



**Utilization of solar energy for automotive dealership Veho's environmental goals**

Veho Oy Ab

Lappeenranta–Lahti University of Technology LUT

Master's degree in electrical engineering, Master's thesis

2022

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Examiners: Professor Jero Ahola

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## ABSTRACT

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Electrical Engineering

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Master's thesis

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57 pages, 30 figures, 6 tables and 0 appendices

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Keywords: PV system dimensioning, PV system, Photovoltaic system, Solar panel system, Solar panel, Solar electricity emissions.

The main goal of this work is to find how the automotive dealership Veho could utilize solar energy to meet its environmental targets in a cost-efficient manner. In this work will be optimized a PV system for the Veho's property in Kokkola through self-sufficiency and payback-time. The production data is simulated with the PVsyst software. The purpose of the optimal system is to reduce electricity purchased from the grid with self-production. The system is compared to other Veho sites in Olari, Raasepori and Latvia. In addition to this, the charging of electric vehicles in Kokkola will be considered through theoretical scenarios. The effects of the PV system throughout Finland are calculated by duplicating Kokkola's system to 24 Veho sites in Finland. The share of energy produced by the systems in the electricity consumption of 24 sites are going to be calculated, as well as the percentage reduction of the annual electricity bill with different electricity contracts. The emissions of grid electricity and solar electricity will also be compared.

The main goal for optimizing a PV system to Kokkola was to have lower payback-time than the real estate rental agreement of the property and self-sufficiency high enough to meet the consumption and load growth also in the future. Was found that the 70 kWp PV system is optimal for Kokkola with 38.9 % self-sufficiency. When purchasing and selling electricity at low SPOT prices of the year 2020, the monthly electricity bill was found to be the lowest on average in Kokkola. At high SPOT prices of the year 2021, the electricity bill was the second lowest. The biggest savings in Kokkola came from Veho's current contracts when sales were calculated with 2020/21 SPOT prices. The payback-time 8.5 years was found to be the lowest with the Veho's contract 2021, when the electricity was purchased with fixed price in the contract and the overproduction was sold at high 2021 SPOT price. With contract

2020, the payback-time was the second lowest 8.7 years. These two payback-times were inside the green area, which means that the system could pay back the investment before the rental period of the property ends. The payback-time changed between 1.2 – 6.6 years between the lowest 0.8 eur/W system price and the highest 1.05 eur/W system price, means that the eur/W price of the PV system greatly affects the payback-time. In the location comparison with the 70 kWp system and with Latvia's solar production, the self-sufficiency in Kokkola rose about 0.65 % when comparing to the Kokkola's solar production. Also, the capacity factor rose from 11.35 % to 11.44 %. This shows that the PV production is more profitable further south where the sunlight intensity is higher.

When Kokkola's data with the nominal 70 kWp PV system was duplicated to 24 Veho's dealerships in Finland, was found that the production of 24 PV systems is about 13.2 % of the total annual electricity consumption of 24 dealerships. Also, with Kokkola's current contract and 2021 SPOT prices, the percentual reduction in annual electricity costs was the highest 9.7 %. With contract 2020 the reduction was the second highest 9.4 %. The total price of 24 PV systems was 1 558 440 € and could theoretically pay back the investment under nine years.

When comparing emissions between grid electricity production in Finland and solar electricity production, was found that the solar power has 0 gCO<sub>2</sub>/kWh emission factor compared to the emission factor of electricity production in Finland 89 gCO<sub>2</sub>/kWh. The comparison was done during electricity production. Also, was found that the PV array reaches the net-zero state in 3 – 4 years, where it has produced enough emission free energy to cancel the manufacturing energy and emissions.

## TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

School of Engineering Science

Sähkötekniikka

Valto Martikainen

### **Aurinkoenergian hyödyntäminen autojen jälleenmyyjän Vehon ympäristötavoitteissa**

Diplomityö

2022

57 sivua, 30 kuvaa, 6 taulukkoa ja 0 liitettä

Tarkastajat: Professori Jero Ahola, Apulaisprofessori Antti Kosonen

Avainsanat: PV järjestelmän mitoitus, PV järjestelmä, Aurinkosähköjärjestelmä, Aurinkopaneelijärjestelmä, Aurinkopaneeli, Aurinkosähkön päästöt.

Työn päätavoitteena on löytää keinoja, miten autoliike Veho voisi hyödyntää aurinkoenergiaa saavuttaakseen ympäristötavoitteensa kustannustehokkaasti. Työssä mitoitetaan PV järjestelmä Vehon kohteeseen Kokkolassa omavaraisuuden ja takaisinmaksuajan kautta. Tuotantodata simuloidaan PVsyst ohjelmalla. Optimaalisella järjestelmällä on tarkoitus vähentää ostettua sähköä verkosta omalla tuotannolla. Järjestelmää verrataan muihin Vehon kohteisiin Olarissa, Raaseporissa ja Latviassa. Tähän lisäten, sähköajoneuvojen latausta Kokkolassa tullaan pohtimaan teoreettisten skenaarioiden kautta. PV järjestelmän vaikutuksia koko Suomen tasolla lasketaan monistamalla Kokkolan järjestelmä 24 Vehon kohteeseen Suomessa. Järjestelmillä tuotetun energian osuus 24 kohteen sähkönkulutuksesta lasketaan kuin myös vuosittaisen sähkölaskun prosentuaalinen vähennys eri sähkösopimuksilla. Verkkosähkön ja aurinkosähkön päästöjä tullaan myös vertailemaan.

