TEKNILLINEN TIEDEKUNTA

Rooftop photovoltaics: Sizing, markets and resource balancing in small communities

Thea Christensen

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Christensen, Thea

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Suomalaisten kattojen aurinkosähköpotentiaali pienen mittakaavan energiayhteisöissä on tunnustettu talous- ja teknologiatutkimuksen projekteissa ja tutkimuksessa. Tämä on kandidaatintutkielma tulevaisuuden näkökulmista aurinkosähkön tuotantoon taloyhtiöiden katoilla Suomessa. Uusiutuvista energialähteistä on tulossa yhä suositumpia, sillä saastuttavan energiantuotannon, kuten fossiilisten polttoaineiden teknologioiden, verottaminen ja energiakustannukset nostavat sähkön hintoja kuluttajille. Tämän tutkimuksen menetelmä on kirjallisuuskatsaus viime vuosien oikeudelliseen, taloudelliseen ja tekniseen tutkimukseen. Tulkintojen tarkkuutta edellyttää tärkeiden parametrien, kuten tuotannon omavaraisuuden, tehokkuuden, takaisinmaksuajan ja kysynnän joustavuuden yhdistämistä verrattuna uusiutuviin energialähteisiin tehtäviin alkuinvestointeihin. Älyverkon kuormituksen tasapainottamiseen vaikuttaa mikrotuotanto yhteisöissä ja virtuaalisia datapalveluja tarvitaan, jotta voidaan noudattaa optimaalista mitoitusta energian pientuotantoon käytettävissä olevalle tekniikalle.

Toisaalta on väitetty, että aurinkosähköjärjestelmiin, kuten kuljetukseen, johdotukseen ja akkuihin, käytettäviä sähkölaitteita ei ole vielä kierrätetty tai tai niiden tuotantoa järjestetty kestävästi. Siksi myös tuuli- ja ydinvoima ovat mukana energiatalouden muodonmuutoksessa, jossa uusia teknologioita testataan energiayhteisöissä ja ympäristöystävällisyyden käsite voidaan määritellään uudelleen. Taloyhtiöiden laajenevat kulutustottumukset ovat todennäköisiä älylaitteiden, kuten uuden sukupolven sähkömittarien ja sähköautojen integroitumisessa asumiseen ja liikenteeseen digitalisaation tuloksena. Teknologisten laitteistojen ja ohjelmistojen yhdistäminen on syy siihen, miksi taloyhtiöt voivat toimia jaetuilla verkkoalustoilla älykkään sähkön jakamisen ja energiamarkkinoiden taloudellisten etujen saavuttamiseksi.

Asiasanat: Aurinkosähkön tuotanto katoilla, energiayhteisö, mikroverkko, kuluttaja-tuottaja

Abstract

Rooftop photovoltaics: Sizing, markets and resource balancing in small communities
Christensen, Thea
University of Oulu, Environmental Engineering
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Supervisor of the work: Antonio Calò

The photovoltaic potential of Finnish rooftops in small-scale energy communities has been acknowledged in case studies and research among economic and technology studies. This is a Bachelor's thesis about the future expectations of rooftop photovoltaic generation in finnish housing companies. The renewable energy sources are becoming increasingly popular as taxing and energy expenses from polluting energy generation such as fossil fuel technologies are raising electricity prices for consumers. The methodology of this study is a literature review of legal, economic and technical research from recent years. The important interpretation requires connecting the important parameters such as self-sustainability, efficiency, payback time and demand flexibility compared to initial investments on renewable energy. The smart grid load balancing is affected by micro-generation in communities and online data services are needed to follow optimal sizing for the available technology included in small-scale energy production. On the other hand it is argued that the technology equipment used for solar arrays including transportation, wiring and batteries are not yet recycled or resourced sustainably. That is why wind and nuclear are involved in an energy transition where new technologies are tested in energy communities and an environmentally friendly image is redefined. Larger consumption patterns for housing companies are likely if smart appliances such as smart meters and electric cars are integrated to housing and transportation with the result of digitalization. Connecting hardware and software is why housing communities could provide management in shared online platforms for smart electricity sharing and energy market economic interests.

Key words: rooftop photovoltaics, energy community, micro-grid, prosumer

Omistettu valovoimaisimmalle Mikaelille. Yhdessä ja yksin.

Acknowledgements

I am not sophisticated enough in solar technology to analyze the technology critically, nor will I go deeply into exploring electricity storage and heating integrated panels. Also legislative research in this paper is targeted to find the needed functions and there is a whole new world in the game of agreements and policy making. Communities are studied in investigating the terms of deployment. I will concentrate on what has worked out fine and what has not. I will not go too deeply into the structures of economic hierarchy, financed optimization tools or policy making in communities. That has relevant information but this thesis will just briefly introduce the terminology and theory at hand in the current changes in energy self-generation. Technical information about panels is connected to a one company (Green energy Finland) which provided the production system to the case studies and no comparison in that area is done.

My financiers are Kela, my friends and family and the rest of the finnish people. So partly this is also dedicated to all the people that have visited Finland or live in Finland or are somehow trying to get to know the culture and language. All the people wanting to take part in the electrification of the country and housing helped to work forward in the complexity of this work. For people using and inserting smart appliances and environmentally woke people are hopefully affected by this work

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Thea Christensen

Contents

Abbreviations

Units

kWp	kilowatt peak
kWh	kilowatt hour

1 Introduction

An industrious society in a Nordic climate is dependent on large shares of energy services. [33] In Finland all electricity industry parties including the energy providers and users must enhance the efficient and frugal use of electricity in their functions according to the Electricity Market Act. [16] Provisions are needed for local energy communities and groups of active customers to support their functions related to the energy sector and to prevent energy poverty. The new legislation is expected to answer with solutions for consumption and production problems of electricity at the customers end-use site and for net metering of production. Sharing of self-generated electricity and further regulations in the report of distributing electricity are still under discussion. [17] Conventional methods of energy use will not be sufficient because societal pull and technology push will proceed the digital transformation that supports the ecological transition during the managing of environmental disasters. [34]

The main owner of high-voltage transmission grids in Finland, is Fingrid Oyj. p38 [4] Fingrid practices electricity transmission and balance services on the main high-voltage grid. The enterprise provides Guarantee-of-origin certificates, electricity market information and exchanges information in the retail market of electricity. In exchanging power it has an increasingly significant role as Fingrid Datahub Oy provides a information-platform for large electricity purchases called Datahub while maintaining information and electricity security. [15]

This thesis seeks to answer how housing companies can move to the smart energy network supported by photovoltaics: Sizing, Finland electricity market and case studies.

1.1. Literature review

The databases used in this thesis are websites of companies, electricity and environmental legislation, google scholar, scopus and the university library service oula finna. In the literature some expectations on outdated data can be found from legislation, since the topic of the research has been re-evaluated during recent years. Technological and technical aspects are mostly from locations in Finland and a few from Sweden and Canada,because they have similarities in climate and electricity policies.

1.2. Electric power distribution

Since 2013 policy has restricted demands in reaction to blackouts in distribution of electricity. The changes pressure distribution network companies to adjust and improve their systems so that all grid connections wouldn't have blackouts more than 6 hours inside a city layout plan or over 36 hours outside of it. This is to be deployed before 2029 and those who applied for extra time have until the end of 2036. Distribution network actions are regulated so that reliability incentives compensate for areas of forest management and constructing of cabling. In practice, the cabling should be moved to the side of the roads or constructed underground. Efficiency- and quality incentives are correctional government measures for preventing too long blackouts caused by storms. p64[4]

1.2.1 Electricity load balancing

Some regulations demonstrated in the Act of Metering Devices compose operations for an energy community, mostly in balancing- and distribution of electricity. [4] The EU directive also notes that storage capacity has improved the flexibility of the electricity networks. In addition, new platform technologies provide flexible demand on the electricity market. All forms of individually or jointly active customers should be taken into account by the Member State with specifically designed taxes and levies. [1] In the management of the main grid in Finland, consumption and production of electricity are planned ahead. In practice there are deviations during each hour. [13] The current legislation in the directive of electricity market, including modifications, enables a market concept for a distribution network company to use distributed or decentralized electricity resources for maintaining efficiency in the grid. [16]

It is expected in the European Green Deal that the power sector will face changes while electricity will remain securely supplied and affordable for consumers and businesses. [34] Self-generation of electricity can be increased if technical and economical aspects collide. [12] The total electricity production of Finland was 86 TWh in 2021 of which 69 TWh is considered carbon free electricity. [14]

A big portion of electrical energy (20,1%) is imported yearly to the domestic grid from neighboring countries. [14] Fingrid Oyj, imports electricity from Norway, Sweden, Russia and Estonia. [15] Because Finland is a seasonal country, heating consumes a lot of energy in low temperature months. In 2020 heating consumed 261 601 TJ of energy [24].

