Vaasan yliopisto
UNIVERSITY OF VAASA

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Design of a virtual battery system

Add-on service for commercial Finnish solar plants

School of Technology and Innovations
Master’s thesis in Information Systems
Master’s programme in Information Systems

Vaasa 2022

UNIVERSITY OF VAASA			
School of Technology and Innovations			
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Title of the thesis:	Design of a virtual battery system: Add-on service for commercial Finnish solar plants		
Degree:	Master of Science in Economics and Business Administration		
Discipline:	Information systems		
Supervisor:	Tero Vartiainen		
Year:	2022	**Pages:**	68

ABSTRACT :
Matching electricity consumption and production becomes an important aspect when a solar plant is added to the electricity system of a building. Companies are currently economically and environmentally incentivized only to install solar plants whose energy production matches the consumption as well as possible. This is due to the excess energy production being not as valuable as production that is consumed instantaneously locally. Such is the case in regions without a net-metering system in place. This study aims to provide means to solve this proposed problem by designing and testing a solution that increases the environmental value of excess solar production from the perspective of a Finnish company that produces solar energy. This should incentivize companies to build larger solar plants, which in turn would increase the additionality of renewable energy.

First, this paper builds a theoretical fundament by examining the standard practices and frameworks in design science research and cyber-physical system development. Based on these two, the initial design and development of the proposed virtual battery artifact is executed. Its functionality and architecture are depicted. The artifact is then demonstrated via a simulation that produces real-world financial and environmental effects of its usage. Lastly, the artifact is evaluated by presenting the artifact and gathering feedback in semi-structured interviews. Seven interviewees were picked randomly from a pool of potential customer base. In addition, the artifact’s design process is mirrored to design science research framework to ensure a rigorous and thorough product.

The demonstration phase showed that oversizing solar plants in Finland led to slight economies of scale effect. Additionally, relative production to own use increased in the spring and fall as a by-product. The interview's key findings were the difficulty in affecting environmental indicators by transferring overproduction between properties. However, contrary to the initial presumptions, the environmental indicators' range was far more concise than thought. The interviewees were surprisingly keen on moving towards producing excess solar energy to their needs. The two main reasons behind this were the set ambitious environmental goals and recently increased financial return on investment due to the elevated electricity prices. Increasing own renewable electricity production was seen as more valuable than purchasing CO_2 emission-free electricity due to the concept of renewable additionality. On the other hand, the proposed virtual battery system also raised a few concerns. These concerns were limited to mainly two issues: the power purchase agreement model and recognition of transferred overproduction by environmental indicator administrators. In combination with the proposed virtual battery system, the power purchase agreement model would lead to diminishing profitability. These two issues need to be considered in future development.

KEYWORDS: Virtual battery, Solar energy, Renewable energy, Design science, Prosumer

VAASAN YLIOPISTO
Tekniikan ja innovaatiojohtamisen akateeminen yksikkö
Tekijä: Leo Berg
Tutkielman nimi: Design of a virtual battery system : Add-on service for commercial Finnish solar plants
Tutkinto: Kauppatieteiden maisteri
Oppiaine: Tietojärjestelmätiede
Työn ohjaaja: Tero Vartiainen
Valmistumisvuosi: 2022 **Sivumäärä:** 68

TIIVISTELMÄ :

Kun rakennuksen energiajärjestelmään lisätään aurinkovoimala, sähkön kulutuksen ja tuotannon oikea-aikaisuuden merkitys kasvaa ratkaisevasti. Nykytilassa yritysten on niin rahallisesti kuin ympäristökannaltakin kannattavaa rakentaa aurinkovoimaloita ainoastaan, mikäli niiden tuotanto ja kulutus kohtaavat ajallisesti mahdollisimman hyvin. Ylituotannon tuottaminen ei ole yrityksille kannattavaa, etenkään alueilla, jossa sähkön netotusmittaus ei ole käytössä. Tämän tutkimuksen tavoitteena on tarjota ratkaisu kyseisen ongelman selättämiseksi. Tutkimuksessa on suunniteltu ja testattu ratkaisua, joka lisää aurinkovoimalan ylituotannon ympäristöarvoa suomalaisen yrityksen näkökulmasta. Kuvattu ratkaisu kannustaisi onnistuessaan yrityksiä rakentamaan kookkaampia aurinkovoimaloita, mikä vuorostaan nostaisi todellista uusiutuvan energian lisäävyyttä.

Tutkimuksen teoreettinen pohja rakentuu suunnittelutieteessä sekä kyberfysikaalisten järjestelmien kehittämisessä yleisesti käytetyistä viitekehyksistä sekä käytännöistä. Virtuaaliakkuartefaktin suunnittelu sekä luominen on toteutettu tämän teoreettisen pohjan perusteella. Tutkimuksessa kuvataan artefaktin toiminnallisuus sekä arkkitehtuuri. Artefaktia demonstroidaan simulaatiolla, jonka avulla saadaan selville sen käytöstä koituvat rahalliset sekä ympäristölliset vaikutukset. Lopuksi artefaktin onnistumista arvioidaan esittelemällä se osana teemahaastatteluja. Haastateltavia oli seitsemän, ja heidät valittiin sattumanvaraisesti artefaktin potentiaalisten asiakkaiden joukosta. Viimeiseksi tutkimuksessa tehty suunnitteluprosessi peilattiin suunnittelutieteen viitekehykseen, perusteellisen lopputuloksen takaamiseksi.

Demonstraatiovaiheessa kävi ilmi, että aurinkovoimaloiden ylimitoitus johti pieneen mittakaavaetuun, ja suhteellinen tuotanto omaan käyttöön lisääntyi keväällä ja syksyllä. Haastatteluissa kävi ilmi, että ympäristövaikutusten mittareihin oli odotettua vaikeampaa vaikuttaa ylituotantoa siirtämällä. Tosin, käytettyjen mittareiden laajuus sekä niiden mielletty tärkeys olivat oletettua suppeammat sekä pienemmät. Haastateltavat olivat yllättävän innokkaita siirtymään tuottamaan ylituotantoa aurinkovoimaloilla. Tähän liittyi kaksi pääsyytä; yrityksien kunnianhimoiset ympäristötavoitteet sekä kohonneesta sähkön hinnasta johtuva aurinkovoimaloiden takaisinmaksuajan lyheneminen. Oman uusiutuvan sähköntuotannon lisääminen koettiin uusiutuvien energiamuotojen lisäävyyden vuoksi arvokkaammaksi kuin hiilidioksidipäästöttömän sähkön ostaminen. Toisaalta esitetty artefakti nosti esiin myös muutamia huolenaiheita. Nämä huolenaiheet rajoittuivat pääasiassa nykyiseen aurinkoenergian sähkönostosopimuksen malliin sekä ympäristömittareiden toimintatapaan olla tunnustamatta siirrettyä aurinkoenergiaa. Sähkönostosopimuksella asennettu aurinkovoimala yhdistettynä virtuaaliakkuratkaisuun tarkoittaisi todennäköisesti rahallisen kannattavuuden laskua. Nämä kaksi asiaa on huomioitava ratkaisun tulevassa kehityksessä.

AVAINSANAT: Virtuaaliakku, Aurinkoenergia, Uusiutuva energia, Suunnittelutiede, Prosumer

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1 Introduction

The timing of energy production becomes an important aspect when transforming energy production towards renewable sources. Yin et al. (2020) identify a problem regarding solar energy production and intermittency. They point out that when solar power production is not timed favourably, it diminishes the reaped benefits. Overproduction, the excess production that meets no consumption, must be stored for later use or sold to the grid. Physical batteries, however, are not the only option for storing excess solar energy produced. A system that virtually stores and transfers the excess energy produced between properties might achieve similar benefits. This paper aims to design and present a cyber-physical system (CPS) that improves the environmental value of solar energy overproduction and incentivizes companies to invest in more sizeable centralized solar plants, and secondly, to evaluate, test, and convey the findings. The output of this paper is an artifact that acts as a virtual battery system (VBS) for commercial size Finnish solar plants.

1.1 Background

The intermittency of renewable energy production is a problem for the electricity grid's stability as the total consumption needs to match the production (Saxena et al., 2021). However, this problem is a reality for prosumers – a term derived from the combination of the two words producer and consumer (Ritzer & Jurgenson, 2010) – as well. Prosumers in countries without a net-metering system are left with lower benefits for solar production that does not meet consumption. In such instances, prosumers are usually paid by the hourly market price for their overproduction (Ahola, 2020). This is remarkably lower than the price prosumers pay for their inbound electricity, which consists of the energy fee, transmission fees and electricity tax, as seen in chapter 2.1.

Although hourly net-metering has been implemented, to some extent, a full net-metering that is, for example, equalized yearly instead of hourly has not been deployed in Finland (Ahola, 2020). Furthermore, the current direction is quite the opposite. Finland is set to be transitioning into a 15-minute equalization period in 2023 (Fingrid, 2021a). A shorter equalization period leads to more overproduction, as the consumption and production must now meet in a shorter time frame. A virtual battery might be one of the solutions to combat this. Virtual battery is a concept that might have different meanings depending on the context of the discussion. Hughes et al. (2016) present a control system that allows for flexibility in loads to provide frequency regulation in a heat, ventilation, and air condition setting. In contrast, Laoharojanaphand and Ongsakul (2021) describe a virtual battery system that uses hydropower plants to reserve the overproduction from solar and wind plants. This paper, in turn, uses the term virtual battery as a description for a service used by commercial and domestic solar prosumers that provides improved utilization of overproduction.

A variation of a virtual battery concept is currently offered in the Finnish domestic solar add-on service market (Helen, 2021a; KSS Energia, 2021). The virtual battery enables prosumers to virtually store their solar overproduction on a ledger administered by the electricity provider. In practice, this is done by valuing the overproduction equally to bought electricity. Prosumers are paying a subscription fee in return for the higher overproduction compensation. Such solutions are lacking in the commercial solar market.

Shifting the domestic virtual battery model into the commercial realm might not be the best course of action. This is due to some critical differences between the two. As a rule, commercial buildings have more stable base loads than domestic buildings. This enables the solar plant to be sized optimally, which often means avoiding overproduction. However, if the value of overproduction increases, the sizing practices might change. Another aspect to be considered is that companies can own multiple buildings. These buildings might have differing potential for solar production. This is why the cross-property utilization of overproduction is an exciting aspect to investigate.

1.2 Aim and scope

The main objective of this research is outlined in the following research question:

> How should a cyber-physical system that enables cross-property solar overproduction transfer be implemented in the Finnish market?

To answer the research question, such a system is designed based on prior literature, tested via simulation, and evaluated by gathering feedback. Thus, an understanding of the technical limitations is built, which is helpful in the initial development phase. In addition, the gathered feedback provides a guideline for future design and development.

Past research in virtual batteries, in the context presented in this paper, is scarce due to its novelty. This impression was shared by Puranen et al. (2021), who recently studied the effectiveness of domestic virtual batteries offered in the Finnish market. However, virtual battery research in the commercial realm is still scant, if not completely non-existent. In addition, to the research being scarce, the offering of solutions to the proposed problem is lacking. Thus, research that aims to fill these gaps can be considered relatively novel.

To fill this proposed research gap, an understanding needs to be built of the limitations and possibilities such a solution entails. After designing a solution, it needs to be tested and demonstrated. Lastly, the solution’s success must be evaluated and presented to the real-world customer base to gain insight into the future development direction. The next chapter describes how this paper aims to fill the gap.

1.3 Methodology and structure

The theoretical section of chapters two and three builds a basis for the development of the artifact in the later phases of this paper. The first theoretical chapter defines the underlying problem of solar intermittency and the current state of solutions. Gregor and Hevner (2013) categorize knowledge in descriptive and prescriptive knowledge, which in the case of this paper places solar intermittency to the former and the current solution state to the latter. The third chapter outlines a framework and guidelines utilized in the development of the artifact. Best practices from design science research (DSR) and cyber-physical system (CPS) design are used. This concludes the theoretical framework portion of this paper.

The fourth chapter initiates the methodology portion. The initial design and development process of the proposed VBS is presented in this section. The functionality and the architecture of the artifact are described. In the fifth chapter, simulation was used to demonstrate the real-world results of the virtual battery's usage. Two cases are presented, first without and second with the proposed VBS in action. Comparisons between the two are made with an emphasis on environmental and financial effects.

