The Economy and Possibility of Energy Community in Finnish Solar Energy Production

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Abstract—The amount of solar energy production in the electricity distribution networks is increasing. This is due to technology conventionalisation, which in turn has led to solar panels becoming more affordable. The aim of this study was to analyse real-life, domestic electricity consumption data, that has been digitally monitored on hourly basis. The hypothesis was that a group of individual solar power producers could benefit from a common system, as compared to each group member having a solar production system of their own. In Finland, private households benefit from solar energy production via savings on both energy and transmission costs, as well as the taxes included in these costs. It is economical to install and utilise solar energy even though the price of solar energy is higher than that of fossil fuels. In this study, the economies of energy communities with larger solar panel units were compared with individual households with small-scale solar production units. As a conclusion, the study results indicate that the overall economy of solar energy would be better if the solar panels in the network were installed in larger units. However, this possibility requires energy communities to be legally permitted in Finland.

Keywords—solar energy, energy community, economy

I. INTRODUCTION

Solar energy has increased in popularity during recent years in Finland, although the share of solar energy nationally is only around 0.07 per cent in the total energy production [1]. However, the aim due to climate change should be increasingly towards renewable energies whilst reducing the use of fossil fuels [2]. To reduce carbon emissions in the European Union, EU legislation is currently moving towards removing legal, bureaucratic and technical barriers that have hindered the transition to the use of renewable energy sources [3]. Furthermore, there is a strong indication that private sector representatives in Finland would be increasingly interested in investing in renewable energies such as solar energy [2,4,5]. In contrast, fossil fuels are still subsidised in the world by 5.8 per cent of Gross Domestic Product globally [2]. Therefore, the Finnish government should aim at promoting the use of renewable energies in the long term, since the desirable changes in energy production will be led by private investments [2]. Currently, private households and other private sector representatives invest in solar energy mainly because it is

becoming more affordable and available [5].

In Finland, private households pay about 15 cents per kWh for electricity consumed [6]. The price consists of three main components that account for roughly one third each. These price components are the price of energy, transmission costs and taxes. [7] By producing and using solar energy, a private household can avoid paying the majority of these price components to the electricity provider. The only downside is that it is relatively expensive to purchase a small solar energy production unit [8]. Therefore, this study case is aimed at researching whether a larger, centralised and shared solar production unit could be financially beneficial to both individual households and the electricity network.

II. MATERIALS AND METHODS

A. Solar energy production modelling

In Finland, solar energy production varies strongly depending on the time of the day and year. However, the summertime with its long daylight hours and favourable outdoor temperatures, makes the Finnish climate more suitable for solar energy production than is commonly thought. [5] In this study, the daily and seasonal variation of the solar radiation was considered by creating a model where the hourly production of the solar panels (in kWh) could be studied. In addition, solar energy production is dependent on the size of the solar panels (kW), as well as the cloudiness of the day. Therefore, the cloudiness was modelled using a random factor, so that the utilisation period of the solar power was around 800 hours per year.

B. Household electricity consumption cases

In this study, household electricity consumption was analysed using the digitally monitored hourly electricity consumption of six real-life household cases [9,10,11,12,13]. Each of the electricity consumption cases represents an example of domestic electricity and buildings in the South Savo (Finland) area. The study group was purposely chosen as heterogenous in building size, number of inhabitants, heating system and type of use. The studied building sizes varied between 67 and 167 m², the number of inhabitants varied between 2 and 5, and the heating systems represented were electric heating, district heating and thermal heating. Four of the study cases were private family houses. The fifth study case was a household with a separate livestock building connected to the households' electric consumption network. Lastly, the sixth study case was a privately owned summer cottage. Both the fifth and sixth study cases are

typical of the South Savo area and are therefore of value to the study.

The common denominator for the study household cases was that they do not yet have solar energy production. Furthermore, in this study they are considered as neighbours, when in real life they are not situated next to each other. The shared solar electricity system would require them to be neighbours to be able to utilise the solar electricity directly on site.

The hourly production model for solar radiation and production (described in Section A) could be compared with the electricity consumption profile of the study case households. Every household in Finland can obtain its own electricity consumption as digitally monitored hourly data. The data is created by remote-controlled energy consumption meters, which are obligatory in Finland [14]. By comparing these two sets of data, it was possible to determine how much of the produced solar energy each study case would be able to utilise, and what portion of the energy produced could be sold to the electricity network.

C. Solar power system price components considered

The investment price for solar power production depends on the size of the production unit. The price of the system (Euros per kW) decreases with the increase in system size. The investment price for small-scale units is presented in Figure 1, and for larger-scale units in Figure 2. The system prices represent those typical of the South Savo area [4, 15].

Fig. 1. The investment price for a small-scale solar power plant in Euros per kWp according to the size of the solar unit in kW [4, 15].