Electricity consumption in 2021 increased by 4,6 TWh from 2020. Net import of electricity grew by 5,8 TWh from Russia and declined from other nordic countries by 3,5 TWh. The import to Estonia grew by 0,1 TWh. Electricity prices grew and the average price was 72,34 €/MWh. [14] Solar and wind energy being highly intermittent, the direct use level was estimated to be 47% which endorses storage applications to be used. [33] In a 2050 Finnish decarbonized energy system it is estimated to grow the production capacity of photovoltaics by over 3500 MW and provide 3 TWh for electricity-, heat- and transportation sectors. [35] Solar power accounted for 0,3% of electricity production in 2021. [14]

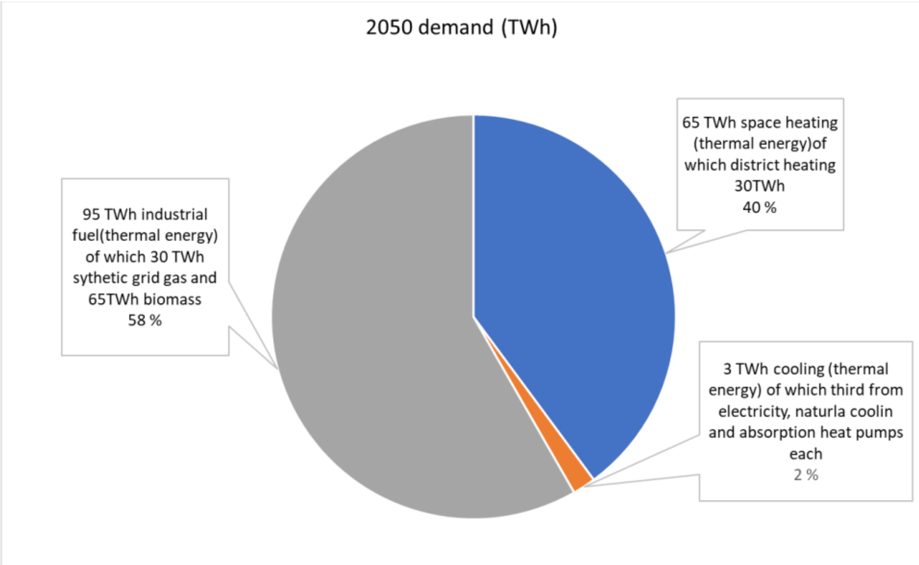

Figure 1. Calculations from 2016 year study, energy demand predictions for the year 2050. [33]

Setting the price for the supply of electricity by public service obligations should keep the open market operations in reasonable limits and durations. The intervention of regulatory authorities and competition authorities is necessary in these circumstances for the problems would disturb low-income consumers and their income at disposal. [1]

1.2.1.1. Scalability of distribution grids

Although electricity or energy consumption is considered to be larger in 2050 the grid services are yet unpredictable. It is difficult to estimate how the distribution and generation of electricity will change the grid stability in 2050 based on current data due to large changes in production methods. In addition, the electricity consumption in intermittent production patterns vary depending on temperature, cloudiness and humidity [3]. The area and services of the grid is based on unknown variables of the future that are difficult to calculate or provide since they are based on models and assumptions. Cost estimates are therefore made on the current available data and calculations. In 2050 energy demand prediction for electrical energy is 95 TWh of which 5TWh as flexible demand [33].

The European Green Deal notices limits and efficiency targets for integration, interconnections and digitalization. Decarbonation of the energy system is the goal for a clean energy transition and all consumers are expected to benefit by being involved in providing renewable energy resources. A circular economy requires a transformation of 25 years to reach all the value chains in the industrial sector. That is why fast sustainable energy deployment is needed. Security of supply and investment aids will help housing companies sustain consumption when facing energy poverty issues. [34]

As a transmission systems operator, Fingrid Oyj has the responsibility to take care of the dependability in the electricity networks. Dependability means that all components work thermally and mechanically, voltage levels stay in restricted limits and the electric system stays as stable as possible. If bottlenecks are created in electricity transmission, Fingrid acts by buying transmission capacity from where it can. The operations of balancing electricity include compensating at the necessary grid area and agreeing how the centralized power companies should sub-adjust in energy production. The energy-companies then can lower the power feed based on wattage limits inside the grid. [4] Imbalances can be detected by following frequency values. A nominal value in the grid is 50Hz. [14]

Small detached electricity systems are recognized to be more vulnerable to market failure. This can be securely prevented and supply of energy requires specific solutions on a national level with connections via the electricity systems and networks to other Member states and with right signaling of electricity prices which then affect investments. [1] Balance clearing means that electricity imbalances and indifferences in consumption or production values are detected in the grid area of responsibility. When the wattage levels vary largely inside the grid means that the owner of the national main grid acts as a buffer. This procedure requires businesses that depend on open supply of electricity and participate in the free electricity market. [4] Fingrid maintains and develops the balancing power market and they have reserves of electricity at the market. [19] Electricity reserves consist of power plants and consumption resources. [13] In the nationwide balance clearing the transmission systems operator, Fingrid oyj, identifies all electricity balances from the main high-voltage grid and all balance managing parties. Differences in the balance are detected between the balance units from each balance period.[4]

If the distribution system operator flexibly directs electricity for a few peak loads of the year of produced power it does not affect the balance in the distribution grid. If these actions are implemented the grid can be scaled to be smaller and electricity losses are cut respectively. To lower peak loads the grid components are sized small and therefore the wasted electricity amount is lower. Additionally investments on technical grid extensions, compensations and the insecure and risky load development can be avoided. In addition, large expanding measures and investments to restore losses are avoided. [4]

1.2.1.2. Microgrid

A microgrid inside an energy community has one connection point to the public distribution network and functions normally as a part of the whole electricity network. In many cities this exists in a housing company internal grid. It has been studied that intermittent electricity production can enable a continuous and renewable energy source to be used in microgrids. A microgrid can promote sustainable production of energy and lower the expenses of electricity. It can be isolated from the public grid as its own island which requires power self-sufficiency from adequate local resources and a possibility of controlling them. In this way the microgrid can facilitate electricity balancing in distribution interruptions and make sure that inside the microgrid there is a way to maintain a reliable supply and quality of electricity. [4]

Microgrids help maintain stable electricity connections in areas that are subject to changing weather and extreme conditions. A microgrid is a part of a low- or medium voltage network which functions in direct- or alternating current. It consists of coupled loads and decentralized energy resources and a control system for them. [4] A separate line is possible to be created and operated between the consumption site and the production site of electricity without the permission of the distribution company or a electricity network license. There are no be obligations of a distribution network or third party actor, if the produced electricity is shared only to the agreed consumption or production premise and not further. The distribution is subject to license if a ring connection is made in parallel with the local distribution network or electricity is compensated for in connection with the distribution network lines. Distribution companies have a prioritized right in constructing consumption premice connections to the distribution grid. This right prevents under 110 kV wiring without the distribution company permission unless it is made to connect with them from a production or consumption facility. [4]

A credit calculation model sums information about production and consumption of electricity apartments of single tenants. Profits for the energy community and consumer come mostly from self-generated electricity by preventing outsourced electricity and in increased production times selling excess electricity to the grid. [4] Aggregated electricity resources can be used in balance settlement. The problem is that there are different calculation methods of produced power in different electricity meters, distribution companies and locations in Finland. This will be explained later in 2.2.1. Credit calculation model. [2]

1.3. Energy community

There are approximately 90 000 housing companies in Finland and they accommodate 2,6 million tenants all together in Finland. They live in approximately 142 000 apartment story buildings and terraced houses. [35] Countries located far from the equator have to reduce dependence on fossil fuels as a primary energy source. For example in Canada both the federal and local governments [5] have noticed that the commitment actions to the Paris agreement are at hand. Technological and technical issues prevented removing aging storage facilities and the remedy of contaminated nature reserves. [12]

According to article 16 of the EU Commission Directive on rules for the Internal Market for Electricity and Amending, Member States should enable rights for communities, such as housing companies, to build, own and rent their own grid and manage the network independently. In addition they have the right to participate in a non-segregational organized market directly or by aggregation. They must not be discriminated against as an end-user, producer, distribution network operator or coalitional party according to their actions, rights and obligations. All costs for communities must be open source, cost reflective, righteously handled, relative to the right proportion. [4]

Legislation is meant to strengthen energy communities and secure every member a right to be voluntarily involved. A member of the community should have the right to move out for free in a three week notice time and can resign whenever. Even though one would not be a member, they have the right to choose the source of electricity consumed. [4]

Many parts in the Finnish legislation prevent or slow down the formation of various types of energy communities. Local commitment, neighborhood connections, sustainable participation and economic resources are needed before any deployment can be applied to become self-sustainaining in energy. In addition expertise, science and support from administration are necessary in the successful implementation of energy communities. [4]

1.3.1. Electricity consumption and demand flexibility

There are 3.7 million electricity accounting points in Finland. [21] An accounting point gives out information about the consumer of electricity. That information can be consumption data on that point or information about the owner or holder. The data is available for distribution systems operators and electricity suppliers in various systems. When a customer switches between electricity suppliers that data is then handed out to the new supplier or grid management. The Electricity Market Act notices that by supporting energy efficiency demand-control affects consumption goals of electricity. [16]

Electricity consumption is typically largest in the evening and morning. Because solar energy production usually peaks at midday when the irradiation is the electricity consumption is saturated and electricity must be stored or fed into the distribution grid. [29]