The sixth chapter is dedicated to evaluating the developed artifact. This was done to measure its success and seek future development direction. Companies that fit the potential customer profile were interviewed, which is a commonly used evaluation approach (Peffers et al., 2006). They were conducted as semi-structured interviews to enable improvisation while still keeping the results uniform and comparable. Galetta and Cross (2013, p. 75-76) describe semi-structured interviews as a valuable tool in cases where the subject is novel and free-form ideation is needed. Hence, the suitability for this instance is apparent. The interviews were hour-long, conducted for seven companies, which were randomly selected from a pool of 47. The initial pool size was 92, and it was formed by listing references presented by Finnish solar plant providers. The pool size shrunk due to companies being excluded from the initial pool for them not fitting in the potential customer base for having only a single building, too small solar plants, or if they were a farm. In addition to the interviews, the sufficiency of the development and design process is conducted by mirroring the executed research to a DSR framework by Peffers et al. (2006). Lastly, the discussion chapter summarizes feedback gathered, draws conclusions, and proposes recommendations for practice and future research.

2 Solar energy intermittency and current solutions

This section explains intermittency in solar plants. This is the underlying issue that causes the excess solar production to be not as valuable for the prosumer, which is the main problem this paper presents. In addition, the current most common solutions for solar production intermittency are presented. Thus, an understanding of the application space is formed.

The understanding built is one of the main base building blocks for the research. It is used in the artifact development and design phase to form requirements and objectives for the result. Understanding the underlying issues and the application space are critical requirements for the VBS artifact proposed in the latter sections of this paper.

2.1 Intermittency in solar plants

According to Gowrisankaran et al. (2016), one of the key problems with solar energy production is its intermittent nature. Among other variables, they studied the social costs associated with solar energy production due to the intermittency of production. Three contributing factors were considered. The variability of production and its correlation between electricity consumption. In addition, they included the ability to forecast incoming production and the cost of backup options required for ensuring grid stability. These factors were considered from the perspective of the electricity grid infrastructure's administrator.

However, the same three factors are relevant for prosumers as well. Being able to match consumption with solar production leads to more significant benefits. This is due to overproduction usually being sold for the current hourly market price of electricity (Ahola, 2020). Inbound electricity costs include an hourly market price or a fixed price for the energy, transmission fees, and electricity tax. Thus, offsetting bought electricity with solar production is more beneficial than selling the overproduction to the grid. These circumstances are presented in figure 1, where three-year moving averages for each of the prices in Finland are presented. For simplicity and comparability, hourly market price averages were used in both inbound and outbound electricity. Secondly, accurately forecasting the consumption along with the production allows for optimal sizing. Lastly, optional backup options might be relevant for prosumers if the costs associated with them are reasonable and economically viable.

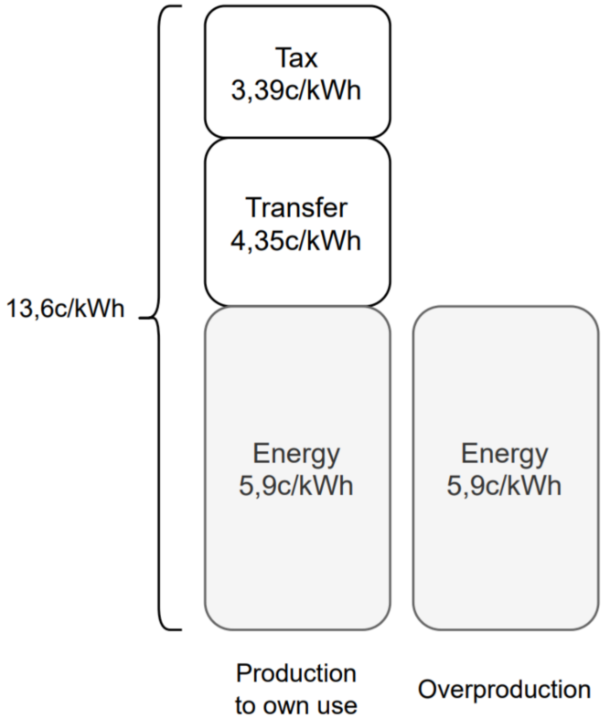

Figure 1. Economic difference between production to own use and overproduction (data from energiavirasto, 2021)

Finnish meteorological institute (n.d) has compiled solar radiance data to surfaces at a 45-degree angle in Southern Finland in 2012, which is visualized in figure 2. The intermittent nature of solar presence is clear, as radiation faces a significant decline roughly from October to February. In the summer months, a peak in radiation appears. This fact ties into the difficulty of solar plant sizing in Finland. A Finnish governmental sustainable development agency, Motiva (2021a), recommends using the consumption data of base loads of sunny hours, which means the minimum consumption in the hours excluding nighttime and wintertime. This is meant to result in a maximal amount of production used locally. This is a prevalent approach in the field, commonly addressed in solar power providers' websites for domestic and commercial solar plants. Some companies seem to focus more on the summertime base loads, and others include spring and fall (Helen, 2018; Lumo Energia, nd; Powera, nd). In turn, some companies seem to rely on sizing based on yearly electricity consumption, at least tentatively (Finnwind, n.d).

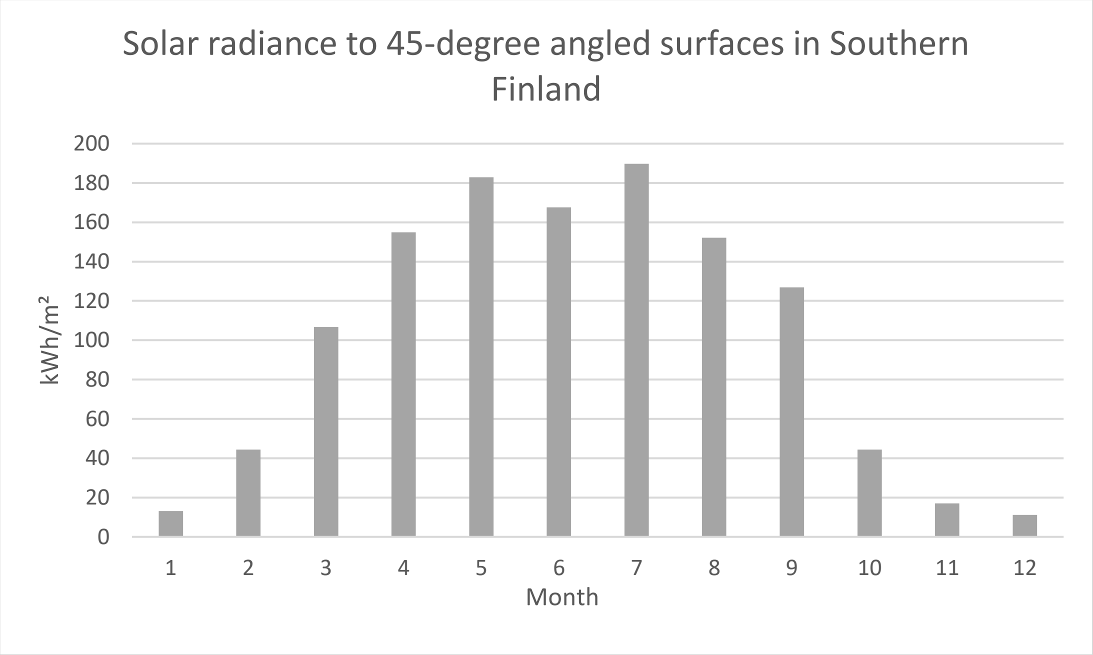

Figure 2. Yearly solar radiance in Southern Finland in 2012 (data from Finnish meteorological institute, n.d)

As stated above, solar plant sizing commonly follows two common practices. Yearly overproduction is minimized if summertime base loads are used, but spring and fall production rarely meets the consumption. Whereas if yearly consumption data or intentionally oversizing is used, overproduction is expected to increase as the sizing is not optimally measured to match the consumption. Although this leads to overproduction in the summertime, it might lead to improved coinciding of production and consumption in the spring and fall when the potential for solar production is lower.

To summarize, Finnish companies with plans to install a solar plant have two options from which they need to choose an approach. Firstly, they can choose the economically best-fitted route, optimally sizing the plant to match the consumption in the summer months. In turn, they can choose to overproduce, which means that a higher percentage of their inbound electricity is offset with their own production, but the amount of overproduction increases.

2.2 Corporate social and sustainable responsibility for buildings

According to Peffers et al. (2006), one of the fundamental building blocks after problem recognition is forming requirements for the solution. In the case of this study, it means gaining insight by observing how businesses measure their environmental, economic, and self-sufficiency goals regarding electricity and renewable energy production. Often, this is done by setting indicators and goals to aim for, which are embedded into the strategies of the companies.

One of the most common standards used for voluntary environmental accounting is the greenhouse gas protocol, which is part of a more extensive corporate responsibility reporting system (Hickmann, 2017). This standard focuses on providing a comprehensive structure for reducing direct and indirect emissions. Greenhouse gas protocol categorizes emissions into three categories by their respective scopes (GHG protocol, 2004). The scope 1 category includes emissions occurring locally due to the company's operation. The scope 2 is dedicated to indirect emissions associated with the emissions of energy production for purchased energy. The scope 3, in turn, is for other indirect emissions occurring due to procurement and logistics, for example (GHG Protocol, 2004).

Organizations have also shown interest in environmentally certifying their buildings to prove environmental friendliness. This can be done multiple ways, one of which is a rating provided by the LEED certificate, which is an acronym for leadership in energy and environmental design (Azhar et al., 2010). USGBC, the administrator for LEED certificates, provides a framework for the certification standards in the rating system guidelines. Renewable energy is given points for the amount of energy it offsets of inbound energy. On-site and off-site production have different requirements. In the case of on-site renewable production, to receive maximum points from the renewable energy section, the buildings' energy usage should be offset by renewables by 20%. In comparison, off-site production should offset total energy usage by 50% to receive maximum points. Renewable energy production also affects the energy performance optimization section (USGBC, 2021, p. 86).

Similarly, BREEAM, which is short for building research establishment environmental assessment method, provides certification and a framework to be used in a buildings environmental effect assessment. The primary metric used by BREEAM to evaluate renewable energy effects is the reduction of CO_2 emissions. Another critical aspect to consider with BREEAM’s guidelines is that any on-site renewable energy produced exported to the grid can be counted as used within the building (BREEAM, 2015). In practice, this means that production is netted yearly, which in essence leads to the disappearance of overproduction on paper.

Contrary to the voluntary environmental reporting, one compulsory metric used for building’s environmental effects is the energy performance certificate, which has been gradually implemented as a requirement for most buildings in Finland. The certificate’s goal is to provide an easily accessible rating that conveys general information about the energy performance of a building. One key metric used is the energy consumption for the area of the building (Laki rakennusten energiatodistuksesta 50/2013). In addition to being a requirement, the energy performance rating is also being used to grant subsidies. Finland's housing finance and development centre grants subsidies for energy renovations that improve the energy performance rating of a building (ARA, 2021). The current decree (Ympäristöministeriön asetus rakennuksen energiatodistuksesta 1048/2017) states that local renewable energy production only affects the energy performance rating by the portion of production that is used locally. Thus, overproduction does not count towards the improvement of the rating. The effect of overproduction utilization in a separate building on the energy performance certificate can only be speculated, as the forementioned current legislation only vaguely states that production should occur *near* the property with production units that *belong* to the property if the production would be counted toward offsetting inbound electricity. There is no precedent for this type of situation; however, the requirement for the production units to belong to the property might prevent the energy performance rating benefits of utilizing remote overproduction.

2.3 Net-metering

Eid et al. (2014) describe net-metering as a practice that enables prosumers to offset their inbound energy for the amount of their excess production in a given timeframe. As used in this paper, the timeframe or equalization period is dependent on the local grid administration and legislation; thus, variability exists. Net-metering with longer equalization periods can be considered a subsidy (Puranen et al., 2021; Eid et al., 2014).

Finland will be transitioning into a 15-minute equalization period for net-metering in the spring of 2023 (Fingrid, 2021a). This is done to adjust to the changes happening in the energy system due to distributed production. Also, the goal is for all of Europe to transition into the 15-minute equalization period to standardize the systems (Fingrid, 2021b). This, however, will most likely increase the portion of overproduction for solar energy producers, thus diminishing the economic benefits, as shown in chapter 2.1. A Finnish study by Puranen et al. (2021) found that the shift from instantaneous equalization to hourly equalization resulted in a three to five percent increase in self-sufficiency with solar prosumers. In other words, this means a decrease in overproduction and an increase in the offset inbound electricity.

