs of 9 Finnish DSOs were used here. Tariffs of small customers (general tariff, GT) include a fixed charge (€/month) and a volumetric charge (c/kWh) with possible time-of-use features. For larger customers, there is tariff structure (low-voltage power tariff, LVPT), also includes the two components, and a separate charge for demand (€/kW). The maximum connection size for a small customer is often considered to be 3x63A, depending on the size of the EC, the tariff option is case-dependent. If the EC uses the DSO network, then the DSO gets bills all members of the EC as separate customers. If the EC is formed inside the property borders with a single connection to the DSO network, then the DSO bills all EC members collectively, and the possible electricity transfers that occur between the members of the EC does not incur costs. The current legislation states that the DSO can charge a maximum price of 0.07 c/kWh (VAT 0%) for the surplus energy that is injected to the grid [4]. Some DSOs in Finland use that price for injection, and some DSOs do not bill the injection at all. In this paper, 0 c/kWh price for injection was used.

In Finland, the state collects a 24% VAT from all the tariffs that the customers pay to the DSOs and the energy retailers. Additionally, the state collects an electricity tax (2.73 c/kWh, VAT 24%.) When the scale of the energy production in the EC is small (i.e., the maximum annual production of 800 MWh, which is achieved with an approximately 1 MVA PV system size), the produced electricity is not subject to electricity tax. However, the customers must pay the electricity tax that is subject to VAT for the purchased electricity from the DSO network. This means that, if an EC operates over a DSO network, then all members of the EC must pay the electricity tax on their consumption. If the EC is formed inside the property borders, then the electricity tax must be paid only on energy that is purchased from outside the EC. If there are shared ERs inside the EC, then the tax aspects must be accounted for.

## IV. STUDY CASES

In this paper, three cases were investigated in which ECs are formed by different combinations of customers. Actual hourly consumption data was used in the study. The three EC cases are as follows:

1. The local EC is formed by a group of 16 detached houses
2. The EC is formed by the citizens living in a multi-apartment building and common consumption of the housing company
3. The EC is formed by six different multi-apartment buildings and the common consumptions of the housing companies.

In all the studied cases, the ECs have PV panels as a shared ER. Calculations are made with and without a battery energy storage system (BESS) as a shared ER in parallel with the PV panels. The group of detached houses (case 1) is selected randomly from the customers of a dataset that covers approximately 8000 customers of a Finnish DSO. Data includes hourly load profiles from the year 2015. Customers whose annual total consumption is under 4 MWh are limited outside of the study group. The total annual consumption of the customers varies between 4.2 MWh and 15.9 MWh. The total annual consumption of EC (case 1) is approximately 135 MWh.

The sizing of the PV systems for the ECs is done by using an economic optimization method presented in [2]. The PV production profile is determined for the studied year by using actual irradiance measurements. The optimal PV size for EC formed by detached houses (case 1) is approximately 35 kW without BESS, and with a 10 kWh BESS, the optimal size is approximately 40 kW. The size of the BESS (10 kWh) was assumed as a suitable energy storage size considering the load profiles of the studied ECs. The main goal of the BESS is to increase the self-consumption rate of the PV production, which leads to a higher optimal PV size.

The data of multi-apartment buildings includes the hourly load profiles from 6 different buildings from the capital area of Finland. The smart metering data is from the years 2016-2018. The data are used in cases 2 and 3. In the case 2, every multi-apartment building is considered as a separate EC on one property, and in case 3, the six multi-apartment buildings form a single EC together located inside a single property border, i.e., on the same block. The EC formed by six multi-apartment buildings is called "B," that signifies a block. The ECs formed by multi-apartment buildings are presented in Table II which shows the total annual consumption, number of apartments, and the results of the PV sizing. In the initial situation, all the apartments and the common consumptions of the housing company have separate contracts with the DSO and the energy retailer. This means that, in EC "B," the 228 contracts are changed to a single shared contract. The sum of optimal PV systems in case 2 is 229 kW. When the same buildings would form an EC together (i.e., "B"), the optimal size is 300 kW. The larger EC makes it possible to utilize PV production more efficiently, which can be seen also from the self-consumption percentages.