Demand flexibility is a market based control mechanism that allows efficient electricity use and secured supply of it. Technologies that support faster efficiency control are expensive and therefore in low deployment level for now. p13 [9]

The overall effect of demand flexibility can be well determined in the long run. In a short time scope study demand side was in the center of study on real-time-pricing. Real-time-pricing can be beneficial to adjust demand by lowering peak power loads on the demand side and respectively affecting the supply side of energy in demand response schemes. Determining the relative timing of demand and supply is necessary to deploy effective demand flexibility. [18]

According to article 16 of the Directive on rules for the Internal Market for Electricity and Amending, Member States should enable rights for communities to build, own and rent their own grid and manage the network independently. In addition they have the right to participate in a non-segregational organized market directly or by aggregation. They must not be discriminated against as an end-user, producer, distribution network operator or coalitional party according to their actions, rights and obligations. All costs for communities must be open source, cost reflective, righteously handled, relative to the right proportion. Legislation is meant to strengthen the community and that every member has a right to be voluntarily involved. A member of the community should have the right to move for free in a three week notice time and can resign whenever. They have the same rights as non-community members, the right to choose the source of electricity. [4]

For now a community is possible to establish with limited and restricting metering devices. According to EU regulations about the measuring instruments of electricity, legislation should enable credit calculation models that make energy balance sheet periods internal net metering clearer and more coherent allowing small and big players on the market. Finsolar project manager Karoliina Auvinen suggested that for now exceptions can be pledged from the EU commission to make a temporary agreement for a credit calculation model or other before new regulations take place. Hereby net metering is possible to research inside the network community before Datahub-integration is taken into practice. According to Lähienergialiitto Finland suitable programs exist for these measures. [4]

By utilizing distributed renewable energy systems it is possible to achieve better electricity security, lower the investments in an energy sector and lower electricity distribution losses and create new jobs. [4] The electricity distribution charge is based on the bought energy type. [2]

Policy makers are incentivising active customers such as households or housing communities to participate in the electricity market. More entities in the market would enable a system-wide benefitting and price-driven demand flexibility scheme much more likely. [18] In practice demand response can be to decide to charge an electric vehicle and use it as storage based on energy efficiency schemes. [1]

1.3.2. Smart appliances & electric cars

A technological breakthrough means people in the entrepreneurial field should re-evaluate their academic consistency and many business models are updated. [35] As new technologies advance the real-time consumption of electricity in buildings evolves. One big step is the appearance of electric car charging stations in residential buildings. [9] Electric vehicles integrate flexibility and electromobility into the electricity network but investing is yet to be discussed on a national level. [1] This will significantly affect the electricity use and require energy efficient schemes as well as building designs making it possible to control electricity in the grid. The Smart Grid Working Group incentives that an electrified systems requires actors from all fields to take part in the energy transition. Buildings are yet not as presented in the market or the controllability functioning hand in hand with it. This requires that design of HVAC, electrical wiring, plumbing and automation should enable energy controllability. [9]

The electricity consumption updates the cause from smart electronic appliances. This means that even more devices in households can be used to automatically track and utilize the cheapest available electricity on the market. Therefore the provider of electricity may invest in utilizing the information about consumption close to real-time. [9] Online predicting services will guide consumers how to act on the network and a microgrid control system such as a Microgrid advisor - controlling program connects Fingrid to the apartment and so the household technology can participate in providing electricity reserves. The total energy and electricity of the house, the cold and heat storages and the solar production facility can be automatically optimized online. [4]

In Finland self-sufficiency is considered a virtue to the energy system. Goals to support becoming self-sufficient come from societal commitments, sustainable use of renewables and competitiveness of the Finnish energy industry in a cost-effective manner. [33]

1.4. Rooftop Photovoltaics

In high latitudes only summers are the times there is a reason to use solar irradiance as an energy source. [3] The affordability of renewable-energy was already reducing household European energy bills in 2019. [34] The photovoltaic effect is electrical energy created from solar irradiation. Highly standardized solar modules or panels are made of silicon or gallium arsenide photovoltaic cells where this effect happens. There are different generations of solar cell technologies. Multiple panels form a solar array. [6] Photovoltaic panels produce electricity which is measured in kilowatts (kW). A kWp in solar panels indicates a peak (p) power value which is measured in a standard environment, STC standard conditions. The nominal value is specific for the grid connections and system conditions the power is produced. [25]

Prosumers of energy are becoming more common in self-sufficient energy systems and microgrids. Mostly because the climate actions are raising fuel prices and energy poverty is increasing globally. [11] Although energy is considered a necessity, consumers of energy are noticing that they too have to act a part in the energy transit. Some have already changed by becoming generators of electricity and questioning their values as environmentally friendly suppliers are becoming more popular. Customers participating this way in financing the new smart technologies is one of the solutions to achieving climate targets on a larger scale. [9]

Electricity consumption can be highly variable and traditional production methods cause exhaustions that are constantly polluting the environment. Simply responding to consumption by adjusting production is no longer worthwhile and integration of the mathematical models can be difficult to achieve, if suggestions on legislation are not acted upon. [4]

A business as usual scenario in the Finnish energy sector is not sufficient to stop global warming to less than 2 °C. Other than carbon dioxide emissions, such as nitrogen-based air pollutants and heavy metals, were consistently lower for solar technologies in a study from 2016. It was pointed out that studying the global life cycle impact measurements reveal the devastating truth in the lack of greenhouse gas emission reduction in some technologies. In the perspective of solar together with wind-power technologies, a learning-curve concept was considered as a potential benefit in minimizing the energy-pay-back time and greenhouse gas emissions. [33]

Zero greenhouse gas emissions are one of Finland's energy production targets. The study from 2015 did not take into consideration a life cycle approach of production, but discovered the greenhouse gas level can be lowered 80-90% from 1990 measurements by the year 2050. This means Finland must reduce carbon dioxide emissions to 4-14 Mtons if biomass is considered to be burnt according to a low integration of nuclear- and renewable energy. The total energy system cost in a “business as usual” scenario, will go up by 250 000 000€ in a year if the carbon price increases 10€ per ton of carbon dioxide. [33]

1.4.1. Billing periods and metering electricity

The electricity consumed in a housing company may be different compared with other locations and neworks it is connected to. The amount of electricity is also billed differently in larger consumption volumes or smaller residential houses although there are similarities in network services and information systems models. [38]

A energy community inside a housing company lowers accumulation of electricity taxing and the distribution charges in the electricity bills from network companies. This can incentivise the distribution network companies to raise tariffs and distribution charges from other electricity consumers or make up new payments from communities. The benefit from intermittent self-generated electricity is reliant on the cost price of own production and the recovery rate. Therefore correct sizing of production is needed to support self-generation. [4] Inside one or several real estates of the same energy community, sharing is done in a time of a balance sheet period. Conservatively the period is an hour long. In the future, intermittent photovoltaic production in housing communities can be shared based on a credit calculation model. [17]

A backmetering model for photovoltaic production requires that the housing company has their own net metering device for produced electricity and the same electricity provider for everyone. The metered electricity is not under electricity taxing or distribution charge since it does not involve the distribution network company metering system. [4]

Customers that can use the meter's control services get benefits from customers that don't use it if they have the same distribution network company. Automation improves control and options while living comfort is improved. The Smart Grid Working group suggests next-generation meters have a capacity to measure variables in shorter net metering periods so that energy trade can be conducted closer to real-time. The meter should be updated as the market changes. Some other measurements for example voltage and duration of outages can be valuable information to customers including that information security is taken care of. [9]

New additions are done to regulations concerning the net metering of internal production and consumption. These measurements are obtained from the distribution network companies metering device and summed periodically in each balance sheet report. The regulations benefit small scale production and end-user possibilities to take advantage of self-generated power. In practice all calculations and net metering is going to take place in Datahub in the near future. Before that, distribution network operators can manage it directly and services can be continued half a year after Datahub takes over. Because of this, interest has been rising in customer service among distribution network companies. [17]

Helen sähköverkko Oy provides their Credit calculation model so that there is either consumption or production of electricity in the hourly balance sheet period of the household. [27] An interface power is the same as the sum of power that presents a community or the area of administrators consumption stated in the energy-contract. p16 [4]

1.4.2. Contract options for communities

The regulations in a notice from the Ministry of Economic Affairs and Employment it was informed that Valtioneuvosto [17] accepted changes to electricity distributions and measuring regulations of Finland. They came into force in November 2021. The changes enable sharing of self-generated or stored energy to other members of the energy community in general, by using the distribution network company metering systems [20].