Eid et al. (2014) argue that net-metering has downsides as well. Legislatively subsidizing distributed production means decreasing revenue for network utility companies. They found that a yearly equalization period would result in revenue vanishing entirely from the network utility company for customers that use solar to produce their energy. This might mean cross-subsidization for consumers that are only consuming electricity instead of producing it as they might end up being the cost bearer for the decreased revenue.

2.4 Virtual battery

Due to its novelty, past research into solar virtual battery models is still scarce, as stated by Puranen et al. (2021). They describe virtual battery as a service for electricity trading between the provider and the prosumer. Instead of selling the overproduction to the electricity provider for the market price of electricity at the time, it is stored with a value of average inbound electricity price. This value is then subtracted from the electricity bill of the prosumer. The virtual battery services are subscription-based, either monthly or yearly. They have a predetermined fixed capacity.

The Finnish market has at least two electricity providers offering a virtual battery service in the form presented in this paper (Helen, 2021a; KSS Energia, 2021). Current virtual battery services are targeted at domestic prosumers, and solutions for commercial prosumers are lacking, at least in the Finnish market.

2.5 Energy communities

In late 2020 Finnish government accepted a decree that enabled energy communities and distributed energy communities to be formed. This decree came into effect at the start of 2021 (Valtioneuvosto, 2020). It enabled communities, such as housing cooperatives, to produce energy primarily used for general property consumption, including ventilation systems and elevators, for example, locally. Any overproduction that surpasses the property consumption can be distributed to individual residents (Valtioneuvoston asetus sähköntoimitusten selvityksestä ja mittauksesta annetun valtioneuvoston asetuksen muuttamisesta 1133/2020). This enables energy community members to benefit from renewable production fully, meaning that their inbound energy is offset by the portion allocated to them. This, though, is only the case for local energy communities. The most common use case presented for energy communities is housing cooperatives; however, companies can similarly form energy communities with their owed properties (Elenia, 2021). An example of this could be a business park with multiple companies operating from the same property. The local electricity production could be distributed between the different companies as agreed upon.

In addition to local energy communities, concepts for other forms of energy communities exist. One such concept is distributed energy community, which enables overproduction to be distributed anywhere within the confines of the Finnish electricity grid. This model, however, only offers benefits in the amount of the energy price, as transfer and electricity tax cannot be avoided. A second variation is energy communities with neighbouring properties not behind the same electricity consumption point. This might be the case for neighbouring companies with differing potential for solar consumption, for example. This would enable both companies to benefit from one local solar production unit fully, without transmission or electricity tax costs. It looks like this concept is becoming a reality if the Finnish parliament approves the electricity market transform act (Elenia, 2021).

3 Design science and cyber-physical systems

In this chapter, a design framework for the proposed VBS is created. The key theory drawn on is DSR, of which the most commonly known articles and practices were used. In addition, practices for developing a CPS are examined. This is helpful, as the proposed VBS is a service that embodies components in the physical and the digital world, as shown in chapter 4.3. This fits the description of CPS' presented by Baheti and Gill (2019), for example. They describe CPS' as systems that have integrated physical and computational capabilities with multiple ways of communicating with humans.

The step of building a theoretical base is crucial to achieving the goal of producing a meaningful artifact. This framework provides a cross-section of the best practices in developing a CPS that can be utilized in this paper's actual formation and development of the proposed VBS. This chapter firstly examines the DSR approach, after which focus is shifted to specifically CPS artifacts and their development.

3.1 DSR framework

DSR is an information systems (IS) research paradigm, and ultimately it is a problem-solving approach. Hevner et al. (2004) have constructed a framework for IS research that contains both most commonly seen paradigms in the field, behavioural science, and design science. The goal of behavioural science in this setting is often to research truth by observing human interaction with IS. In contrast, the goal of DSR is to provide utility by solving organizational problems with the IS. The latter is the focus of this paper. A modified version of the framework is presented in figure 3. The original framework is modified to solely fit the DSR approach, which relies on the building and evaluation of artifacts. The environment is the source of realized business needs. On the other hand, the knowledge base provides the underlying source of knowledge. IS research is in the middle of these two, utilizing the stream of information from both directions. An artifact is built and evaluated often in an iterative manner by going back and forth with the assessment and refining of the artifact. The end goal of IS research is to provide a real-world basis for applications for the selected environment and contribute to the knowledge by growing the current knowledge base (Hevner et al., 2004).

One of the key elements is to study the application environment and add new or improved solutions to it. These added solutions, or artifacts, cannot be built without understanding the underlying knowledge base, which contains past theories and artifacts, for example. This is why novelty in artifacts is often accompanied by complexity, as the knowledge base is nascent (Hevner et al., 2004).

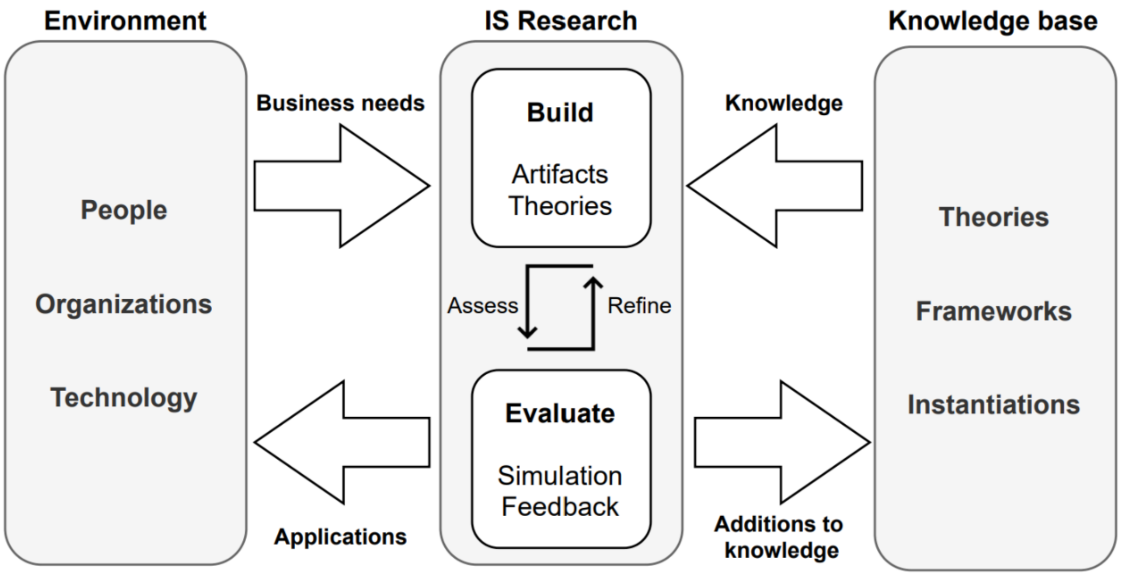

Figure 3. IS research framework (adapted from Hevner et al., 2004)

The goal of DSR is to contribute to the knowledge base with rigorously evaluated and tested artifacts. The knowledge base is thus growing in small increments. As the number of contributions increases, the maturity of a given knowledge base rises, as stated by Gregor and Hevner (2013). They also propose a categorization of artifacts, which visualize the different stages of maturity for knowledge, presented in table 1. The artifact presented in this paper fits into the lowest bracket of contributions, as it is built for a singular, isolated case with little to no prior knowledge base, as presented in chapter 2.

Table 1. Maturity of knowledge (adapted from Gregor & Hevner, 2013)

	Contribution types	**Examples of artifacts**
Mature knowledge	Mid- and grand design theory	Theories
↑	Nascent design theory	Constructs, methods, models
Nascent knowledge	Artifact developed for a single isolated case	Instantiations

Hevner et al. (2004) emphasize that DSR should result in a viable artifact, categorized into four. They describe the first, constructs, as the means of communicating problems and solutions, such as vocabulary and symbols. Artifacts in this category are needed for the description of the problem space, which on the other hand, is a crucial element for the design process. The second, models, they describe as relaying the real-world state of problems and solutions by constructing them into whole bodies of information. Thirdly, methods, are characterized as processes that guide the navigation of the problem and application spaces. Lastly, they label artifacts that demonstrate the feasibility of the design process and the artifact product itself in the selected isolated domain as instantiations (Hevner et al., 2004). Brady et al. (2013) describe instantiations as a real-world demonstration of an artifact, as they use prior constructs, models, and methods and bring them to life by using them in practice. The VBS proposed in this paper falls into the instantiation category. The goal is to produce a real-world artifact whose application and problem space are in the early stages of development. Additionally, the validity is tested and demonstrated via simulations and interviews.

The young age of the DSR approach equals no established uniform practices for conducting research. However, loose guidelines and common practices have been compiled in research by Peffers et al. (2006). They present a six-part guideline that has been constructed by combining prior DSR meta-research. Additionally, they validated their guidelines by mirroring them to prior DSR-papers. The guidelines are summarized in table 2.

Table 2. DSR guideline (adapted from Peffers et al., 2006)

Step	Activity
1. Problem identification and motivation	Justify the solution's value, define the specific problem, and show how it fits the problem space.
2. Definition of objectives for a solution	Describe and list what the solution needs to accomplish to succeed. It should be kept realistic and feasible.
3. Design and development	Actual development and formation of the artifact. The artifact should be a construct, model, method, or instantiation.
4. Demonstration	Demonstrate how the artifact solves one or more of the proposed problems. e.g., Simulation, experiment, or case study.
5. Evaluation	Evaluate how well the proposed artifact solves the problem or group of problems. Evaluation can range from specific to abstract—theoretically, any form of logical or empirical proof.
6. Communication	Combine prior steps into a concise format. Showcase the quality and utility. Meta-level examination of the conducted research.

Peffers et al. (2006) present a closer description of each step presented. The first step of the process is problem identification and motivation, which is done to gain insight into the problem and the environment it is situated in. This will prove a tremendous help and a crucial step in designing a solution. This step also motivates the researcher to conduct the research along with motivating the reader to carry on reading. The second step is for defining objectives for the research. This could mean measurements, such as system speed requirements or how much of the problem should be solved with the proposed artifact. Thus, qualitative, and quantitative requirements can be used depending on the type of research and the artifact to be built.

After the initial groundwork is done, Peffers et al. (2006) propose a move into the actual practical development of the artifact. The third step is for the design and development of the artifact. The already built groundwork is combined to show a direction and an empty space in which the artifact will be built. After the artifact has been formed, its value and quality are demonstrated in the fourth step. The demonstration should be reflective of how the problem is solved. Practically, this could be done by e.g., simulations, case studies, or experimentation. Evaluation is the fifth step, which is dedicated to mirroring the set requirements for the study to the actual observed results provided by the proposed artifact. Like the requirements phase, this step could be done in practice via many different ways, e.g., client feedback or comparisons. In theory, this step could be executed in any way that uses logical reasoning or empirical proof.

Lastly, and conceivably most importantly for the focus of this paper, the communication phase is presented. This step should be utilized to convey information gathered during the research in a concise manner (Peffers et al., 2006). The importance of the problem, the utility, and the quality of the proposed artifact should be reinstated. The rigor and research methods should also be presented here. In the next chapter, a theoretical base for the development of CPS is presented.

3.2 Cyber-physical system design

CPS’ are technological applications that have both physical and computational aspects. The recent developments have transitioned many traditionally non-computational applications to be more accurately described as CPS. Some account for the transition can be given to the emergence of affordable sensors and better means of collecting and utilizing data (Lee et al., 2015). Present-day solar plants are a great example of a CPS. They encase physical parts, such as the solar panels and inverters, and cyber parts, such as production metering and visualization provided by electricity providers and grid administrators. Thus, designing a solar plant add-on service with CPS design principles is justified.

Lee (2008) describes CPS as integrations of computational and physical processes. Figure 4 depicts the categorization of physical and computational components in a solar plant and the add-on service proposed in this paper. The physical side consists of the solar panels, inverters, and metering components the electricity grid administrator provides. On the other hand, the cyber side consists of the ledger managed by the grid administrator and the electricity provider, visualization based on the metering ledger’s data, and the proposed VBS that transits overproduction between properties.