TABLE II. ECS FORMED BY MULTI-APARTMENT BUILDING

| *EC* | *Case* | *Total annual consumption (MWh)* | *Number of apartments* | *Optimal PV size (kW)* | *Self-consumption (%)* |
|---|---|---|---|---|---|
| 1 | 2 | 36.25 | 23 | 16 | 67.8 |
| 2 | 2 | 83.26 | 23 | 31 | 79.4 |
| 3 | 2 | 264.97 | 58 | 65 | 96.3 |
| 4 | 2 | 200.09 | 42 | 50 | 91.0 |
| 5 | 2 | 116.79 | 48 | 37 | 80.6 |
| 6 | 2 | 83.75 | 28 | 30 | 77.4 |
| B | 3 | 785.11 | 222 | 300 | 79.5 |

## V. RESULTS

The economic impacts of forming an EC can be divided into two stages. At the first stage, the EC is formed, and the economic impacts result primarily from changing the number and the type of the contracts. At the second stage, the EC installs ERs, and the impacts result from the changes in the load profiles. In this Section, the economic impacts of those two stages are presented separately for all the studied cases. The profitability of the separate line is calculated based on the benefits achieved in the second stage.

### *A. Case 1 – EC formed by detached houses*

The economic impacts on the EC, the DSO, and the state at the first stage are presented in Fig. 1. The calculations were made for three different situations. First, the EC is formed within the property borders using the individual tariffs for each customer (A in Fig. 1) or the LVPT (B in Fig. 1) and EC formed by using a DSO network (C in Fig. 1). The average, minimum and maximum of the results from the study group (9 DSOs) are presented. The highest savings for the EC are achieved by forming an EC inside the property borders with GT. This option also leads to the highest loss of income for the DSO and the state. If an EC is formed by using a DSO network, then the taxes and the income of the DSO increase, and the EC still gets savings in most cases. Impacts on the energy retailer are not shown in Fig. 1, because they are constant in all the situations. The energy retailer's income decreases by 547 € when an EC is formed because the income from the fixed charge decreases.

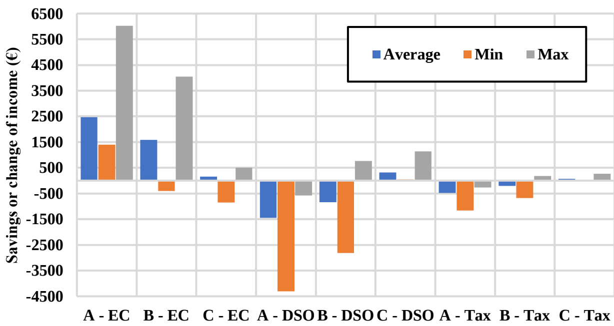


Figure 1. Economic impacts of EC forming (Case 1) on the EC, DSO, and taxes in three situations: A) EC inside property borders using GT, B) EC inside the property borders using LVPT, and C) EC using the DSO network.

The economic impacts of installing either PV panels or PV panels with a BESS, as a shared ER for EC, on the DSO and state are shown in Table III. If the EC is formed inside the property borders, then the impacts are almost the same for the EC regardless of the distribution tariff used. However, if the EC is formed by using a DSO network, then the savings are approximately half of those, when an EC formed inside the property borders. By adding ERs to the EC, it leads to a loss of income for both the state and the DSO, but, if an EC is using a DSO network, then the DSO will gain a small extra income. The loss of income for the energy retailer is 60 € if only PV panels are used, and, when PV panels are added together with a BESS, the loss of income is only slightly higher (69 €).

TABLE III. ECONOMIC IMPACTS OF CONNECTING THE SHARED ENERGY RESOURCES TO THE EC ON THE EC, THE DSO, AND THE STATE

| | 35 kW PV | | | 40 kW PV and 10 kWh BESS | | |
|---|---|---|---|---|---|---|
| | *Average* | *Min* | *Max* | *Average* | *Min* | *Max* |
| A - EC | 2 499 | 2 165 | 2 883 | 2 829 | 2 449 | 3 267 |
| B - EC | 2 388 | 2 107 | 3 065 | 2 705 | 2 384 | 3 475 |
| C - EC | 1 241 | 1 241 | 1 241 | 1 396 | 1 396 | 1 396 |
| A - DSO | -486 | -796 | -217 | -554 | -907 | -247 |
| B - DSO | -291 | -836 | -64 | -332 | -953 | -73 |
| C - DSO | 19 | 19 | 19 | 22 | 22 | 22 |
| A - Tax | -1 011 | -1 085 | -946 | -1 151 | -1 236 | -1 078 |
| B - Tax | -1 096 | -1 226 | -1 041 | -1 229 | -1 378 | -1 167 |
| C - Tax | -315 | -315 | -315 | -340 | -340 | -340 |