A tenant producing energy by photovoltaic generation has three possible options: A single house-, a shared housing community- or distributed energy community power plant. Sharing of electricity can be conducted by a credit calculation model or a backmetering model. [2] The EU commission informs that a fair competition in the internal market for electricity involves promoting reasonable ways for a consumer to choose a supplier which would then be liberally choosable to everyone on the same electricity market. The responsibility falls on each Member state to make available opportunities for participation and platforms to support it. [1] Because the Energiavirasto does not acknowledge that microgrid management and flexible demand on the customer side is a part of electricity market actions, agreements are not incorporated in terms of Electricity Market act or regulative models. Fixed electricity storages are also not incorporated in online businesses. This is why these should be separated as their own business activities and legislation updated fast. [4]

Self-sustainable production lowers the electricity being transferred, but in Finland this is not a problem because the peak loads occur during winter. [2] If the community includes many housing electricity systems, the electricity load is more predictable and balanced inside a housing community microgrid. Predictability affects directly production or storage sizing and helps to address payback time of production. Traditionally, a backmetering model increases profitability because a combined energy contract lowers the power needed to make a contract to connect with the distribution grid. Contracts are cheaper for groups of individuals because the energy-time dependency is more predictable and apartments together can act as mediators for supply and consumption allowing the system sizing easier. [4] The problems of backmetering are that there must be a difficult unanimous vote to agree on and the electricity measuring devices are owned by the housing community. [2]

According to the Electricity Market Act article 13 §, property premises and property owners' shared internal grid can be constructed by the local distribution system operator that is responsible for the final operator in the electricity transmission. Additionally, other than the operator can make a wire from an accounting or consumption point, production site, power facility or reserve to the distribution network. Two accounting points cannot be connected although prosumers can move electricity from their production site to the consumption sites through separate wiring. [4]

A distribution charge can be lowered if consumption as a consumer is balanced. If consumers opt for a shared subscriber connection there are crossing consumption profiles that can be calculated to a smaller basic part in the electricity bill than it would be for an individual alone. Balancing the consumption profiles of individuals is seen as lowered restrictions in the transmission operations. Flexible demand and decentralized energy resources have possibilities for different market actors. This increases the utilization of the production plant. Since solar electricity production is highly variable, the electricity can be stored in other forms of energy or consumption optimized to follow production curves. New service providers arise in the market as a business link between the production site and the consumer. Additionally, network charges and electricity taxing is lower on the energy component. [4]

Visible renewable energy systems affect individual persons' minds, property value and tourism in positive or negative ways depending on where the system is placed. [33]

A virtual storage means that a prosumer[1] sells produced energy unused and you can save that amount of electricity to use it later. Meaning that a deposit in the energy bank counts the reserves back to the consumer when they are low in electricity production. It is an online storage for electricity. Distribution system operators can then use this excess electricity to balance the grid in peak load situations. [32]

If the solar power system is under 1 MVA, the energy community inside the housing company must share electricity inside building wiring to places of use according to the shares agreed in the balance settlement. This means applying credit calculation in the hourly balance settlement period. According to law this means that sharing must be applied so that each electricity consumption point inside a local energy community or group of jointly acting active customers gets the electricity from the distribution network according to one's share and the communities or groups sold energy shares that are calculated together in the balance settlement period hourly. [20]

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[1] Prosumer= Producer and consumer of energy.

If one cuts electricity the share for that electricity distribution point will be fed to the shared premises of the solar power system. Internal net metering is done first for the consumption and production in each balance settlement period hourly and then credit calculation. The final result must be used in the billing of electricity.[20]

During sunny days electricity production is enough to fulfill the needs of individual tenants. They save in network service tariff, energy tariff and electricity taxing for the share they self-produce. A credit calculation model has been applicable in Helsinki, Finland from the beginning of 2021. [27]

The self-produced electricity does not enter the distribution network. That is why the distribution company did not see a reason to ask for electricity distribution charges from the housing company. [2]

Some companies like Lumo buy all excess energy from panel systems they apply. Even so, it is not useful to oversize the system just to sell energy. Self-consumption can be over 300% more profitable than selling electricity.(consuming 13 cents selling 3 cents) The net payback time might exceed the lifetime of the large system and initial investments start to lose their value. [30]

2 Theory

2.1. Renewable energy integration in the electricity grid

Intermittency is a property of many energy technologies that are labeled renewable. It was studied that nuclear-, biomass- and mostly wind power will cover a 100% renewable Finnish energy system in addition to photovoltaics. The simulation and results were considered as potential guidelines for other high- or low latitude communities using renewable energy. [33]

Energy self-sufficiency[2] means being able to support most of consumption during a certain period of time and area for example in a housing community. The household technology and automation systems require energy from outside the microgrid to connect with electricity supply in peak load situations. Wires and meters must be installed so that they function with the distribution network and smart appliances in the housing company grid. [4]

2.1.1. Solar energy

The oldest solar cell technologies are 1st generation (1GEN) cells. They are expensive to produce but are mostly used and the cost of panels is reducing as they become more common. Silicon is a durable raw material

[2] In comparison, energy-independence would cover all consumption, peaks included and less electrical compatibility is needed to the main grid.

and non-toxic which lowers the wear and maintenance of the panels. It is currently the second most abundant material in the earth's crust. [6]

A pitch of a solar panel indicates the inclination from a panel facing zenith on a flat roof. A larger pitch to face the southern position of the sun means more energy can be gathered. Inclining lowers the eastern and western sun's effect. For example 45° was studied to be an optimal fixed slope in Middle-Finnish conditions in a study from the city of Jyväskylä. [10]

In example case studies a panel system from Green Energy Finland via Lumo Energia of a peak power of 8,76 kWp is achieved with 24 panels in the array and surface area of 45 m^2. Yearly production value estimation is 7446 kWh and savings in electricity bill 968€. The installation price is 11426€. Estimated 50000kWh yearly electricity consumption calculations are based on average electricity consumption for the selected kWp power value. The calculations are based in finnish conditions the total electricity price is 14 c/kWh on average on a 100% self-consumption rate. Panel electrical values are described in Table 1. [30]

Table 1. Solar panel from GreenEnergy Finland (Named GEF-370-HM120 F35 Black) technical values [25].

Electrical values	STC, Standard test conditions	Nominal operating temperature (41 +/- 3°C). Temperature outside 20°C, radiant power 800W/m^2 , wind speed 1 m/s and airmass 1,5.
Peak power (W)	370	278
Peak power voltage (V)	34,78	32,40
Peak power current (A)	10,64	8,58
Efficiency (%)	20,31	
Open circuit voltage (V)	41,77	39,70
Short circuit current (A)	11,24	9,06
Operating temperature (°C)	-40 to +85	

2.1.2. Efficiency

The power efficiency of solar modules is lower as the temperature rises. This makes Finnish mild and cool conditions suitable in early spring and late fall for solar energy although irradiation is lower than in summer months. [25] The ambient temperature and the temperature coefficient of the solar cell together affect the total power production of photovoltaic technologies. Finnish irradiation conditions in summer can cause the temperature of the panel to rise which lowers the electricity production. In higher temperatures the voltage is lower but the current is higher than in normal conditions. The voltage is more responsive to the temperature so the current changes less. [3] The peak power temperature coefficient of solar panels from GEF is -0,36%. [25]

The goal of minimizing costs of electricity can be achieved by maximizing the efficiency of used power. Lowering peak loads and saving energy together with technologies or optimizing tools are examples of efficient functioning operations. [4]

A 27% increase of irradiation is achieved with a 45° pitch compared to a flat roof installation, but the longer shadows of arrays cause problems in locating panels on a small roof and mounting must be stabilized properly. [10]

A HSY map of Helsinki city measuring services provides information on solar production potential. The model is presented in Figure 2. The solar electricity potential from roofs is indicated with different shades of red. The total model encrypts direct- and cloud reflectiveness, the outlines and direction of the roofs, shadows from other buildings or trees and the sun's position at different times of the year or day. Input is based on cloud monitoring data from 2008 to 2013. All panels are modeled to match the angle of the roofs. A 0,5m clearance of roof edges and a minimum of 5m^2 area and 847 kWh/m^2/year sun irradiation are the lower limits for a studied photovoltaic roof space. The efficiency of solar production is considered to be 15%. Suitable areas are not shaded and have enough solar irradiation to place a solar panel. [31]

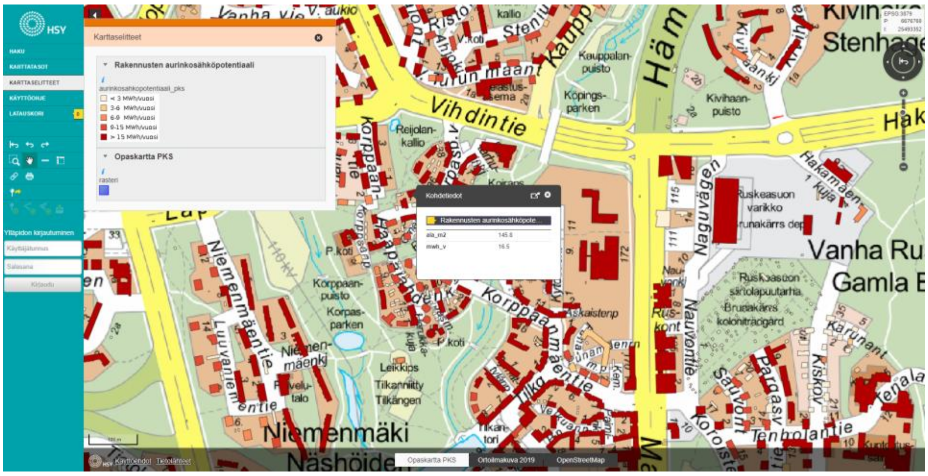

Figure 2 Photovoltaic potential on Helsinki rooftop areas in Pikku-Huopalahti area. [31]