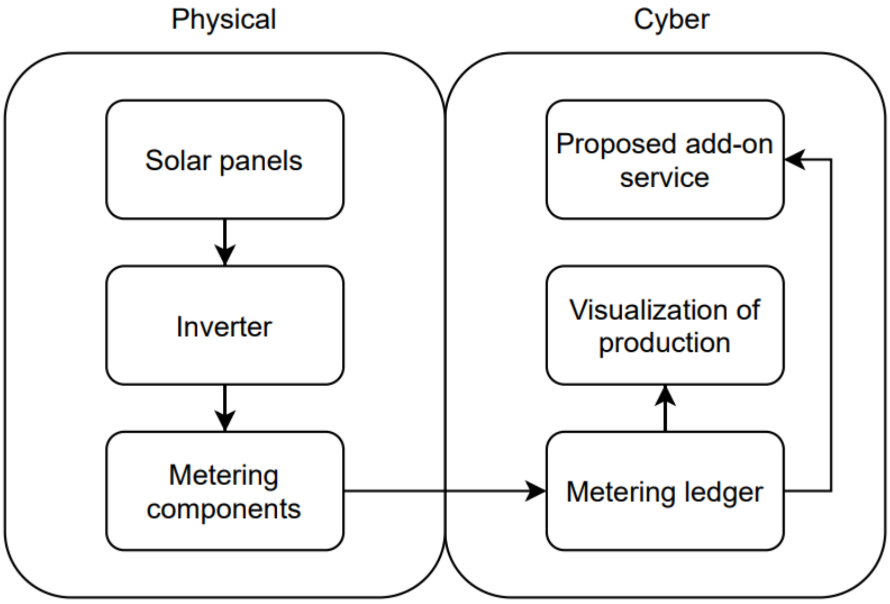

Figure 4. Cyber and physical components of a solar plant

Marilungo et al. (2017) propose a framework for designing a CPS based on past literature. The CPS development and design process are initiated by analyzing and mapping the status quo of operation. Lee (2008) proposes that building a CPS essentially mixes computation with the physical world, which is bound to increase the system's uncertainty.

Computational applications are more easily implemented in a closed, controlled environment. In solar plant terms, this might become a brutal reality with the weather. Thus, one key issue to consider with CPS design is the application space's uncertainty. Though, uncertainty can be reduced in some ways. For example, applications in the solar energy space can utilize weather and electricity consumption data to reduce uncertainty. Merlo et al. (2019) established that one of the key challenges in CPS development is using user-oriented design. To combat this, they propose an iterative design process initiated by the customer needs that gives the basis for the requirements for the result. The process is divided into exploration, synthesis, and development. In the next chapter, this chapter's theories and the proposed problem space are synthesized into a real-world artifact proposal.

4 Description of the VBS

In this chapter, the proposed VBS is presented. The artifact is formed as a synthesis of DSR and the proposed problem space of solar intermittency combined with the lack of solutions. Hevner et al. (2004, p. 3) propose that DSR outputs, artifacts, can be categorized into four different types. The developed artifact here is closest to an instantiation. In brief, an instantiation is an affirmation that shows a concept in operation in a real-world setting, as described by Hevner et al. (2004, p. 5). Brady et al. (2013) remind that instantiations might precede the underlying constructs, methods, and models in some cases. This is to be expected in the case of this study, as the application base and knowledge base are still very nascent.

The proposed VBS is positioned to fill the requirements built in the previous chapters. The key requirements for the artifact were for it to improve the value of overproduction, incentivization to build larger solar plants, and for the design to be executed according to fundamental DSR principles. These requirements should indirectly lead to added value. Expected results are for the overproduction to increase environmental value and improved utilization of solar electricity during the lower production months of spring and fall, along with relatively reducing the solar plant investment costs by utilizing economies of scale. In addition, this hopefully increases the total amount of renewable energy circulating in the electricity grid.

4.1 Design process

According to Peffers et al. (2006), the DSR process can be divided into six parts. The design process of this paper fits closely to the framework presented by them. The actual formation and development of the artifact was preceded by problem identification, building objectives, and requirements for the artifact. The first step, problem identification, was performed by locating an apparent gap in current research knowledge and solution offering. The requirements and objectives were then built upon close consideration of the application space in the second and third chapters of the paper.

The next step, which was the initial design of the VBS was the most challenging, as many presumptions on the needs of the potential customer base had to be made. However, the initial formation of the VBS presented in this chapter was a crucial step in the design process, as it was used as a baseline for gathering feedback and for the future improvement. The later phases of demonstration and evaluation are done as a continuation of this initial design.

A general objective for the artifact is to provide a solution that enables business prosumers to reap more significant benefits from solar overproduction by transferring overproduction to be utilized in other buildings owned by the prosumer. As stated in chapter 2, the timing is well suited, as many regulatory changes have been affecting the application space (Elenia, 2021; Finngrid, 2021a; Valtioneuvosto, 2020). Another objective for the artifact would be incentivizing companies to invest in more sizeable centralized solar plants. The requirement for the artifact is to provide benefits by positively affecting environmental indicators used by prosumer companies. However, the big picture result should not only affect the environmental friendliness of a company on paper but also in actuality. In other words, the artifact should increase the true additionality of renewable energy circulating in the grid. This requirement is included to avoid providing means for greenwashing, which might happen if focused blindly on improving the indicators.

4.2 The functionality of the VBS

The key idea behind the proposed VBS is to enable prosumer companies with multiple properties to transfer the overproduction from one building to another, thus improving the environmental friendliness of the building receiving the overproduction. The proposed VBS is in the form of a service that combines multiple interfaces into a simple bundle for the clients, as seen in chapter 4.3. A simplified version of the aim of the artifact is presented in figure 5, which depicts a situation where property A's production is distributed between two properties that are both owned by the same organization. All of the production that meets consumption is consumed within property A, whereas all of the production that exceeds the current consumption is transmitted to property B. However, the number of outputting and inbounding properties is not limited. The most apparent provider for the solution would be electricity providers. However, nothing stops third parties from stepping in.

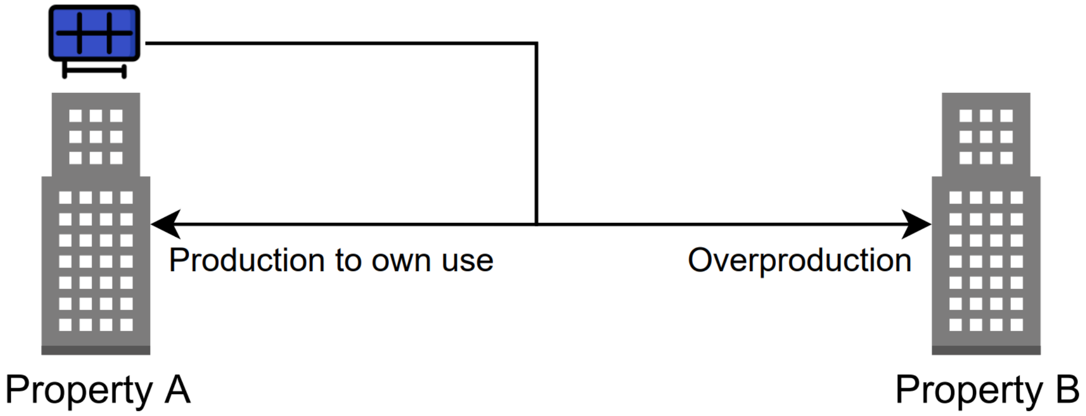

Figure 5. Simplified depiction of the artifact's functionality

The distributed energy community concept is one of the major building blocks utilized in the proposed VBS. It is not yet a firmly established concept, and it has not faced major regulation, enabling a relatively untouched field for service providers. In essence, distributed energy communities are used to conjoin multiple separate properties, at least one of which has a local electricity production system, a solar plant in this case. The overproduction is then distributed amongst the energy community members as agreed upon with the client (Elenia, 2021). In the case of the proposed VBS, the members are buildings owned by the same company. However, the ownership does not necessarily need to be centralized to a single company. In the future, applications that conjoin properties owned by multiple companies might emerge.

This paper’s primary focus is design science; thus, business examination remains narrow. However, it must be said that the proposed VBS does not offer direct economic benefits. Transferring electricity between buildings via distributed energy community concept usually offsets only the energy price portion of the total electricity price (Elenia, 2021). Thus, it can be presumed that companies might not be willing to pay for the service. Hence, one way of providing the solution would be to complimentary offer it with solar plant acquisition as a way to differentiate from the competition. Burke (2013) found that ease-of-use was often one of the most important factors when deciding between options, which is one of the benefits provided by the proposed VBS, as multiple different procedures are combined into a single service. Even though no direct income would become of the proposed VBS for the service provider, Loy and Weiss (2019), among others, further verified the well-known fact that differentiation leads to more significant margins and a decrease in price competition. So, even though no direct income would follow the implementation of the proposed VBS, benefits associated with differentiation are expected to be obtained.

4.3 The architecture of the VBS

The proposed VBS relies on three relevant actors, as shown in figure 6. The first of the three is the client, which refers to the end-user. Service provider refers to the actor providing the proposed VBS, and grid operator refer to the electrical grid operator that enables electrical transmission with grid infrastructure.

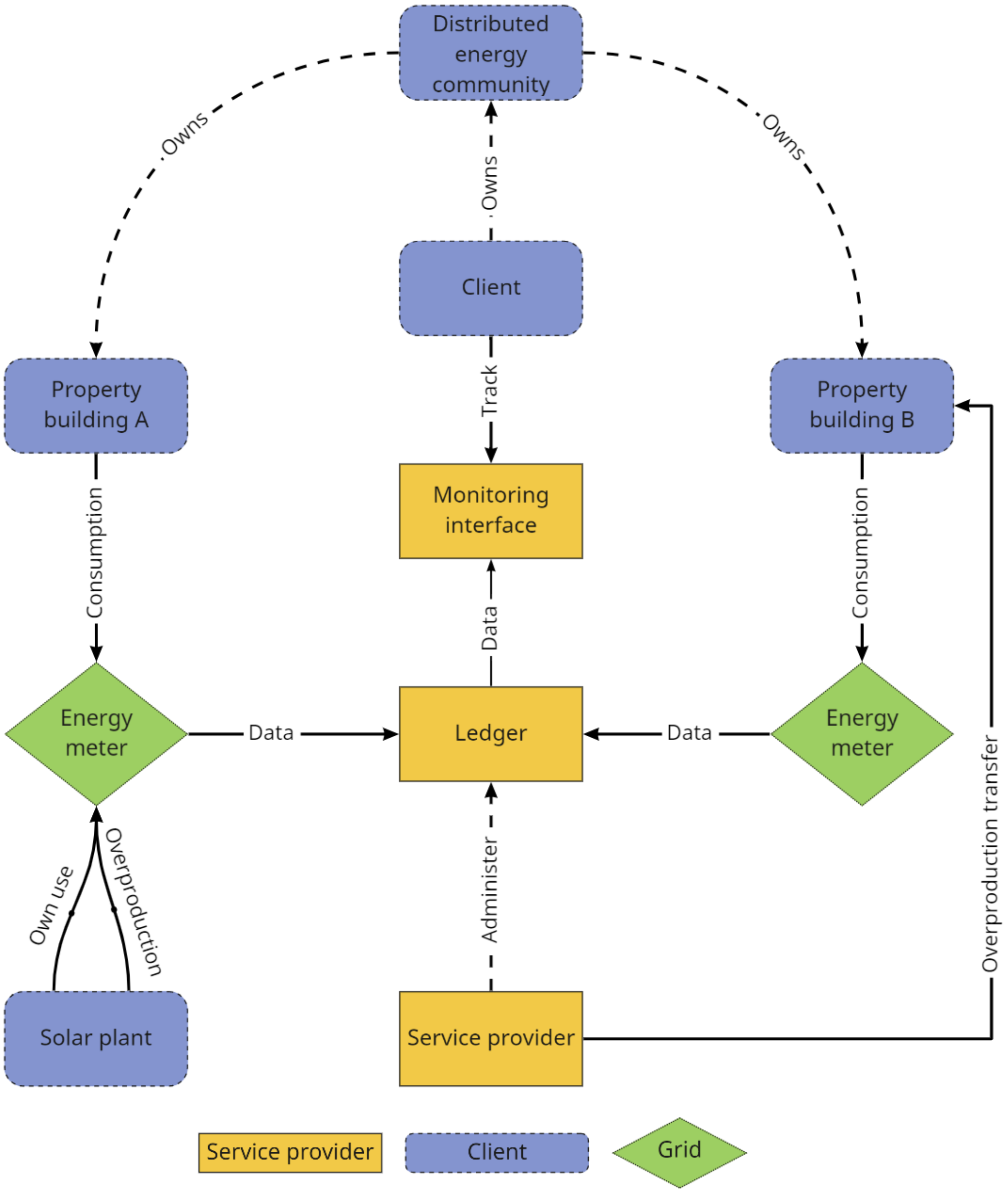

Figure 6. Architectural depiction of the proposed VBS

Starting from the client, or the end-user of the VBS, it owns a distributed energy community. The energy community consists of multiple properties owned by the client. At least one of the buildings should have a solar plant installed. However, the VBS is not limited in the number of associated buildings. Multiple buildings with solar plants could produce electricity to be shared to member buildings of the distributed energy community. Likewise, a singular building producing solar energy could share its yield to multiple non-solar buildings.