Fig. 2. The investment price for a large-scale solar power plant in Euros per kWp according to the size of the solar unit in kW [4, 15].

The electricity price for domestic users in Finland includes three price components: energy costs, transmission costs and taxes [16]. Each of these components represents

about one third of the total price which the domestic electricity user pays for the consumed electricity. Furthermore, each of these price components consists of both a flat rate and a consumption-dependent part [16]. The flat rate share of the costs must be paid in any case. Therefore, the economic value of solar energy for the households can be considered as 8.5 cent/kWh [4]. In addition, the maintenance costs for the solar panels in this study have been considered as 1.5 cent/kWh [17]. Furthermore, the economic value of the solar energy may be considered as 3,5 cent/kWh for the domestic solar producer, when excess energy is sold back to the network [18]. The total cost of the electricity provided by the electricity network, may be considered as 15 cent/kWh [6]. In the calculations, however, the value of produced solar energy is considered as 8.5 cent/kWh, since the difference is the flat rate [7].

The solar energy produced and utilised in a household naturally reduces the amount of electricity needed and bought from the electricity provider via the electricity network. Furthermore, due to energy production taxation in Finland, the share of the electricity that needs to be sold to the network should be as low as possible [17]. The household producing solar energy should not produce excess energy, since it cannot benefit from the sold energy economically. The price of solar energy, when sold to the network, is less than half of that of the energy that the household uses itself to replace purchasable electricity. [18]

The size of the solar power unit for household users depends on the electricity consumption profile. The analysis would have not been possible to make without modern digital methods, where the electricity consumption was digitally monitored by the hour. The critical issue is to match the consumption and production as closely as possible. As stated above, solar electricity sold back to network is not profitable for the household producer due to the lower selling price. Therefore, in this study, the solar panel size was chosen so that at least 70 per cent of the produced energy could be used in the household, and the remaining 30 per cent could be sold back to the electricity network [16]. However, all the study cases were set with a minimum of a 2 kW solar system.

III. RESULTS

The aim of this study was to research a group of households to determine whether an energy community in solar energy production would be more economically favourable for the households as compared to each having an individual solar panel system of their own. To make the needed comparison possible, both cases and their results are demonstrated in the following.

A. Household cases with individual solar energy systems

The study group of six South Savo household cases is presented in Table I, where they are numbered from 1 to 6 as individual consumption cases. Table I includes electricity consumption, maximum power, building surface area and source of heating. [9,10,11,12,13].

TABLE I. HOUSEHOLD CASES ANALYSED IN THE STUDY

Case	Yearly electricity consumption	Maximum power	Surface area	Heating system
1	21 554 kWh	12.91 kW	130 m ²	Thermal heating
2	13 909 kWh	7.32 kW	122 m ²	Electric heating
3	14 664 kWh	6.68 kW	167 m ²	Thermal heating
4	8 696 kWh	8.13 kW	67 m ²	Electric heating
5	15 549 kWh	7.23 kW	83 m ²	Electric heating
6	4 497 kWh	4.33 kW	120 m ²	District heating

Table I demonstrates that the study cases vary, with annual electricity consumption between 4 497 and 21 554 kWh. However, to be able to study the solar energy production in each case, the basic information for the studied household cases has been utilised to obtain the information on what would be a suitable size for each individual solar energy system. The results are presented in Table II, where the minimum size for the solar panel system was considered to be 2 kW.

TABLE II. CAPACITY OF THE HOUSEHOLDS TO USE SOLAR ENERGY

Case	Solar panel size	Solar energy production	Share used in households' own consumption
1	3 kW	2 384 kWh	71 %
2	2 kW	1 617 kWh	72 %
3	3 kW	2 390 kWh	74 %
4	2 kW	1 620 kWh	48 %
5	4 kW	3 130 kWh	72 %
6	2 kW	1 594 kWh	45 %

Table II lists the solar system sizes, the modelled solar energy production and the percentage of the energy being utilised in the household itself for each study case. It should be noted that the simulation for cloudiness using a random factor is the reason why the same sized systems have produced different amounts of energy. However, each of the cases has had a maximum load between 797–810 hours per year.

The results in Table II indicate that cases 1, 2, 3 and 5 would be able to use more than 70 per cent of the solar energy in their households, whereas cases 4 and 6 could only utilise less than 50 per cent. This ratio indicates that the cases 4 and 6 would not be able to utilise solar energy enough for it to be economically feasible for them [18].

In addition, the economy of the solar system needed to be studied in more detail to see what the investment for each household case would be. These results are stated in Table III, where due to Table II's outcome, cases 4 and 6 are excluded.