The azimuth of a panel is the position compared to the true north axis. Efficiency was researched by changing the azimuth of the panels during each day by rotating them to be perpendicular to the sun. A panel's power generation can be increased 76,9% more but in theory up to 89,9%. The problem is that because the sun trackers are photoresistors they work poorly in dimmed light and cloudy weather which is more common during the winter. [37]

2.1.3. Sizing of self-sufficiency rate

Solar is estimated to produce 28% of end user electricity consumption in Finland and generate approximately 29 TWh of electrical energy in 2050 [33]. Another estimation is that the rate of installed photovoltaic panels on residential rooftops in Finland is low and a 12GW peak potential of power could be utilized all together. [10] Correct sizing of power generation increases the value of the energy source used and lowers power losses. [4]

The self-consumption ratio of a residential house in Finland was studied and found to be lower compared to commercial buildings. Residential houses have a challenge in matching high consumption winters to high production summers. Spring and autumn are more optimal for self-consumption. The overall rate of self-consumption in a residential house with a 5.2kWp photovoltaic system was 79.5% with no battery storage, because lower system sizes also lower the payback time although self-consumption is almost 100%. [3]

As renewable technologies are adopted and installed to increase clean capacity for electricity generation, the cumulative amount of applied technology correlates inversely with cost per unit of capacity. In a so-called fast growth scenario the levels of photovoltaic production are estimated to rise to 14 000 GWp potentially in 2050. Accordingly, photovoltaic module prices will be 400€/kWp lower simultaneously. Rooftop photovoltaics will remain more expensive than ground mounted panel systems. [33] Compared to solar production without batteries a cost reduction to 100USD/kWh would be profitable for an economically feasible solar photovoltaic system with battery included. [11]

Self-generated photovoltaic electricity becomes profitable if the self-consumption ratio is maximized. If self-consumption increases and demand of electricity stabilizes, it can lead to an undersized system regarding monetary profitability. A larger system size indicates a smaller self-consumption ratio at a domestic house case. [3] It is suggested that selecting the battery technology size first as an electricity storage for solar production is beneficial, because the array sizing is dependent on the load profile and storage application. [29] A typical load profile matched with three general and different size photovoltaic arrays is presented in Figure 3.

Included in the FinSolar study a 51 kWp solar array was studied from university premises. The median price of electricity was lower during that year than when 66% of electricity production was measured. It indicates that production seemed to be more common during times of higher prices than on average. [2]

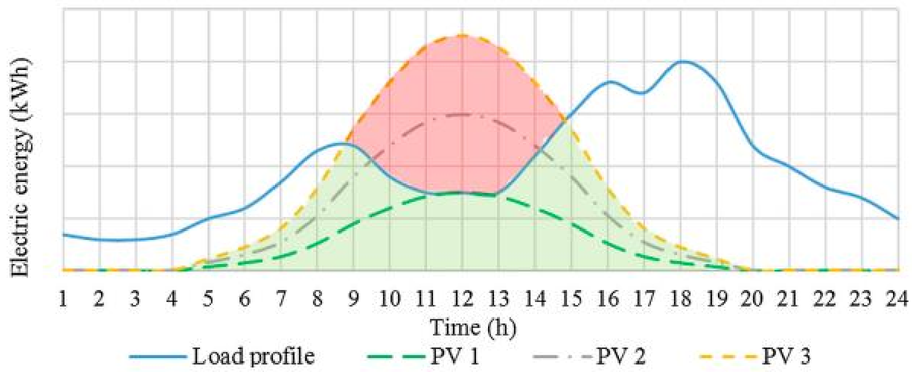

Figure 3. A general load profile for Finland electricity consumption during one day compared to different PV system sizes (kWh). Green area indicates the possibility of self-consumption. [37]

It was researched in a profitability analysis about the best way to be self-sufficient in solar production. The study demonstrated that a large solar panel system that produced 143 MWh/year could support 29% more self-consumption in an energy community than the same amount of individuals consuming electricity from separated power facilities. [4]

A power tariff on low-voltage grids affects the optimal sizing of photovoltaics. Because the power grid is increasingly in contact with a lot of new small-scale produced photovoltaic electricity voltage levels become highly intermittent and matching to energy consumption is difficult. [29]

2.1.4. Energy storages

With modern calculations the intermittent production of wind and solar can not be used directly (47% direct use) but the excess energy can be stored. [33] Batteries and other forms of electricity or power storage increase energy self-sufficiency and it can benefit in the long run although energy-independence of isolated micro-grids could be a faster way to stop the entropic climate change. Nordic countries might have to continue exchanging electricity in the future if battery technology improvements are dismissed. [5] The Battery Storage plan by Valtioneuvosto claims here is an opportunity for the know-how to be sustainable simultaneously in the Mining industry and this affects battery demand positively because electrification is expected to continue trending at least until 2025. [23]

Lithium-ion batteries have declined in price in decent years. The virtual and battery storage benefits are mostly connected to the time of use, since weather dependency is the issue in high- or low latitude countries. The load profile of a customer can affect the maximizing the photovoltaic sizing, but batteries are poorly chosen if the photovoltaic system is sized first. Batteries are effective when market-based controls are used to charge them for extra savings during high prices of electricity. [29]

A virtual battery storage was studied to be profitable for a 8 kWp photovoltaic system with optimal import-export values of electricity approximately worth 400e. In larger systems the limiting factor is the annual fee for the virtual storage service. It does not improve the annual value compensation of the excess energy stored of which is agreed in the contract especially if the exported electricity follows general electricity pricing. [11] At Helen Oy electricity is priced 13 cents/kWh for consumed electricity from a virtual storage system included that the electricity contract is made with them simultaneously. [32]

If electricity can be used directly instead of conforming it to another form of energy it is most efficiently used. Storing electricity for later use or for example transportation can also be done by hydrogen technologies although electric vehicles are unlikely to decline as electricity storages in the future. More affordable photovoltaics are becoming available and finding ways of storing energy or transforming it also supports energy expensive hydrogen production. Emission-free hydrogen is called green hydrogen because it is formed using renewable sources of energy. An emission free way of producing energy can support the network electricity balancing. Burning hydrogen produces additionally extra heat in winter times to households. [36]

If the electricity of solar production can be stored on site, the electricity in the distribution grid becomes more stable and this can lead to a lower electricity price in the future [29].

2.1.5. Inverter

One advantage of solar photovoltaics is the scalability of the system. As long as the bought inverter is sized large enough, extra panels can be added later to increase production capacity. [22] The relative electrical load affects how the inverter efficiency develops. Inclination and the technology of the photovoltaic modules had very little effect on the inverter efficiency. The relative load of a photovoltaic inverter is the biggest technological parameter that affects the inverter size. In addition the energy efficiency of an inverter is affected by the DC-side voltage. The first stage of an inverter is the DC-DC converter stage where voltage levels from the panel are leveled out to match the circuit. This stage degrades the efficiency of the inverter if voltage levels are alternating largely. Even though varying amounts of solar irradiation causes the current to vary more than the voltage in the circuit, the efficiency is not constant. The efficiency for smaller inverters is higher because the load is relatively larger from the panel. The inclination or technology used did not have a major effect on inverter sizing. Indirect low intensity irradiation covers 25,5% of the total annual irradiation in Finland and in these cases optimizing efficiency means undersizing the inverter. [10]

An array-to-inverter ratio is affected greatly by the location and climate of the site. It was studied for 10kW, 6kW and 3kW solar inverters that array-to-inverter ratios were 1.8, 1.9 and 2.17 respectively using data from Jyväskylä (62°N), Finland. Although inverters have typically 15 years lifetime in Finnish conditions, it is studied that lower annual irradiation could increase the lifetime performance. [10]

2.1.6. Metering devices and electricity center

There have been installations of smart remotely read electricity meters for over a decade in Finland. These meters measure electricity consumption and generation at an hour netting period. [11] Approximately 80% of finnish distribution system operator customers have smart meters installed in Finland. They are mostly all automatic meter reading devices that distribution system operators use to detect consumption patterns and estimate the state of the electricity network. Gathered data is used for the hourly net metering of electricity. [3]

The hourly data that is shown is the kWh amount of electricity billing per hour all together, not per step or wire. The calculation in the meter is cumulative. Example of unequal metering registering is demonstrated in electricity centers of the housing company micro-grid where appliances are wired in three steps. Each step is wired for specific appliances or power outlets. If in an hour the photovoltaic production of electricity is 3kWh the produced electricity is divided evenly into the steps of 1kWh. One meter sums all the electricity produced after one hour of netting period minus all bought electricity from the grid. It does not take steps into account like other meters that bill the steps individually after one hour. To that end, the second customer would have lost some money in buying and selling electricity because they are separately priced. The first meter owner would have covered the consumption with what is considered self-generated electricity although electricity is consumed identically. [2]