The energy meters situated in the buildings are administered by the grid operator, they work as they would without the VBS in place measuring the inbound and outbound electricity of a building. This information is then relayed to the electricity and VBS service provider, which maintains a ledger of inbound and outbound electricity for a given client. In the case of the example provided in figure 6, the service provider is able to transfer the overproduction of building A to building B by deducting electricity consumption of building B by the exact amount of overproduction produced in the building A. When more than two buildings are a part of the VBS, overproduction can be distributed as agreed upon with the client company. The service provider also provides a monitoring interface that provides semi real-time information about the client’s electricity flows. The client can utilize this monitoring interface by using it directly or embedding it to their own monitoring systems. The VBS proposed here will be tested practically via a simulation in the next chapter.

5 The VBS in practice

Virtual simulations for two cases are carried out to demonstrate the functionality of the proposed VBS. The first case is an option without the proposed VBS, whereas the second case is with the proposed VBS. The first case is sized to prioritize economic benefits while the second case has been oversized to guarantee some overproduction to be shared between the two buildings. Case 2 is sized one and a half fold larger than case 1. This number was used, as it is fairly realistic considering the roof area commonly available. The key purpose is to give a general idea of the actual results from the usage of the proposed VBS. The simulations were carried out for the same flat roof in the Southern-Finland with solar panels installed with a 15-degree inclination. Consumption data used for the simulations was premade built-in average hourly load profile for an office from the simulation program, PV*SOL (Valentin Software, 2021). This was done to avoid data anomalies that might be present in real-world narrow data sets.

In each of the cases, a single client company owns the buildings and the solar plant. In both cases, each of the buildings has annual total electricity consumption of 100 000 kilowatt-hours (kWh). Total consumption refers to electricity consumed from the grid and the solar plant. To reiterate, the cases are just a descriptive example, and in reality, the oversizing could be done more drastically to increase the amount of overproduction to be utilized.

5.1 Case 1: Optimally sized without the VBS

The first case could be compared to the status quo common practice of sizing a solar plant, as defined by Motiva (2021a). The sizing is done, prioritizing the production to own use locally and minimizing the overproduction transmitted to the grid. This is done in order to reach the economically optimal result. The economically optimal sizing led to a solar plant with 100 solar panels, which amounts to 37 kilowatt-peak (kWp) with 370Wp solar panels being used.

Table 3 shows the annual results of the simulation. Consumption is divided into electricity bought from the grid and the electricity produced from the solar plant. Overproduction is the portion of production sold to the grid. Only one building is taken into consideration, as the proposed VBS is not being utilized in this case thus no other buildings will face effects from this equation.

Table 3. Case 1 simulation annual results

	Consumption from the grid (kWh)	Production to own use (kWh)	Overproduction (kWh)
Building A	71 496	28 528	4 685

Figure 7 shows the monthly inbound and outbound electricity in case 1. Inbound refers to consumption being transmitted from the grid and the solar plant. Outbound electricity is the portion of production that meets no local consumption and thus is exported to the grid. In this case, 28,5% of the total electricity consumption is produced locally via the solar plant. This number can be considered the self-sufficiency level of the building, which is the degree of on-site production sufficiency to offset inbound energy consumption, as defined by Luthander et al. (2015).

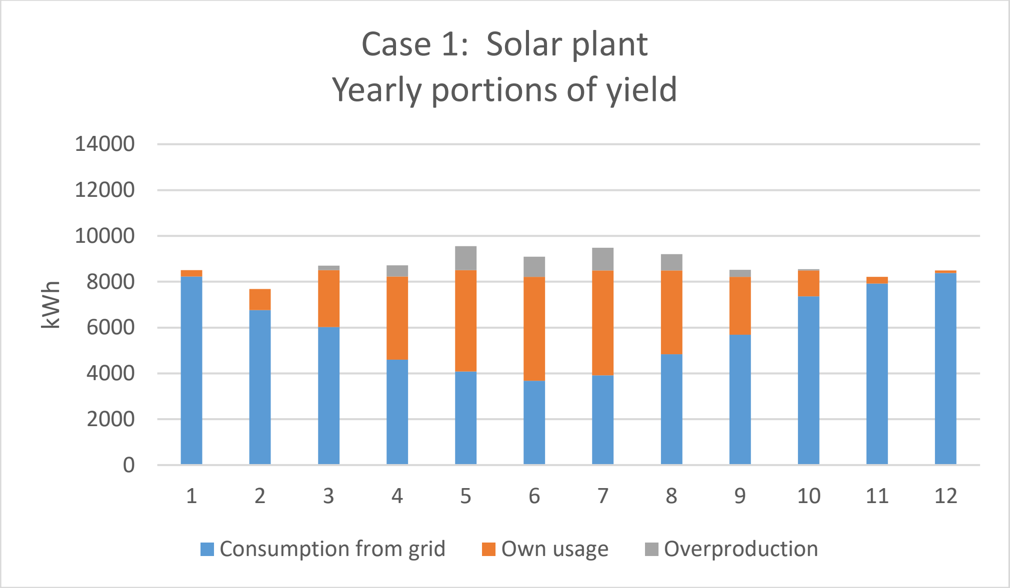

Figure 7. Simulated yearly yield with economically optimal sizing

Figure 8 shows the distribution of produced solar yield between production consumed locally and overproduction, which was transferred to the grid. 14% of the total annual production is eventually sold to the grid.

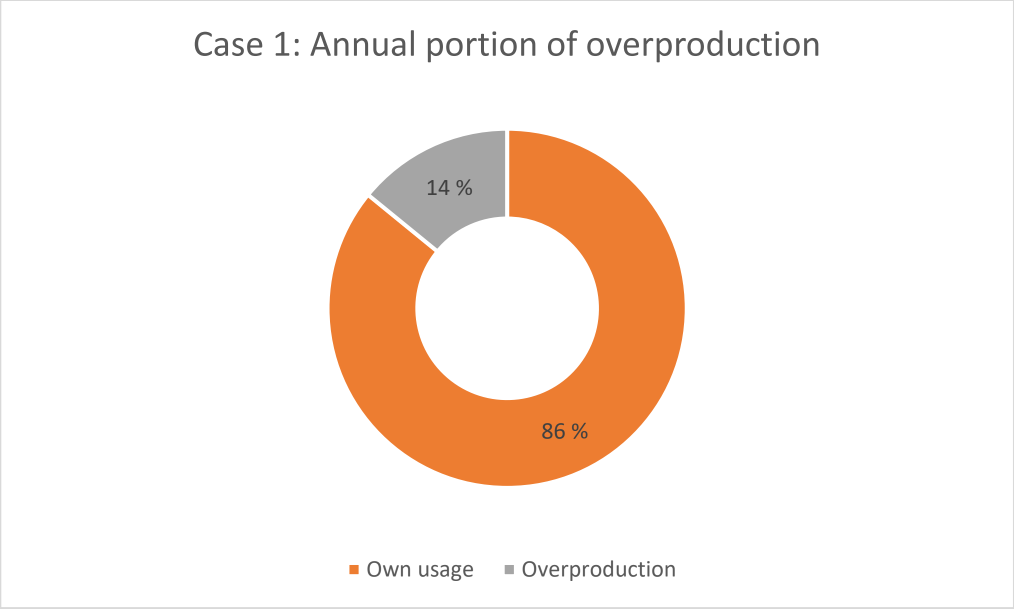

Figure 8. Simulated portion of annual overproduction for case 1

The presented amount of overproduction is considerable, seen as some companies tend to aim for all of the production to be own usage with zero overproduction. However, the sizing is suitable for comparisons conducted in this paper, as it is still a realistic portrayal of a typical solar plant installed in Finland. The economic effects of the simulation results are discussed and compared in section 5.3.

5.2 Case 2: Oversized with the VBS

The second case is sized one and a half fold from the sizing of the first case. This enables examination of a situation where yield is high enough to be shared with other buildings as well. Even more drastic oversizing can be adopted if the roof area is sufficient. The oversizing method led to a solar plant with 150 solar panels, which amounts to 55,5 kWp power with 370Wp solar panels being used.

Table 4 shows the simulated annual results for case 2. In this case example, two buildings are used, building A and B. As proposed in chapter 4, any overproduction generated in building A will be transferred to other buildings owned by the same client company. Total electricity consumption is the same as in case 1. However, the absolute amount of production to own use and overproduction are greater as the solar plant's size increases. In addition, overproduction is transferred to building B instead of being sold to the grid.

Table 4. Case 2 simulation annual results

	Consumption from grid (kWh)	Production to own use (kWh)	Overproduction (kWh)
Building A	65 520	34 527	-
Building B	-	-	15 454

Similarly to case 1, figure 9 shows the inbound and outbound electricity in case 2. Self-sufficiency is at 34,5%, a slight increase compared to case 1. This is due to an increase in on-site production while the total consumption remains level, even though an increased portion of the production is not met with consumption, and thus is overproduction.

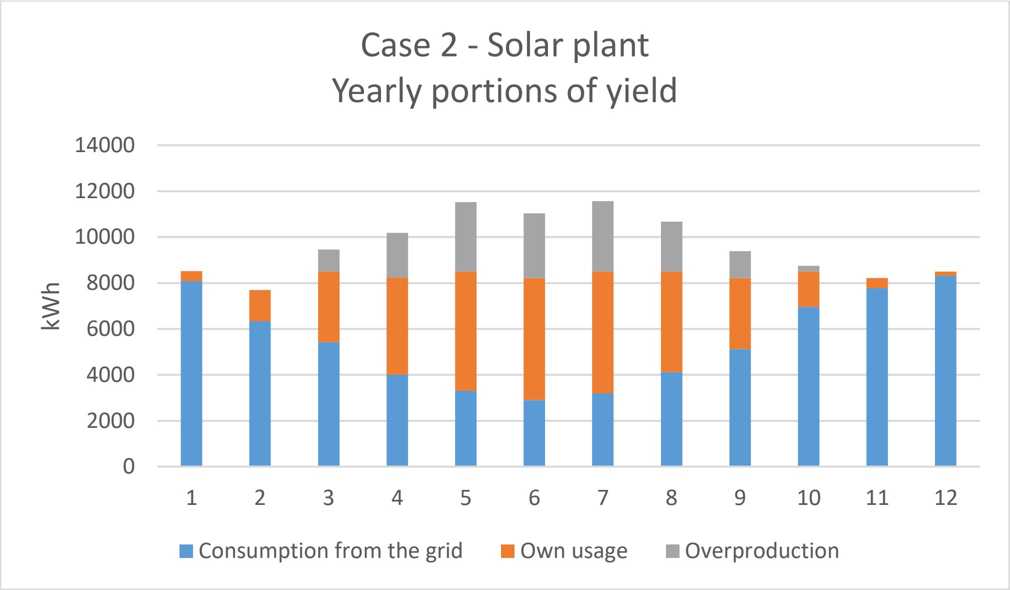

Figure 9. Simulated yearly yield with oversizing

Figure 10 shows the annual yield distribution between production to own use in building A and overproduction, which is transferred to building B. In this example, an increased portion of the total production is overproduction, as intended.