**Case descriptions:**
Case A: The EC is formed inside the property boundaries and GTs are used.
Case B: The EC is formed inside the property boundaries and LVPTs are used.
Case C: The EC is distributed to different property boundaries and the DSO network is used to transfer electrical energy between the members.

The profit for installing ERs can be calculated by subtracting the annual investment costs from the savings of the EC. The assumed investment costs of an PV are approximately 900 €/kW, and the costs of a BESS are approximately 500 €/kWh. The average costs per year for the next 15 years for a 35 kW PV system are 2 100 € and for a 40 kW PV system together with a 10 kWh BESS are 2 733 €. The PV system is profitable when an EC is formed inside the property borders, but a PV system together with a BESS is profitable only when GT is used, with a or when LVPT is used in the case of a few DSOs.

The payback period of a separate line is calculated from the profits in those situations where an ER is profitable. In regular digging conditions with a 100 m separate line, the payback period for the PV system is less than 30 years in 8 of the 9 DSOs when GTs are used and in 6 of the 9 DSOs when LVPTs are used. When the line length is 500 m, with GTs, there are 3 DSOs, in which the payback period is under 30 years; with LVPTs, there are only 2 DSOs. When the line length is 1000 m, in all the cases, the payback period is over 30 years. In difficult digging conditions, with GTs, there are 7 DSOs, and 4 DSOs with LVPTs, where the payback period is under 30 years. With longer line lengths, in all the cases, the payback period is longer than 30 years.

## B. *Case 2 – EC formed by multi-apartment building*

Forming an EC in a multi-apartment building means that all the apartments and the common consumption of the housing company are coupled, and they have a mutual contract with a DSO and the energy retailer. This results in savings for the EC mainly through the reduced fixed charges, but also through other components of the DSO tariff. Savings for the EC and losses of income for the stakeholders are shown in Table IV. The amount of the change depends on the number of apartments in the building and the load profile.

TABLE IV. ECONOMIC IMPACTS OF FORMING AN EC IN MULTI-APARTMENT BUILDINGS

| *Building* | *EC* | *DSO* | *Energy retailer* | *State* |
|---|---|---|---|---|
| 1 | 4 928 | -3 246 | -839 | -842 |
| 2 | 4 922 | -3 387 | -839 | -695 |
| 3 | 15 376 | -11 127 | -2 116 | -11 674 |
| 4 | 9 711 | -6 924 | -1 532 | -1 255 |
| 5 | 10 338 | -6 953 | -1 751 | -1 634 |
| 6 | 6 034 | -4 106 | -1 021 | -907 |

The economic impacts of installing shared ERs on the EC and different stakeholders are presented in Table V. The results are calculated with optimally sized PV systems with and without a 10 kWh BESS. The results represent the average values of the results that calculated by using all 9 DSOs' distribution tariffs. The ER affects the cost savings of the EC depending on the size of the PV system and the load profile of the EC. The losses of income for the stakeholders are the highest in the buildings where the EC cost savings are the highest. The state as the tax collector experiences highest losses of income. The energy retailer experiences only small losses of income.

Investing in PV systems as a shared ER is profitable for the buildings 2-6 and investing in PV systems together with the BESS is profitable only for buildings 3 and 4. If a PV system is connected to the EC by using a separate line, in regular digging conditions, the payback period is under 30 years in buildings 2-5 with a 100 m line. If the line length is 500 m, then the payback period is under 30 years only for the building 3. In difficult digging conditions, the payback period is under 30 years only for buildings 3 and 4, when the line length is 100 m. When connected the shared ER is a PV system with a BESS, the payback period is under 30 years for the building 3 with a line length of 100 m, and, for building 4, when the line length is 100 m in regular digging conditions.