Current meters for controlling load in the accounting point are nominally 1800MW in capacity. Smart meters are beneficial purchases if many of them are bought simultaneously because operating electricity loads in real-time is inevitable in the future. This could be done with load control functions in future smart meters. Other demand-side management actions support customers in day-and-night control and make distribution network companies' interfaces suitable for combining network power loads which can be balanced with the functions of smart meters. [9]

A next-generation smart meter has minimum requirements to function with increasingly larger power loads. Demand-side management must be done so that supply of electricity is not compromised for a large group of customers in the electricity market. This includes demand flexibility from consumer-customers and other market actors. [9]

Next-generation smart meters are increasingly being installed. In general, smart meters provide new options for the customers and help to secure electricity supply. Requirements have been studied to make necessary and positive changes to metering devices. If the production of electricity is significantly large, meters must have a load control functionality. [9]

A bigger energy bill might indicate a malfunctioning meter. Monitoring and comparing consumption and cost trends is important for the benefit of consumers. For now consumption and production is possible to monitor in online services from power company websites. Information provided is from hourly sales, purchases, power peaks and billing period measurements. [2]

AMR- meters are needed for demand response, credit calculation and new online services and agreeing on certain resources because they have the function of having metering data online. [4] It takes from a few minutes to two days, due to slowness in information sharing, that a power signal from an energy company load directing purposes has reached the consumer meters. A power relay in a housing company meter allows the directing of power from the electricity center. [4] Although load management relays support demand flexibility management they are not identified as sufficient to help in real-time load directing. Instead AMR meters help consumer-customers today to participate in electricity markets. [4]

2.2. Intermittent energy production in an electricity market

Traditional businesses have achieved changes mostly due to their dependency in path related innovation. This could cause difficulties in a prosumer, citizen or consumer-customer centered electricity market supported by solar energy. Constant change could be directed so that creative destruction creates a variety of business models that remain interchangeable. [35]

2.2.1. Credit calculation model

After 2021 the hourly net metering must be done so that the balance settlement period is the sum of consumption or production separately; this generalization of using housing company electricity meters is feasible for small-scale photovoltaic production. [39] In a credit calculation model the small-scale production of electricity is first consumed in the housing company shared premises and after that the distribution system operator allocates the rest to meet individual apartments consumption. Electricity metering data from consumption and production in a housing company can be utilized to provide a suitable model in information systems. [4] Virtual metering or a credit calculation model is tested and applied [27] in housing companies and separate houses. It is an option for electricity measuring compared to back metering which was the second most common in energy-communities. Backmetering means that the individuals share an electricity contract together. The system of credit calculation agreement and payments are a different reality from what goes on in the metering system of the house and how the electricity is distributed. For now the regulations prevent measurement readings from the metering settings to be used in billing. Design in future AMR-meters should be corrected and noticed according to the suggested regulations. [2]

Without storage capacity excess electricity cannot be stored for times of no sun. In these cases it is useful to sell electricity and get a small profit in exchange. The excess electricity is bought by power companies for different prices. [30]

In the credit calculation model all tenants in the housing company have their own electricity bill and electricity meters. The electricity center is the distribution system accounting point and connects information from the housing company consumption and production if such a contract is made. The distribution system owns the metering devices. [4] The result of the online registered electricity from electricity meters inside the apartments are calculated to the shareholders according to an agreed share. An hourly net metering system has three registers and steps, although there is one net result for billing of electricity. In reality the electricity travels through three phase conductors or wires. That is why information online provided for the customer in an hourly net metering is not an accurate demonstration of an equal method for billing. [2]

Datahub was identified as a functioning platform to conduct large electricity market measures and as a solution for a unified credit calculation model [4]. Without changing regulations, it is difficult to make progress in practice. The problem was detected specifically in the regulations concerning displays in metering devices. Measurements are the foundation on which the electricity billing is based on and checked by the entitled parties. Tukes states that some online services are yet insufficient for comparing the measurements of metering and billing to check if they correspond with each other. Online systems need third party actors which verify measurements as a part of the type approval tests of electricity meters. Information results from reading systems such as electricity meters have proven to be sufficient in security of information. [2]

Information sharing through communication mobile networks can be securely provided. Security risks are associated with the information entering from the mobile network through internet connection to the company data systems. [2]

Hourly net metering was not considered a subsidy method because the electricity market uses the same timeframe which is used to integrate prosumers with other operators in the market. Hourly net metering was found to increase the monetary benefit of prosumers significantly for imported and exported electricity and a different time frame for billing would introduce the metering model as a subsidy. Unpredictability is a property of metering unsymmetrical loads and interhour balance fluctuation which make subsidizing achievements difficult. [11]

2.2.2. Investments and automation

A Green Energy Finland investment grant for solar energy is discretionary 20% and directed to companies and municipalities from administration by Business Finland. In addition, GEF provides calculations and documentation services needed. [26]

The net present value of a solar system purchase is affected by the cash flow of the produced electricity compared to the interest rate and system residual value compared to the payback time. A positive net present value is when the investment on the system is profitable. [3]

Investments on rooftop photovoltaic production facilities are estimated to be 40% lower in 2030 compared to 2015. This is made possible with government support. [2].

The tenant of a housing company can directly own panels from a panel system. Direct payment is the easiest investment method. A loan is profitable to take for investments if the interest rate is higher than the interest charges. If a Power Purchase Agreement is made the production risk is on the constructor of the panel system and a possible bankruptcy risk is involved. Electricity is more expensive to produce in this case than in a privately owned system. Other procurement formats are hire purchase, financial leasing, operational leasing and crowdfunding. [4]

2.2.3. Payback time

The energy payback time is not in the scope of this study although relevant when comparing different energy production methods and life cycle sustainability aspects [33][3]. The profitability calculations [3] of optimizing the sizing of a photovoltaic production facility with measured electrical load curves included a discounted payback parameter. It is suitable for comparing different photovoltaic investments. The payback period does not grow significantly when increasing production capacity because the self-consumption ratio decreases respectively. The pitch of the panels and the configuration results in different payback periods. In limits to the lifetime of panels, increasing the size of panels did not affect the internal rate of return and the study suggested a larger panel system makes the investment more profitable. The lowest discounted payback period (28 years) was optimized with a 5,2kWp panel system size for a domestic house with electric heating and government subsidies. [3] For example Oomi energia offers a 25-year guarantee for a solar panel. [8]

Electricity is a unifying energy carrier because it is easily facilitating synergies between energy storage and resulting factors in use. Life cycle

[3] In comparison to nuclear energy, photovoltaic energy payback time is considered lower. [44]

impact and learning- curve-concept were models in which the sustainability, payback time and Green House Gas emissions were in good limits after evaluating installed solar energy for citizens. [11]

2.2.4. Electricity pricing

The electricity price consisted of the sold energy type (35%), distribution charges (33%) and taxes (32%) in 2019. [4] Inside the microgrid of a housing company a distribution network charge was claimed as unnecessary [2][4]. It is also suggested by The Smart Grid Working group [9] since the electricity produced and consumed on the same premise does not cross an accounting point of the property to the distribution grid. The distribution companies have placed more significance on the monthly fixed basic charge on network tariffs. It is adjusted for the main fuse dimension, which is affected by fixed investments and capital commitments. This makes the tariff more cost-reflective for the distribution network companies but reduces customer options on affecting their distribution tariff structure. The variable part of the tariff is energy-based (c/kWh). [9] The electricity bill can be higher during winter demand peaks. [30]

Electricity taxing is regulated on the EU level and a fixed tax on consumed energy increases the efficient use of energy. It is suggested that from the point of view of the electricity system, a fixed tax does not direct customers to act on price signaling from the electricity market. An alternative is the proportionate electricity tax, which is dependent on the price of electricity meaning that it is higher during high prices of electricity. Although a proportional electricity taxing is beneficial for customers that can be flexible on the electricity system, the burden of taxing falls largely on ones that do not have this opportunity and makes it questionable in nature. [9] A tax credit for photovoltaics could increase the installation rate in Finland. [3]

An interface power is the same as the sum of power that presents a community or the area of administrators consumption stated in the energy-contract. [4] Service of steering electricity loads can be provided by the distribution network company. Separation of functions is regulated in the Electricity Market Act and decree made by the ministry of Trade and Industry (2005). The regulations have demands that have to be followed respectively. [4] 68% of electricity consumption in 2017 was mostly caused by winter time electric heating. The rest of the consumption was water heating 18,2% and residual 13,8% in detached houses. [28] The effects of forecasting errors have been studied in [9], for example.