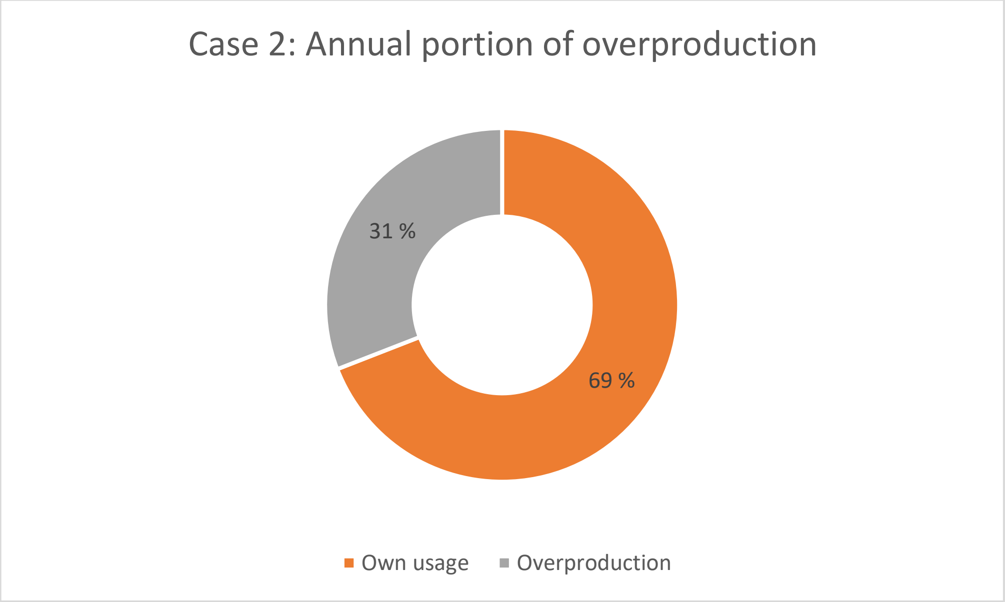

Figure 10. Simulated portion of annual overproduction for case 2

The amount of overproduction here deviates from the current common practices used in solar plant sizing in Finland. Almost a third of the total production is overproduction when companies often aim for all of the produced electricity to be used locally with zero overproduction. However, this fluctuates with the fields of companies examined, as consumption profiles alternate.

5.3 Case comparison

This section is dedicated to examining the outcomes of each of the simulated cases. Environmental and economic results are considered. The environmental effects are considered by measuring the portion of total consumption offset by the solar plant and CO_2 emission reduction, which is achieved by offsetting the bought electricity with electricity produced by the solar plant. On the other hand, the economic effects are measured by the annual savings from own production and income from overproduction.

Table 5 compares key results between simulation cases 1 and 2. The approach calculating the annual monetary effects between the two simulations differs slightly. As monetary effects are only seen in a singular building in case 1, production is consumed locally, and overproduction is counted into the monetary result. Production to own use is given value of 0,136€/kWh, which is the sum of electricity energy price (0,0590€/kWh), electricity transfer cost (0,0435€/kWh), and electricity tax (0,0339€/kWh), all of which can be offset by own production. All prices have been gathered from statistics maintained by the Finnish energy agency (Energiavirasto, 2021). Moving averages of the last three years were used, excluding the year 2020, of which data was missing. For simplicity, overproduction is valued at the same static electricity energy price, even though it is usually valued at the hourly changing dynamic electricity market price (Ahola, 2020).

In case 2, monetary effects are seen in two different buildings; thus, the cash flow is measured separately for the two. Building A's result is calculated by valuing production to own use similarly to case 1. Likewise, building B's result is calculated valuing the overproduction similarly to case 1. Investment costs have been approximated by interpolating pricing data gathered from a Finnish solar plant offering website (Motiva, 2021b). 45 offers in Southern Finland ranging from 10kWp to 50kWp were used. A more specific depiction of the approximation can be seen in appendix 1. The payback period is used to compare the profitability of each investment, which was calculated by dividing the investment cost by the annual monetary effect. An annual increase of 1% was factored into the monetary effect to account for an increase in electricity prices, a common practice in the field.

The environmental effects are presented with two variables. The first is the portion of consumption offset by solar production. In both cases building A's value is presented as the ratio between solar produced to own use and total consumption. In case 2, building B's ratio is calculated by dividing transferred inbound overproduction by annual electricity consumption. The other variable is CO_2 emission reduction, calculated by valuing the electricity offset by solar energy, with the value 131 g CO_2/kWh, which is the three-year moving average CO_2 emissions of electricity used in Finland backward from 2019 (Tilastokeskus, 2021). Details of the calculations and values used are presented in appendix 2.

Table 5. Economic and environmental comparison of case 1 and 2

	Annual monetary effect (€)	Self-sufficiency	CO_2 emission reduction (kg)	Investment cost (€)	Investment cost (€/Wp)	Amortization (yr.)
Case 1						
Building A	4 168	28,5%	3 737	38 572 €	1,042 €/Wp	8,89
Case 2						
Building A	4 710	34,5%	4 523	55 373 €	0,998 €/Wp	9,56
Building B	911	15,5%	2 024	-	-	-

As expected, case 2 led to a slightly longer payback period, as overproduction is not as valuable economically as production to own use. However, if the portion of electricity energy price in total electricity price were to increase, case 2 would increase profitability, as overproduction would increase in value. Also, a slight economy of scale advantage can be seen in the pricing between the two cases. The even larger solar plant should logically lead to increased advantage. From an environmental perspective, case 2 is met with 75% greater CO_2 emission reduction, even though the sizing is only 50% greater. In case 1, overproduction is not factored in as affecting CO_2 emission reduction, as no inbound electricity is offset. However, it must be stated that there are different means of calculating this. For example, BREEAM uses annual net metering in inbound and outbound electricity; thus, overproduction is effectively valued as if it were consumed locally (Personal communication, S. Hargrave, 10.12.2021). Overall, the results of the simulation capture the proposed trade-off well. The yield of solar can be utilized entirely, which in practice means improvement in the environmental indicators with relatively diminishing the economic returns.

6 Evaluation of the artifact

Evaluation is the fifth part of the framework presented by Peffers et al. (2006). This section aims to evaluate the success of the proposed VBS by mirroring the set requirements to the actual observed results from the demonstration section. The evaluation could be done in several ways, and in theory, this step could be executed in a manner that uses logical or empirical proof. In this paper, evaluation is conducted via gathering feedback of the proposed VBS and its simulated use and assessing the design process's sufficiency by mirroring it to the aforementioned DSR framework.

The first part of the evaluation, which is feedback gathering, is executed via semi-structured interviews. Interviews are a well-suited tool in the case of a novel subject, along with the need for open-ended questions for free ideation and creative solutions (Galletta & Cross, 2013, p. 75-76). This is an apt way to accomplish the evaluation need of the proposed VBS, which is to see if the idea is plausible and gather ideas for further improvement to fit customer needs.

6.1 Interviewee selection and description

Seidman (2013, p. 55) claims that the exact number of interviews cannot be established in advance when conducting research based on interviews. Instead of a singular number to strive for, he proposes two criteria that should be considered instead. The first is sufficiency, which measures if the sample sufficiently represents the population. On the other hand, saturation indicates when the information gathered turns repetitive, and no new insight is gained. These two criteria are acknowledged in this paper by being mindful of choosing interviewees and trying to recognize the point of saturation during the interview process. A more in-depth description of the interview process and selection is presented below.

The pool of potential interviewees was created using reference lists provided by the six largest solar plant providers in Finland, which amounted to a base pool of 92 companies. Table 6 shows the total number of companies in the pool and why some of the companies were excluded. The original pool was pruned to exclude companies with solar plants with a kWp less than 30. Secondly, companies assumed to own and operate out of a single building were eliminated. Lastly, farms were excluded from the pool. These exclusions were done in order for the pool to represent the potential customer base as accurately as possible. The potential customer base is considered to be companies with larger solar plants and multiple buildings, as they benefit most from the proposed VBS. To ensure avoiding research bias in the selection process, the pool was then scrambled randomly and contacted in order one-by-one. Out of the pool of 47, seven companies were interviewed. Six companies had to be passed, as they could not be reached or did not want to participate in the study; thus, the seven interviewed companies were among the first 13 in the pool.

Table 6. Description of the interviewee pool

Total number of companies in the pool		92
Excluded due to:		
	Solar plant too small (<30kWp)	14
	Only a single building	26
	Farm	5
Number of companies in the pool after exclusion		47

The background of the interviewees is showcased in table 7. The background is presented with the field the company is operating in and the interviewee's rough title. There is a large distribution between the company's fields ranging from retail to pension insurance. On the other hand, the interviewees' positions had less distribution. Most of the interviewees were working as heads of property administration. This is expected as companies would rarely employ workers specialized in energy if it does not play a vital role in the company's operation.

Table 7. Background of the interviewees

	Company’s field	Title of the interviewee
Interviewee 1	Education	Energy specialist
Interviewee 2	Retail	Property manager
Interviewee 3	Municipality	Property manager
Interviewee 4	Real estate	Building services manager
Interviewee 5	Pension insurance	Development manager
Interviewee 6	Retail	Property manager
Interviewee 7	Travel industry	Property manager

With this group, sufficiency and saturation were achieved. Sufficiency by including interviewees from companies operating in varied fields and having distribution between the interviewee backgrounds. On the other hand, saturation was achieved by having enough interviews quantitatively.

6.2 Interview results

The interviews were conducted as hour-long semi-structured interviews, which means having a general structure for the interview. This allows for improvisation during the interview whilst still keeping the results and answers uniform to enable comparisons and summary of results. Semi-structured interviews are a great tool if the subject is novel and open-ended discussion is needed (Galletta & Cross, 2013, p. 75-76). These properties fit the narrative of this paper well, as the subject is novel with a scarce offering of solutions to the problem, and creative ideation is needed for further improvement of the service.

The general structure of the interviews was firstly to pose the problem the proposed VBS aims to solve and affect. Secondly, the proposed VBS was presented, with the main focus on showcasing the economic and environmental effects summarized from the simulation. General feedback for the idea behind the service was gathered. In addition, answers to eight questions were sought. The questions aimed to clarify whether the right assumptions were made during the initial design phases of the artifact and which direction the future development iterations should be pivoted towards. The questions, along with the general sentiment, are shown in table 8.

Table 8. Semi-structured interview summary

Question	General sentiment
1. General thoughts on the proposed VBS	Much needed solution to a well-known problem Oversizing solar plants to become more common Concerns regarding rental properties and PPA
2. What are the environmental impact indicators used?	Reduction of CO_2 emissions Energy efficiency Carbon neutrality
3. Who keeps track of the indicators?	Property management Energy specialists
4. What kind of environmental reporting is exercised?	Annual corporate responsibility reporting Mandatory governmental reporting
5. Does solar plant data create value?	Yes, needed for reporting and marketing
6. If so, is an API or a monitoring interface preferred?	Both APIs integration preferred in the future
7. Are environmental building certificates used?	Not with smaller companies Rarely with larger companies
8. What is the motivation for installing a solar plant?	Environmental effects & company image Financial returns Education

The proposed VBS was received well. The general sentiment was that anything that incentivizes renewable energy is warmly welcomed and needed. Presented in the following chapters are the in-depth summarized answers to each question along with translated citations from the interviews.

6.2.1 General thoughts on the VBS

The interviews provided great insight on issues that might have been overlooked in the development phase of the artifact. For example, the CO_2 emissions associated with used electricity varied greatly between interviewed companies. Some companies bought exclusively renewable energy with no CO_2 emissions, whereas some bought electricity with emissions being over double the average. Companies belonging to other ends of the spectrum had remarkably different benefits from the proposed VBS, as the former only benefitted by increasing their self-sufficiency, and the latter reached over double the simulated CO_2 emission reduction in addition to the self-sufficiency increase.

A much needed solution. Interviewees from bigger and environmentally conscious companies saw increased value in producing their own renewable energy instead of purchasing renewable energy from the grid, even though the CO_2 emissions would remain level. This was due to the concept of additionality being recognized and considered within energy-related projects. Some companies even factored in the CO_2 emissions caused by the electrical grid, which further favoured their own production.”

> *”What you have presented here embodies a solution that we have hoped to have existed in the past – we have asked [solar plant providers] for such a solution but with no luck.”*

Oversizing to become more common. The interviewees were very familiar with the issue of solar energy intermittency. Not being able to benefit from overproduction as much as from production to own use was seen as the main obstacle to building larger solar plants that exceeded the property’s consumption. Another obstacle that arose with oversizing solar plants was the taxation of solar plants’ overproduction in large-scale industrial solar plants. Nevertheless, some of the interviewees reported that they were transitioning into oversizing their future solar plant investments or expanding their existing plants in the future due to the recent increase in electricity pricing in the market.