TABLE V. ECONOMIC IMPACTS OF CONNECTING SHARED ENERGY RESOURCES TO THE EC FORMED BY MULTI-APARTMENT BUILDINGS

| Building | EC | DSO | Energy retailer | State |
|---|---|---|---|---|
| | ***Energy resource: PV*** | | | |
| 1 | 943 | -120 | -28 | -174 |
| 2 | 2 007 | -292 | -63 | -642 |
| 3 | 4 620 | -725 | -158 | -2 393 |
| 4 | 3 468 | -517 | -116 | -1 641 |
| 5 | 2 397 | -339 | -76 | -920 |
| 6 | 1 906 | -268 | -59 | -560 |
| | ***Energy resources: PV with BESS*** | | | |
| 1 | 1 004 | -139 | -32 | -218 |
| 2 | 2 073 | -312 | -67 | -689 |
| 3 | 4 649 | -734 | -160 | -2 412 |
| 4 | 3 514 | -530 | -119 | -1 673 |
| 5 | 2 458 | -358 | -80 | -973 |
| 6 | 1 974 | -289 | -64 | -609 |

### C. Case 3 – EC formed by 6 multi-apartment buildings

When the number of EC members and the amount of total consumption is higher, the economic impacts of forming an EC increase. By forming one EC from 6 multi-apartment buildings results in 59 766 € saving for the EC. For the DSO, this means a 42 382 € loss of income. For the energy retailer, the loss of income is 8 281 €. For the state, the decrease in taxes is 9 103 €. For all others (EC, DSO, and energy retailer), the impact is higher than the sum of all the buildings in case 2, but the decrease in taxes (for the state) is only approximately half of the sum in all the buildings.

When the EC invests in a 300 kW PV system, the savings are 19 244 € and the profit is 1 244 €. For a DSO, this means a 2 667 € loss of income. For the energy retailer, the loss of income is 957 €. For the state, the taxes are reduced by 8 929 €. The payback period for a 100 m long separate line in regular digging conditions is 7 years, and in difficult digging conditions, the payback period is 30 years. For longer line lengths, the payback period is over 30 years. If a 60 kWh BESS is installed in parallel with a 300 kW PV system, the savings for the EC are 19 689 €, but they are reduced by the investment costs, and thus, the PV system with a BESS is not profitable in this case.

## VI. DISCUSSION AND CONCLUSIONS

The results of this paper show that using a separate line to connect the shared ERs to the EC is profitable only when the line length is enough short, the digging conditions are not difficult, and the load profile of the EC is propitious. In many cases, use of a DSO network result in lower costs than building a separate line, especially if an existing transformer is close to the area where the PV panels would be installed. Still, there may be situations where the use of a separate line is the only reasonable option to connect the ERs to the EC.

Forming an EC in multi-apartment buildings and in groups of detached houses as ECs that operate inside the property borders is profitable in most studied cases. If the detached houses form an EC that uses the DSO network, it would not be so profitable for the EC members. Incomes of the DSO increase slightly if the EC uses the DSO network. If a similar EC is formed inside the property borders, then it would result in a significant loss of income for the DSO in most cases. It might be beneficial for the DSOs to determine new tariff structures for the ECs that would make the forming of an EC, that uses the DSO network, profitable.

The battery makes it possible to increase the size of the PV system, use the produced energy more efficiently, and decreases the negative impacts of the injection back to the grid i.e., the power of the surplus energy is lower. This paper shows that a PV system is more profitable without a BESS. In developing tariffs or government subsides, the actors should consider the possibility of adding different incentives into their models that encourage ECs to invest into PV systems together with BESSs. This paper focuses on the residential-level ECs, and, e.g., larger, industrial-level ECs should also be investigated in the future to evaluate if the limitation of 2 MVA related to the distributed energy production that is connected using a separate line should be removed in Finland to follow the EU directive [6]. In this paper, the BESS is used only for increasing self-consumption of PV production. The BESS can be used also for decreasing maximum loads or shifting loads based on market prices when the benefits from BESS using can be higher. This should also be investigated in future.

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