Internal rate of return is a parameter to measure the rate of return of the cash flow during the lifetime of solar panels. The larger the internal rate of return the more profitable the generated electricity and reduced bought electricity are compared to initial investments and maintenance cost. The rate is dependent on the lifetime of the panels. [4] Concentrating on this parameter there is a possibility that the sized photovoltaic panels are sized small. [29]

The strategic stockpile fee is paid together with the electricity generation tax. These payments are for electricity transferred to consumption from distribution grids subject to license, the electricity amount generated by either small or general electricity producers and self-consumed or taxed consumption of electricity. Electricity transferred from micro-generation or used in the production facility are not included in these payments. [4]

The balance sheet error is the result of electricity price predictions and the actual price. These errors can be risky for individual paying customers, although the cause of it comes from larger load directing problems. [2]

The consumer-customer can ask a power company to automatically move consumption to a time when the stock market price of electricity is low using demand flexibility services. This is also possible for the consumer to do manually by themselves. If a power company directs loads, the price of electricity is possibly cheaper because the price risk and balance sheet error both are optimized. By aggregation a lot of consumer-customers amount of directed energy together is large enough to be used in bigger purchases in the different places of the electricity market and even balance out high voltage grids. In return for creating a new consumption pattern the consumer gets some discount in the electricity bill. [4] To optimize self-consumption of photovoltaic production solely the modules might be too little from the economic point of view to be optimal for consumption patterns. That is why buying and selling electricity when the system is in use should affect the system sizing. [10]

2.2.5. Demand flexibility

The Finnish electricity Market is expected to expand. It is assumed that there might be a demand of 95 TWh of electricity in 2050 including 2 TWh of flexible demand maximum electricity balancing per year. The transportation sector is expected to demand 7 TWh of electricity. Space heating is expected to demand 65 TWh of energy, of which 30 TWh of energy from district heating. In this scenario 1500 MW is the capacity of electricity that can be shifted to another time of the day. [33] In addition underground cabling investments on grid expanding measures elevates the electricity distribution prices. [4]

Even with government subsidies, the self-generated electricity is causing alternation in the grid and proposes a challenge to meet consumption without optimization when the load peak is high. Traditionally centralized power companies have adjusted to the consumption of energy and demand flexibility is a common practice to optimize automatic meter readings. [3] In the future demand flexibility might not be a business which distribution network companies can participate in. [4]

Demand flexibility improves and balances the supply of electricity and is stated as a goal when applying intermittency to the energy system. For example houses with electric heating have a power load which is controlled day-and-night so that demand side management is possible. This is cost-effective practice and no noticeable change in heating functions is done. [9] Demand flexibility involves that a load control functionality is created for considerably large power loads as a technical solution for customers included in demand-side management. That includes that the distribution network companies day-and-night control is replaced by smart-meters functions. One issue is that other than flexibly acting customers are subsidized in their common distribution network. [9]

Demand response means that the consumer of electricity is flexibly responding to real-time pricing to improve load profiles. The photovoltaic generation of households is called micro-generation. Micro-generation and demand response are involved in a systemic challenge because integrating intermittent generation like renewable energy will affect efficient pricing which determines the default price of consumption and so the hourly spot price. It was studied how responsive price-based electricity demand from households that have photovoltaic generation can be actively participating in the electricity market in a Swedish context where real time pricing contracts are even rarer than in Finland. The cost of managing the photovoltaic generation is included in the study. In conclusion, real-time-pricing lowers the maximum price and further the variance of the hourly spot price. In addition, energy conservation and efficiency is improved in the primary energy consumption. [18] In Finland some companies have a tariff-structure that can lower the potential of demand flexibility in the electricity market places.[4] The intermittency and new market prices for variable demand and supply cause predicting complicated and weather dependent. [33]

Demand flexibility is a way to increase the efficient use of electricity. Demand flexibility services have offered modifications and technologies to control the demand of power flow in electricity grids by following the customers' needs. The services do not offer electricity production or -storage capacity so they are not part of the free electricity market. [4]

Smart meters allow the distribution system operators to follow the electrical load profile nearly real-time and help when voltages are unbalanced between phases and voltage, current or frequency indifferences occur. Electricity demand control or flexibility can be acheived by using automatic meter readings data to follow and act upon during peak demand to avoid high electricity prices. [3]

Technical- and market-based services offer a solution to control current and future smarter homes. Demand flexibility should be taken into account in designing buildings to make the energy system cost-effective. Design and planning documents of the building should be enabled for the resident so that future demand-side management applications can be installed to answer customers' energy consumption needs. [9]

2.4. Renewable energy integration into the microgrid

The variability of solar electricity production can cause issues in the grid stability. This is a technical challenge although it is beneficial to adopt renewable electricity production in general. [12] It winds more often in the winter and so it complements the electricity produced by photovoltaics mostly during the summer. [35]

Power companies and distribution companies face a conflict if a producer of electricity can change medium voltage cable output load bearing by 10-30% while directing loads. On the contrary the distribution network companies could cause balancing electricity costs for power companies. These are the problems for market based load directing. If demand flexibility on the companies side would only be used for cutting peak loads the effect would be minimal. [4]

If a tenant has multiple sources for electricity as a customer they can react to peak loads in the network by adjusting their consumption or demand of electricity. [3] To conclude, the energy community model affects the photovoltaic panel sizing and profitability. [29]

3 Discussion

3.1 Case studies, Finland

On the website of Energiakokeilut.fi are multiple cases presented from Finland. [7] Two of them are the housing company solutions presented here in the case studies. The Finsolar- project [2] piloted multiple solar panel systems for customers to study what can be done to improve models for housing company shared electricity production. Suitable modifications for the electricity market is the outcome hoped for judging the functionality of credit calculation. In the study market barriers are recognized for solar photovoltaics and a deployment plan is done. Significant data for the construction of energy communities was released from the credit calculation pilot. p23-25 [4]

3.1.1. Credit calculation experiment in Helsinki, Pikku-Huopalahti

One of the cases of the pilot program is the housing company solution in Pikku-Huopalahti. In 2016 As Oy Haapalahdenkatu was facing a roof renovation and the company constructing found out that Aalto University and Helen Sähköverkko Oy distribution system operator were looking for a pilot house. The decision started from an additional shareholders general meeting to vote for the solar photovoltaic system and becoming a pilot housing company for the photovoltaic system credit calculation model. Eventually they decided to deploy a 8,74 kWp solar energy system on their shared roof space. [2]

The housing company consists of a 17 apartment story house and a 7 apartment terraced house. The constructed solar array is a 8,74 kWp power facility. It includes 33 panels and a 12,5 kWp three-phase inverter. The inverter is sized so that there is a possibility to expand the system and get more panels in the future. The system was imported and installed by Green Energy Finland. Helsingin Seudun Suunnittelu- ja Rakennuttajapalvelu HSSR Oy construction company that did the roofing renovation also offered the supply. The system has a 15 year product warranty, 25 year warrant for the panels with 80% production return guarantee and a 10 year warrant for the inverter and fastening. HSSR Oy also monitored the system installation. The building permit was a part of the roof renovation and it was granted by the construction supervision of the city of Helsinki. The initial information base for the profitability calculation in Table 2. of the solar photovoltaic system in Fall of 2016 were with zero investment aids.

Table 2. Conclusion of profitability calculations and investments (Karoliina Auvinen). [2]

Bought electricity price (c/kWh)	4.00
Bought electricity distribution charge (c/kWh)	3.28
Electricity tax and strategic stockpile fee (c/kWh)	2.253
VAT for bought electricity (%)	24
Assumed alternation of the reference price of electricity (%/year)	0.0
Consumption of electricity in the buildings (kWh/year)	65000
Investments for the turnkey system (equipment and installment, including a possible VAT) (€)	13000
Total investments of the photovoltaic purchase from the housing company budget (part of the water-roof renovation and its financing, including maintenance expenses during the lifetime of the system) (€)	23000
Interest rate of financing for the first 10 years (%)	1.0
Investment production demand (%)	0.0
Solar electricity self-consumption (%)	100

Selling price of produced excess electricity (c/kWh)	3.0
Inverter change budget (Presumed to happen in the 15 years from installation) (€)	-1300
Yearly maintenance (Insurance, care and other expenses, includes credit calculation service price approximately 10 eur/month) (eur/kWh)	-€0.019
The energy production value based on the location of panels (kWh/kW)	850
The annualized return of energy in the first year or production (kWh)	7429
Reduction of electricity production in the photovoltaic system yearly (%/year)	-0.5

Net present value of the system on a 30 year retention period is 6280€ with an 3% internal rate of return. Cost price of the photovoltaic electricity produced in that period is approximately 8,8 c/kWh if the estimated price of bought electricity is 12 c/kWh. Helen Sähköverkko Oy would have normally charged 0,07 c/kWh for small-scale produced electricity distribution but the pilot study provided an exception to be made and the distribution charge was dismissed.

In the additional meeting tenants asked questions about the profitability, maintenance during winter and technical risks of the solar power system. The decision was not easy. The payback time for initial investments would have extended if there was not going to be credit calculation possibility to the system operations. The needed changes were expected to be legal issues because at the time the credit calculation model was not applicable by law.

The budget for constructing the system was 23000 € in 2016 in the additional meeting. The superintendent Nina Maukkonen mentioned that the budget should be made riskless and invested in high quality and safety.

Helen Sähköverkko Oy did not charge for the electricity that entered the apartments through the distribution system operator meter. Taxing and distribution charges were not involved in the calculations since electricity stayed inside the housing company grid.