> *"We have considered and tested oversizing as an option since a lot of our roofs are already optimally fitted with solar plants."*

Concerns with rentals and PPA. However, some concerns were raised, which might be preventing companies from using and benefitting from the service. One such concern was the ownership of the properties, with rented properties diminishing the desire to install solar plants in the first place. Furthermore, if solar plants were installed with power purchase agreements (PPA), which in essence enables solar plant providers to invest in solar plants on their client's properties, with the client agreeing to purchase all of the production for a given period. Using the VBS proposed in this paper would result in the client company paying full price for the overproduction, whereas they would receive only the energy price in return, similarly as presented in chapter 2.1.

> *"All of our solar plants are installed with a PPA model, which in combination with the proposed solution, diminishes its benefits, to some degree."*

6.2.2 Indicators and reporting

This chapter addresses questions two, three, and four. The second question aimed to understand the different environmental effect indicators used by companies. This enables an examination of the presumptions made during the development of the artifact and evaluation of their accuracy. If presumptions made at the beginning of the design process prove incorrect or imprecise, the artifact can be pivoted towards the right direction in future development iterations. As expected, some unexpected results were gathered. The most commonly mentioned indicator monitored was the reduction of CO_2 emissions. Second to that was the overall reduction of energy consumption. Thirdly, goals for total carbon neutrality were reported. As common as the previous, energy efficiency agreements were mentioned.

> *"The by far most essential and widely used environmental indicator for us is the CO_2 emission reduction – We also take part in an energy efficiency agreement."*

Contrary to the initial design phase presumptions, energy performance certificate mainly was considered only in the construction phases of new buildings. Especially surprising was that no common frameworks or standards were used in reporting regarding energy usage and production. The results gathered here warrant consideration if the proposed VBS’ development is correct or if pivoting is required. The insight gathered indicates that the effects of the usage of the artifact do not necessarily have to be strictly linked to any indicator because, most commonly, the reporting is done via companies' own means and standards.

The third question is heavily linked to the previous question. This question aimed to find out who in the organization keeps track of these indicators and how often. Marketing of the service can then be more accurately targeted. In addition, the service can be built by focusing on a set group of roles and their needs. The answers to this question were twofold. The companies either had a property management team or a team of energy specialists who kept track of the information. The frequency ranged from daily to yearly monitoring. As a rule, large companies of which energy had a key role in their core business had teams designated especially for energy-related matters; otherwise, property management was assigned to monitor the indicators.

> *“Property management team handles the operational monitoring – Our corporate responsibility team also monitors the data but less frequently and more strategically. The property management team reports to upper management quarterly.“*

The characteristics of environmental reporting are examined next. The reason for asking this question was to evaluate what types of reports companies are conducting. In addition, an interesting aspect to investigate is whether the reporting is done voluntarily or if it is due to legislation or other factors. By understanding these matters, clarity in what aspects the service should affect is achieved. Additionally, the willingness to report environmental effects voluntarily is ascertained. Most commonly, an annual corporate responsibility report was used. This varied in scope, but CO_2 emission reduction was reported without exception. However, the means of calculating the reduction was not standardized; thus, the result might vary greatly depending on the calculation. Depending on the company and its field, mandatory reporting was mentioned to be conducted by some of the companies. This was the case with companies with governmental backing or ownership. For example, a given ministry might require an annual report of progress in environmental goals created in cooperation with the company and the ministry.

6.2.3 Data and monitoring

Questions five and six are discussed in this chapter. The questions address the subject of solar production monitoring and the type of data preferred. By examining this, insight into the customers' requirements for monitoring interfaces and application programming interfaces (API) is formed. Amongst the interviewees, the need for monitoring interfaces was apparent and recognized. The most common solution was for the monitoring to be performed within an interface provided by the solar plant provider. However, this was not seen as the optimal solution. The most commonly proposed optimal solution for larger companies would have been to transmit the data to the client company’s own monitoring systems via an API. Thus, the information could be centralized into one interface. On the other hand, small companies wished for the same thing but did not think of it as realistic with their own current systems.

> *“Undoubtedly, we will need to be able to monitor production and yield from somewhere else than just the electricity bills. In our current projects we have had problems with integrating the monitoring data to our systems, but we see the value in integration.”*

6.2.4 Certificates and motivation for solar plants

This chapter addresses questions seven and eight. The foremost helps define whether environmental building certificates, such as BREEAM or LEED, are utilized and considered worth the investment. Most of the interviewees did not consider environmental building certificates worthwhile, at least to be utilized on a broader scale. However, the larger companies interviewed found them helpful, especially when renting properties to international tenants, as they were familiar with these certificates. In addition to this, many reported having tried utilizing certificates when building a new building. Thus, it was seen as worth consideration with constructing new properties. On the other hand, the interviewed companies mostly renting their properties were not keen to rent only certified buildings. To summarize, the certificates were not seen as important as anticipated in the design phase of the artifact.

> *"We have an environmental building certificate in one of our newly constructed buildings – However, we have not widely adopted used the certificates due to the costs related to them and the uncertainty of seeing any profits from their usage."*

The eighth and last question was to understand the primary motivation behind installing a solar plant. This information could then be used in pivoting and targeting add-on services in the field. The strongest motivator was corporate responsibility and the environmental friendliness angle. These investments were seen as having a significant impact on the company's image with a relatively small cost. Solar plants were also seen as a great way to work towards set environmental goals. If an interviewee reported environmental effects to be the greatest motivator, financial aspects were hardly considered into the equation. Environmental effects were followed by financial return on investment as a greatest motivator. One interviewee reported that the expected return on a solar plant investment was greater than the return on investment with their core business. If financial returns were the greatest motivator, environmental effects were mentioned more as an afterthought. Lastly, companies involved either directly or indirectly in education reported using solar plants as a means of education of renewable energy.

> *"Corporate responsibility and environmental friendliness along with the positive effects on the company's image are the key reasons behind installing solar plants to our buildings. On the economic side, the benefits and effects on environmental friendliness are considerable compared to the relatively modest investment price – The return on the investment is not bad either."*

6.2.5 Summary of the interview results

The main goal of the VBS, which is to increase organization-wide positive environmental effects on the cost of slightly decreasing relative financial returns while increasing the total size of solar plants, was considered valuable. This was further proved by the ambitious environmental goals companies are striving for. No stones unturned was said to be the strategy in reaching environmental goals for one of the interviewed companies. In addition, oversizing solar plants and producing overproduction on purpose was found to be more common, and utilizing as much roof area as possible had been at least considered by many of the interviewees. The currently elevated electricity prices were seen to be in favour of it.

On the other hand, concerns about the proposed VBS were raised from companies with solar plants installed with the PPA model and companies solely purchasing zero CO_2 emissions. Combining the proposed VBS with a PPA solar plant, the prosumer would pay full price for the overproduction and receive only the electricity energy price in return. Thus, it can be argued that the PPA model is not suitable for oversizing solar plants, at least in its current form. One of the companies that already purchased zero CO_2 emission electricity pointed out that using the service would lead to no CO_2 emission offset, as the electricity offset with solar overproduction would already be free of CO_2 emissions. However, this view was not shared with all of the interviewed companies. Most of them valued the effect of renewable energy additionality that came with producing their own electricity versus purchasing zero-emission electricity. In addition, one interviewee reported that in their calculations, all purchased electricity had emissions from the usage of the electricity grid infrastructure, thus making own production the most environmentally friendly option.

Contrary to the presumption made in the design phase of the artifact, only a single indicator emerged to the top of commonness. CO_2 emission reduction was reported to be the main indicator monitored by most interviewed companies. The energy performance rating was reported to be mostly used in the construction phase of a building. Environmental building certificates, such as BREEAM and LEED, were of lesser importance than anticipated.

One important detail to note from the interviews was the vastly differing CO_2 emissions associated with purchased electricity within the interviewed companies. Some companies reported purchasing solely electricity with no CO2 emissions, whereas others reported purchasing electricity with emissions over double the national average. This leads to a high distribution of CO_2 emissions offset with the proposed VBS between companies. Thus, companies that have yet to move into a more environmentally friendly energy policy could take a bigger leap at once.

6.3 Sufficiency of the research process

This section aims to evaluate and pose the sufficiency and thoroughness of the research process of this paper. This is done in part by mirroring the six-part framework created by Peffers et al. (2006) to the execution of the research. In addition, this phase of the evaluation is done partly by comparing the proposed artifact to the loose guidelines and outlines for artifacts that have been proposed in past literature.

The Peffers et al. (2006) framework is presented with the corresponding actions executed in this research in table 9. In this case, none of the phases presented in the framework needed to be left blank. The first phase, problem identification and motivation, is executed in this paper by pointing out a research gap regarding solar plants and overproduction, especially in the Finnish market. In addition to research in the subject being scant, offering solutions is also lacking. This is part of the research motivation, a problem and a need that has not been addressed yet. The requirements for the artifact were built via a synthesis of the two theoretical chapters presented in this paper. The technical side of intermittency and Finnish grid utility provides the technical confines the artifact must fit in. In comparison, the DSR framework provides the artifact's requirements and shape and form.

The actual design and development phase resulted in a proposal of an artifact, which was a synthesis of the two theoretical sections, solar energy intermittency, and DSR framework, presented in the paper. The results of the proposed VBS were then demonstrated by simulating the annual environmental indicator effects and economic effects. Two simulations were conducted, one without the proposed VBS in operation and the other with it; thus, they can be compared effectively. The simulations are then utilized as a part of the evaluation. Results of the simulation and problem description were then presented to the potential customer base. Feedback was then gathered based on the presentation. In addition, to evaluation via interviews, the design process is evaluated in this section. Lastly, the whole research results are communicated in the discussion section. This includes an overview of the underlying problems, lack of solutions, design process, simulation results, and recommendations for future practice based on the feedback gathered.

Table 9. DSR framework and execution (framework adapted from Peffers et al. 2006)

DSR framework	Execution in this paper
1. Problem identification and motivation	Spotting a research gap Identifying a problem and a need
2. Definition of objectives for a solution	Requirements
3. Design and development	Suggestion Solution synthesis
4. Demonstration	Simulation
5. Evaluation	Artifact feedback through interviews Evaluation of the design process
6. Communication	Documentation Communication through research paper

Turning focus of the evaluation solely on the virtual battery artifact proposed, Baskerville et al. (2018) propose guidelines for DSR instantiation publications. First, the clear representation of the artifact is emphasized. Secondly, they pose the importance of demonstrating the improvements and value the artifact provides before making claims on adding to the knowledge base or maturing the design theory. The need for demonstration increases with the novelty of the proposed artifact. Additionally, they emphasize the need to report the intended and observed impact resulting from the use and implementation of the proposed artifact. They also add that the maturing of the design theories is often preceded by isolated singular cases of artifacts.

These aforementioned points have been addressed in this paper, firstly by aiming for a clear representation of the proposed VBS, e.g., architecture depiction is used. Secondly, the demonstration is done thoroughly, considering multiple aspects. Additionally, the simulations utilized in the demonstration section were conducted before the evaluation section. As the proposed VBS falls into unknown ground, a particular focus on the demonstration section was given to exhibit and prove the utility provided. In addition, the VBS proposed in this paper fits the description presented of DSR instantiations by

Brady et al. (2013), as it is a real-world demonstration of the artifact, which has been built by utilizing the past constructs, methods, and models.

7 Discussion

One of the key arguments against solar energy is its intermittent nature (Gowrisankaran et al., 2016). This notion was further validated in the evaluation phase of this study, as interviewees were well aware of the problem's existence, and it was reported to affect their investment decisions. However, the state of the problem might face a shift if the reported elevated electricity prices remain level or increase even further. This would, at least in theory, increase the attractiveness of sizing solar plants by the roof area instead of electricity consumption, often resulting in larger solar plants. Thus, an accelerating increase in solar overproduction could be seen in the near future. This, in turn, would raise the need for services that increase the environmental value of overproduction, such as the service presented in this paper.