TABLE III. THE ECONOMY OF SINGLE HOUSEHOLDS PRODUCING AND USING SOLAR ENERGY

Case	Annual solar energy production	Investment required	Economic yield during 1 st year	Payback time (a)
1	2 384 kWh	4 590 €	132 €	22 years
2	1 617 kWh	3 330 €	90 €	23 years
3	2 390 kWh	4 590 €	137 €	21 years
4	-	-	-	-
5	3 130 kWh	6 115 €	175 €	23 years
6	-	-	-	-

In Table III, for payback time, an assumption was made that the electricity price would increase by 4 per cent each year. Regardless, the payback times for each household case exceeded 20 years. The technical life of the panels is considered to be 20 to 30 years [19]. Therefore, the investment is dependent on the guarantee and durability of the solar system.

The results shown in Table III demonstrate that the total investment in solar power systems would be 18 625 euros, and the revenue from the first year would be 534 euros. Furthermore, the payback time for all the systems together would be 22 years. If solar panels only function for 20 years, the internal interest rate of the return would be -1 per cent. On the other hand, if the solar panels produced energy for 30 years, the internal rate of return would be +3 per cent for the investment.

B. Households sharing solar energy as a community

The idea of the solar community would mean that the household cases in the results for Section A would invest in one larger solar system together, where they would produce electricity together. This would also mean that their consumption would be combined into one. The study for this part considers two possibilities that the community could consider.

Firstly, the combined need for the solar panels, according to Table II and III, would be 12 kW (cases 1,2,3 and 5). In this case, the estimated investment price for the solar panels would be 16 200 euros. In total, the households with combined consumption would be able to utilise 81.7 per cent of the solar energy production. The revenue for the first year would be 579 euros, and the payback time for the investment would be 19 years. If the panels produced energy for 20 years, the internal rate of return would be +1 per cent. On the other hand, an operation time of 30 years would yield an internal interest rate of +4 per cents.

Secondly, the energy community could increase their solar panel size to 18 kW (cases 1 to 6), and still obtain a 70 per cent share of the energy utilised in the community. In this case, the investment for the system would be 23 976 euros. The payback time for the investment would be 20 years, and the first year of production would produce an income of 788 euros. In terms of the internal interest rate, 20 years of production would give a return of +0 per cents. However, 30

years of production would mean an internal rate of return of +4 per cent.

In the case of energy community, a solar power system with limited size would be more beneficial for the community, since it would be guaranteed to yield some profit for the community regardless of its length of production time.

IV. DISCUSSION

According to the results of this study, solar energy communities could be beneficial in several ways. The economic advantage of one larger system produced 13 per cent savings in the investment price of the solar energy system. The solar energy compensation in the energy usage was 8 per cent better than in the individual household cases. Furthermore, the payback time for the investment was obtained at 3 years shorter. In addition, the maintenance of one larger unit could be assumed to be more affordable. In contrast, the disadvantages of solar energy communities are around increased transmission losses.

Moreover, there are also technical obstacles to the use of solar energy, since solar energy production digital measuring versus consumption is still technically very versatile. The system's profitability can depend on how the electricity network operator accounts for the solar system production, and how close to real life the solar production and consumption really come. [20]

The study case presented in this paper also has limitations, set by the real-life data without further analysis. The electricity consumption of the household cases during sunny seasons and daytimes has a significant bearing on the system size, investment price and overall economy of the planned solar system. In this study, the data utilised was that of real-life households that have unique consumption profiles. However, it might be plausible to modify certain consumption peaks if a household producing solar energy wanted to utilise the maximum amount of the produced solar electricity.

For instance, the majority of electrically heated households in Finland produce hot water using electric water boilers. Normally, the boilers are set to heat the water during the night, since in that way their consumption balances the day-time electricity consumption that is much more difficult to predict. If a household had very little day-time electricity consumption, the solar energy could easily be utilised for hot water production. This is just one example of energy intensive consumption that is not totally fixed to the time of the day when the system could be running. Therefore, the maximum amount of plausible consumption would require a more detailed study, where each household consumption profile was studied more in detail.

V. CONCLUSION

The results of this study indicate that energy communities could very well be an answer to obtaining more solar energy production in Finland. Energy communities would be economically beneficial for the households connected to them, but they would also be beneficial for the electricity system providers, since they are easier to manage. There could also be business possibilities in providing solar energy services to individual households or other private sector

representatives to obtain the needed renewable energy without having a system of one's own.

The recommendation of this study is that solar energy should be made more lucrative for all private sector representatives to speed up the transition towards solar energy utilisation in Finland. Private sector representatives are ready to make the transition, but the only benefits obtained from the government are those of domestic tax reductions related to the work when the system is being installed or maintained. The swift transition towards renewable energies requires more benefits for those willing to make the transition. Furthermore, the digital monitoring of consumption, solar power production and power balance in the networks are already digitally monitored in Finland. The complicity of the electricity distribution network requires that smart grid principles and digital methods in both monitoring and consumption steering would be fully utilised and to match this new situation.

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