Most of the electricity (80%) was calculated to cover consumption of shared premises in the housing company. These are machine venting, laundry room and lighting for the stairways and storage rooms. The rest was shared for apartments in the buildings based on the credit calculation model. The system was designed so that all produced electricity would go into the use of the housing company, to prevent electricity being fed into the distribution system operation network.

When applying for the system permit there were plans for the optimal placing of the panels so that most electricity would be produced at the location on the roof. The placement was designed so that solar irradiation and use of solar electricity is optimized. Additionally, wiring and coupling was designed forehand to be easy to apply. In the planning stage, existing snow stoppers were detected to be enough for the photovoltaic system.

There are no management expenses added to the calculations, since it was conducted as a part of the roof renovation project. The allocation of solar energy and credit calculation was agreed in May 2017 between the housing company and Helen Sähkverkko Oy distribution system operator.

The housing company Haapalahdenkatu 11 and Helen Sähköverkko Oy made an agreement about a credit calculation model. The superintendent from Talohallinta Management Oy made the agreement on behalf of the housing company. In the agreement it is stated how the service will be provided by Helen Sähköverkko Oy. The sharing principle of electricity follows the amount each member of the housing company owns of the residential property share. This means that larger apartments have a larger share. Because shares were based on company shares, there was no need for making changes to the company statutes either, since it follows the guidelines of housing stock law and division basis was defined in the company statutes.

The superintendent made an online announcement for Helen Sähköverkko Oy about switching to self-production of electricity before the integration to the main distribution grid. They then planned an agreement which was an online service agreement and self-generated electricity network connection agreement, which makes selling excess electricity possible to the distribution system operator grid. They would not charge for the distribution of that electricity although it is possible to charge 0,07 c/kWh on average a year. The contract agreement for the provider of bought electricity was ongoing with Keravan Energia Oy and no changes for the electricity supplier were made. The only modification was for adding an electricity selling possibility from the housing company perspective. The ongoing agreement was fixed-term but upgraded later so that selling excess electricity would be possible for the housing company. A new electricity supplier would then be searched for to maximize profit from self-generated electricity. The housing company added the photovoltaic system to the existing real estate insurance.

The maintenance service from solar panel companies was declined and a self maintenance of removing snow and pollen was agreed. This was ordered because the cleaning maintenance was seen as a very small portion. The supplier Green Energy Finland Oy offered a GEF Vision-service which was obtained. It consists of close to real-time monitoring of the production volumes of the photovoltaic system. Therefore all the tenants could monitor operations and production online and no external service for that was required either. Additionally, the data online would reveal malfunctions in production and help tenants to follow their consumption. [2]

3.1.2. Credit calculation experiment in Oulu, Ranta-Kastelli

Table 3. Calculations of the applied photovoltaic production for Oulu. [2]

Bought electricity price (including taxes and distribution charge) (c/kWh)	12
Selling price of produced excess electricity (c/kWh)	4-5
The annualized return of energy (kWh)	3300
Investments (€)	<10000

Finsolar project leader Karoliina Auvinen calculated the needed technical and economical feasibility of the model that head of technical advisement Mikko Kylli from Oulun Energia Siirto ja Jakelu Oy invented for the Finsolar project. The project began in 2016 and was done on a terrace house for As Oy Kastellinhelmi in Ranta-Kastelli, Oulu. The house is connected to district heating like most of the houses in Oulu. The housing company got all the benefits from photovoltaic production for self-consumption. There were no changes done in the metering method. The model consists of a part that is made for calculating electricity produced firstly for the building property. Secondly excess electricity is divided in shareholding shares for apartment consumption. Electricity shares are depending on the amount a shareholder resident has bought of the small-scale production system.

Consumption of electricity information goes for the distribution system operators of each member of the housing company. If self-generation is insufficient the information about the amount of energy each needs to buy in steps is metered online for the electricity companies. In practice excess electricity from photovoltaic production is used to compensate the electricity bill of each shareholder.

Legislation did not yet have a solution to comment taxing on the case study. Eventually the tax administration gave a precedent and the project could be implemented.

In the beginning, a shareholders general meeting was held where the project was accepted unanimously. The Housing Company Act requires equal treatment for shareholders and it entered into force in the credit calculation model with no changes to the metering of electricity. The sold energy to the grid is calculated according to the market price for electricity which was 4-5 c/kWh in 2016. Information of calculation basis is presented in table 3. The bought electricity is 12 c/kWh including distribution charge and taxing. The investments stayed under 10000 euros and the payback time was estimated to be between ten and fifteen years. The system produces approximately 3300 kWh/year from a 3,5kWp solar power plant. The housing company chair of board, Timo Pirttimaa noted that the project is about being a leader in responsibility and creating a new functional model.

Additionally the project creates image value for the apartments and is possible to implement in a substantial housing company. The project is interesting from the project point of view, because it enables a model for constructing even bigger solar panel systems. There is plenty of room on housing company building roofs. The project was piloted in hope for it to become a national practice. p19-20 [2]

4 Conclusions

The rooftop photovoltaic project is beneficial because it reduces land use and the electricity is used on site of production. Some studies present that optimized consumption of energy and demand flexibility is one function in electrically efficient ways of utilizing electrical power. Power-, distribution and service companies in constructing energy market structures are still outdated and carbon emissions are a serious problem for biodiversity or economically as well since humans are dependent on natural resources and landscape. Unequal payback times and -billing are addressed with current sizing solutions from small-scale photovoltaic production which was not possible during the Finsolar pilot project. Photovoltaic production is made feasible by legislation improvements and the credit calculation model is provided as a service for prosumers. Case study findings indicate how profitability is achieved by the help of an online calculation of production and consumption from automatic meter readings. When predictability is introduced, energy forecasting significantly affects the deployment measures of solar technology. Smart meters can increase efficiency of photovoltaic production and inverter output. Self-consumption (instead of self-sustainability) maximizing benefit after a 30 year retention period was only calculated in Helsinki and gives a net present value of 6280 € for the 13000 € system price. The net present value is a good parameter to size solar systems and electricity storages to prevent miscalculations in sizing production.

A battery system or virtual electricity storage could provide a larger share of profit from optimizing self-sustainability and is considered essential for efficiency in rooftop photovoltaics. Housing companies as producers cause intermittency problems of balancing power loads in power grids. This can be avoided with demand flexibility and increasing efficient system sizing. As the value of photovoltaic production increases the profit of initial investments will benefit from small-scale photovoltaic production.

To direct excess electricity and securely phase out imbalances the grid management needs access to large quantities of consumer data to unify energy sources. Security of information is in the hands of larger companies than ever before such as the centralized electricity and information exchange system Datahub.

Distribution system operators should consider their role as a supplier of electricity with validation from efficient taxing and network charges. Electricity reserves are needed in use due to variation of intermittent renewable energy production and consumption patterns. Both the credit calculation and backmetering model provide consumers as aggregated electricity resources to the electricity market access.

The payback time of the solution is controversially long. Even so, large amounts of energy must be produced by renewable ways that are known today even though solar technology tariffs are large. Other limitations on sizing are the winter demand peaks for electrical heating and other large peak consumption times. Obstacles can be removed with correcting metering devices because unequal treatment inside the grid can be optimized with new services that provide mathematical models for managing consumption remotely.

Housing companies consumption in case studies was found to be 65000 kWh/year in Pikku-Huopalahti of which approximately 11% is covered with self-generation based on the first year. In Oulu the self-generation to array size was lower based on the estimated calculations for the 3,5 kWp photovoltaic system 3300 kWh/year production value compared to Helsinki 8,74 kWp. This was expected because the irradiation amount based on the location is low in winters. Special for the housing company in Oulu an image value from solar energy and being sustainable were the aspects looking to answer in the project deployment.

The bottlenecks of energy communities are also the interest of this study. Problems are associated with finding the production sizing and equipment beneficial for prosumers and netting periods in the electricity market. Other limitations concerning the payback time are related to generalized parameters for efficiency and self-sustainability for energy communities outside the equatorial area where seasonal effects are minimal. In the case studies these are corrected with calculations from the amounts needed to pay for electricity taxing and distribution charges.

Legislation of metering devices has been supportive of customers confronting the unexpected maintenance and investing problems. In future studies addressing the subsidies, net present value optimization and internal rate of return affect insurances or warranties which are yet addressed insufficiently.. Because energy-independence can introduce larger demand response actions, housing companies could provide load balancing as aggregated isolated-grids and secure the supply in times of peak load situations. The benefit of automation technologies and introducing smartness to the electricity systems should be studied to compare self-consumption ratios for the efficient use of energy. Nuclear and wind are to be deployed in a functioning emission negative energy system, and the connections of different production methods are in the scope of future deployment. The direct use of intermittent production is one outcome hoped to achieve with forecasting studies on climate modeling and customer electricity consumption patterns. The capacitive and inductive loads in grids of all sizes are affected by renewable technologies and energy payback time could help in addressing future emissions connected to power supply. Therefore recommendations on finding parameters to grid stability helps the sizing of applied technologies across different distribution networks. Energy payback time is not in the scope of this study. It is still a good point of view to consider comparing different energy production methods since energy poverty is an issue which is a noticeable step to overcome before unified functions in the electricity market are addressed.

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