The main goal of this paper was to create an artifact that incentivizes companies to build larger solar plants by increasing the environmental value of overproduction, introducing it to the potential customer base, and gathering feedback for further development. The feedback was sought to ensure that the correct presumptions were made in the design phase, repivot if needed, and guide future design and development in the field. The requirements set for the proposed VBS were to be designed using common DSR and CPS practices. Another requisite for the artifact was to increase true renewable energy additionality instead of improving indicators only on paper. The rigorous testing and evaluation conducted in the previous two chapters demonstrate that the requirements and goals set for the artifact have been fulfilled well.

7.1 Key findings and recommendations

The DSR framework presented by Peffers et al. (2006) heavily relies on the iterative design cycle. It was one of the key guidelines followed in the construction of this paper. The research conducted in this paper can be seen as a single iteration of a larger design process. The main output of this paper is the VBS, which is an add-on service for solar plants.

The key aim behind the solution is to maximize the value of solar plant overproduction by enabling utilization of overproduction in buildings that have no ability to produce their own solar energy. A more in-depth description of the VBS is presented in chapter 4 especially in figures 5 and 6. This paper’s key findings and recommendations for practice are presented in table 10.

Table 10. Key findings and recommendations for practice

Key findings	
The proposed VBS	• The ability to affect many of the indicators with the proposed VBS was limited • Transferring overproduction between properties is a relatively unrecognized concept by authorities • Current PPA models might discourage overproduction and thus the usage of the proposed VBS

Potential customer base	• The range of environmental indicators utilized by companies was more concise than expected
	  o Standardization on how the indicators are measured is lacking
	• Companies are considering oversizing as an option
	  o Ambitious environmental goals to widen the spectrum of actions organizations are willing to explore
	• Renewable additionality is recognized and adopted as a concept, to some degree
	• Motivation for installing solar plants:
	  o Corporate responsibility, environmental friendliness & PR
	  o Financial returns

Oversizing solar plants	• Oversizing leads to slight economies of scale effect • As a by-product of oversizing: Relative production to own use increases in spring and fall • Oversizing expected to increase in number in case electricity prices remain level or increase
Recommendations for practice	
Commercialization	• Marketing with emphasis on CO_2 emission reduction • Economies of scale angle • Renewable energy additionality
Current climate	• Solar plant oversizing to grow in number due to financial profitability increase – solutions that increase environmental value to grow in demand
Background activities	• PPA model re-examination • Communication with authorities to recognize remote production of solar better • Bear in mind the property and plant ownership effects on environmental indicators

It was more difficult than expected to have an effect on the indicators set by authorities, such as energy performance certificate, with the proposed VBS. Remotely produced solar energy is rarely recognized as valuable as locally produced from an environmental aspect. Fortunately, the use of these indicators was more uncommon than expected. The most common indicator reported to be used was CO_2 emission reduction, often calculated as best seen fit by the organization itself. Thus, an argument could be made that remotely produced solar energy can be justifiably used to increase CO_2 emission reduction.

The currently elevated electricity prices had sparked a slight interest in companies to oversize solar plants, increasing overproduction. Another critical factor in favor of oversizing was ambitious environmental goals, for which all of the available options have to be used. Lastly, some interviewees recognized renewable additionality as a concept, which led them to value their own renewable production higher than purchased zero-emission electricity.

Within the interviewee group, the most common motivations for installing solar plants were environmental friendliness, company image, and corporate responsibility. Thus, when commercializing the proposed VBS, CO_2 emission reduction increase, renewable energy additionality, and wider marketing possibilities should be the central angles used. The second most common reason was financial profitability. This need can be responded to by emphasizing the economies of scale effect with larger centralized solar plants and the increase in production to own use in spring and fall.

The interviews showed that companies are considering solar plant oversizing as the profitability increases with the price of offset electricity rises. If the currently elevated electricity prices remain level, the demand for solutions that raise the environmental value of overproduction is expected to increase. Thus, possible providers of these types of services should be ready for the incoming demand. Additionally, an examination of the current solar PPA models is needed, as in its current state, prosumers might be discouraged from overproducing as they pay full for overproduction while only receiving the electricity energy price in return. However, if the inbound price of PPA electricity is low enough, it could be profitable to oversize. Lastly, communication between service providers and authorities is needed for up-to-date legislation and specification of indicators and their interpretation of remote solar production and solar plant ownership issues.

7.2 Reflection to past literature and contribution to knowledge

When a prosumer cannot match production and consumption momentarily, they end up benefitting less from the produced solar energy. This is the case in regions without a net-metering system in place. Another vital issue is the discrepancy in solar production potential between properties owned by the same organization. The yield produced in a given location can usually only be benefitted from locally, even though the overall electricity consumption of the organization might surpass the production. A solution that enables cross-premises usage of solar energy would incentivize building larger solar plants increasing total renewable energy produced along with investment cost reduction with greater economy of scale.

The past literature and solution offering in the presented context are scarce. As Puranen et al. (2021) present, there is a few providers offering such solutions in the domestic sector. The commercial sector, however, lacks offering and thus literature. This paper combines the problem space and DSR principles by synthesizing an VBS that improves the environmental value of overproduction, thus incentivizing companies to build larger centralized solar plants. The proposed VBS was also demonstrated via simulations and verified in the evaluation section with interviews. The main contribution of this paper is the developed VBS itself, along with the feedback and insight gathered from its evaluation. Thus, this paper is an addition to the still nascent knowledge base and an attempt to fill the proposed research gap.

7.3 Limitations of the study and suggestions for future research

Commonly with novel subjects and DSR, the range of prior literature is scant. Such was the case with this research and solar overproduction solutions as well. This resulted in most of the design and development phase being based on presumptions, some of which proved to be inaccurate in the evaluation phase. Additionally, the extent and timeframe of this research allowed for a set number of interviews to be conducted, and it functioned well as an initial opener of the study subject. However, for a more extensive future examination of the subject, a more widescale investigation of the potential customer base and an evaluation of actions instead of words is needed.

In the course of the research conducted in this paper, several future research needs outside of this paper's scope were found. The propositions for future research are presented in table 11.

Table 11. Recommendations for future research

Field of research	Future research proposition
Environmental friendliness	• Company’s likeliness to purchase solely zero CO_2 emission electricity if they have a solar plant installed • The financial returns upon investing in environmental building certificates in Finland • The ability of environmental certificates to correspond to true environmental friendliness • The extent of the differences in means of calculating CO_2 emission reduction between companies • The possibilities of standardizing calculation methods of CO_2 emission reduction
Solar plant investment cost	• Closer examination of Finnish solar investment cost €/Wp to see the magnitude of economies of scale effect
Electricity price and solar plants	• The effect electricity price fluctuation has on the will to install solar plants • Sensitivity analysis of electricity price levels and solar plant investment profitability

Voluntary environmental action from companies is a fascinating subject to study. The goal for limited companies is to produce profits for the stakeholders. Thus, environmental actions' true intentions and total effect would be an interesting research subject. Whether companies invest only in the most visible green projects, such as solar plants, and neglect the less visible low-hanging fruits, such as purchasing zero CO_2 emission electricity. Though, it could be argued that a good deed done for the wrong reasons still counts as a good deed. In regard to environmental friendliness, building certificates would be another interesting subject to examine. Many interviewees questioned their usefulness; thus, an inspection of their potential for financial returns would be fitting. Additionally, in the interview phase of the research, the difference in means of calculating CO_2 emission reduction was discovered. Examining the magnitude of the differences would shed light on corporate environmental reporting. In addition, an investigation on the possibilities of standardizing CO_2 emission reduction calculations methods would be justified.

The lack of pricing data for the Finnish solar market complicated the price approximation in the simulation phase of this paper. The data exists, to some degree, but it is rather rough. Lastly, the currently elevated electricity prices were mentioned often in the interviews. Examining its effects on solar investment willingness and profitability would be a current topic to study.

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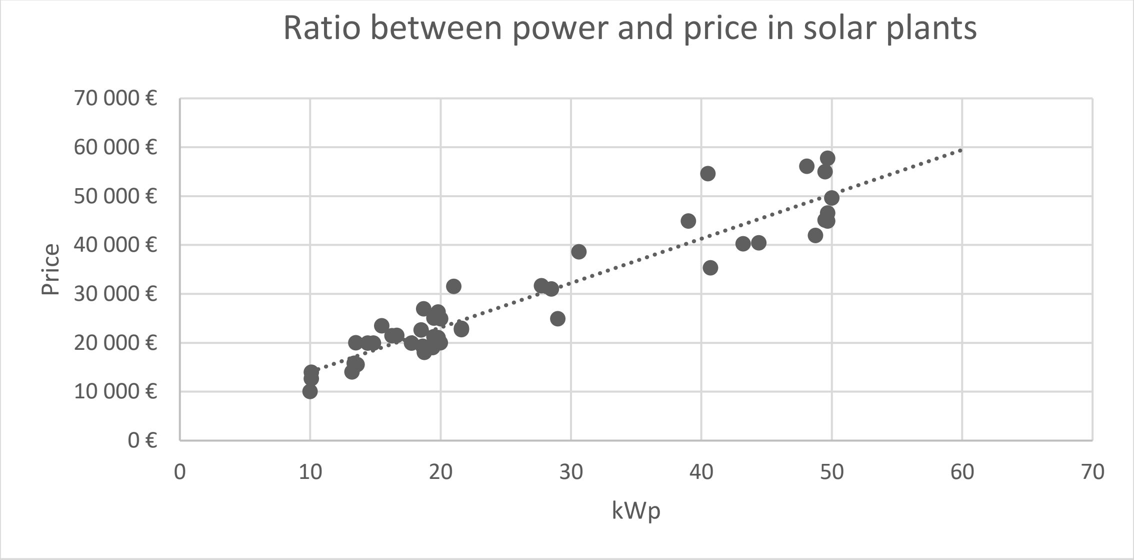
Appendices

Appendix 1. Solar plant pricing in Finland



(Data from Motiva, 2021b)

Appendix 2. Calculations and the values used in annual results of simulations

	Case 1 monthly production		Case 2 monthly production	
	Own Consumption (kWh)	Overproduction (kWh)	Own Consumption (kWh)	Overproduction (kWh)
1	274	0	427	0
2	912	0	1 350	15
3	2 484	202	3 074	963
4	3 621	494	4 229	1 960
5	4 415	1 051	5 192	3 027
6	4 533	879	5 322	2 818
7	4 571	995	5 296	3 073
8	3 657	707	4 377	2 185
9	2 524	305	3 094	1 165
10	1 132	51	1 532	248
11	294	0	454	0
12	111	0	180	0
Sum	28 528	4 685	34 527	15 454

Case 1 monthly monetary & environmental effects

	Own consumption (A)	Overproduction (A)	CO_2 Emission reduction A (kg)
1	37,44 €	0,00 €	35,95
2	124,49 €	0,00 €	119,53
3	338,86 €	11,94 €	325,38
4	494,03 €	29,14 €	474,36
5	602,34 €	62,02 €	578,37
6	618,45 €	51,88 €	593,84
7	623,59 €	58,69 €	598,77
8	498,97 €	41,69 €	479,11
9	344,32 €	18,02 €	330,62
10	154,37 €	3,02 €	148,23
11	40,11 €	0,00 €	38,52
12	15,10 €	0,00 €	14,50
Sum	3 892 €	276 €	3 737

Case 2 monthly monetary & environmental effects

	Own consumption (A)	Overproduction (B)	CO_2 Emission reduction A (kg)	CO2 Emission reduction B (kg)
1	58,272 €	0,01 €	55,95	0,02
2	184,126 €	0,90 €	176,80	2,00
3	419,386 €	56,81 €	402,69	126,14
4	576,949 €	115,66 €	553,99	256,80
5	708,372 €	178,57 €	680,18	396,48
6	726,121 €	166,26 €	697,22	369,14
7	722,533 €	181,30 €	693,78	402,55
8	597,181 €	128,92 €	573,41	286,25
9	422,073 €	68,72 €	405,27	152,59
10	209,065 €	14,63 €	200,74	32,49
11	61,900 €	0,00 €	59,44	0,00
12	24,521 €	0,00 €	23,54	0,00
Sum	4 710 €	912 €	4 523	2 024

Own consumption monetary offset/kWh	
Energy	0,0590 €
Transfer	0,0435 €
Tax	0,0339 €
Sum	0,136 €

CO_2 emission offset kg/kWh
0,131

(Prices from Energiavirasto, 2021; Emissions from Tilastokeskus, 2021)