PV järjestelmän optimoinnin päätavoitteena Kokkolaan oli kiinteistön vuokrasopimusta alhaisempi takaisinmaksuaika ja riittävän korkea omavaraisuus vastaamaan kulutusta ja kuormituksen kasvua myös tulevaisuudessa. Työssä havaittiin, että 70 kWp PV järjestelmä oli optimaalinen Kokkolaan 38,9 % omavaraisuudella. Myytäessä ja ostaessa sähköä vuoden 2020 SPOT hinnoilla, kuukausittainen sähkölasku oli matalin keskiarvoltaan Kokkolassa. Korkeilla vuoden 2021 SPOT hinnoilla sähkölasku oli toiseksi matalin. Suurimmat säästöt Kokkolassa tulivat Veho nykyisellä sopimuksella, kun myynti laskettiin 2020/21 SPOT hinnoilla. 8,5 vuoden takaisimaksuaika oli matalin Vehon sopimuksella, kun osto tapahtui sopimuksen energiahinnalla ja ylituotannon myynti tapahtui korkeilla vuoden 2021 SPOT hinnoilla. Sopimuksella ja 2020 vuoden SPOT hinnoilla 8,7 vuoden takaisinmaksuaika oli

toiseksi matalin. Nämä ajat olivat vihreän alueen sisällä, joka tarkoittaa, että järjestelmä pystyisi maksamaan investoinnit takaisin ennen kuin kiinteistön vuokra-aika päättyy. Takaisinmaksuaika vaihteli 1,2–6,6 vuoden välillä matalimman 0,8 eur/W järjestelmän hinnan ja korkeimman 1,05 eur/W hinnan välillä, joka tarkoittaa, että järjestelmän eur/W hinta vaikuttaa suuresti takaisinmaksu-aikaan. Sijainnin vertailussa 70 kWp järjestelmällä ja Latvia tuotannolla omavaraisuus Kokkolassa nousi 0,65 % vertaillessa Kokkolan tuotannolla laskettuun lukuun. Myös käyttöaste nousi 11,35 % lukemasta 11,44 % lukemaan. Tämä osoittaa, että aurinkosähkön tuotanto on kannattavampaa etelämpänä, missä auringonvalon intensiteetti on korkeampi.

Kun Kokkolan data 70 kWp järjestelmällä monistettiin 24 Vehon kohteeseen Suomessa, huomattiin, että järjestelmien tuotanto on 13,2 % 24 kohteen kokonaissähkönkulutuksesta. Myös Kokkolan nykyisellä sopimuksella ja vuoden 2021 SPOT hinnoilla prosentuaalinen vähennys vuosittaisissa sähkökustannuksissa oli korkein 9,7 %. Sopimuksella ja vuoden 2020 SPOT hinnoilla vähennys oli toiseksi korkein 9,4 %. Kokonaishinta 24 järjestelmälle oli 1 558 440 € ja järjestelmät pystyisivät teoreettisesti maksamaan investoinnit takaisin 9 vuodessa.

Kun vertailtiin päästöjä Suomen sähköntuotannon ja aurinkosähkön välillä, huomattiin, että aurinkosähkön päästökerroin on 0 gCO<sub>2</sub>/kWh vertailtaessa Suomen sähköntuotannon päästökertoimeen 89 gCO<sub>2</sub>/kWh. Vertailu tehtiin sähkön tuotannossa. Työssä todettiin myös, että PV järjestelmä saavuttaa nettonolla-tilan 3–4 vuodessa, jolloin se on tuottanut tarpeeksi päästötöntä energiaa nollatakseen valmistusenergian ja päästöt.

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## SYMBOLS AND ABBREVIATIONS

### Roman characters

AC	alternating current	[A]
DC	direct current	[A]

### Abbreviations

BAPV	Building Applied Photovoltaics
ELSPOT	Day-ahead Market
EV	Electric Vehicle
GHG	Green House Gas
IEA-PVPS	International Energy Agency - Photovoltaic Power Systems Programme
NREL	The US-based National Renewable Energy Laboratory
NSR	National Survey Report
PV	Photovoltaics
PV <sub>sys</sub>	Photovoltaic Software
R&D	Research and Development
SPOT	Electricity price in the marketplace
VAT	Value Added Tax

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# 1 Introduction

The main objective of this work is to find how the automotive dealership Veho could utilize solar energy to meet its environmental targets in a cost-efficient manner. Similar types of theses related to photovoltaic system dimensioning have been done in Finland, for example, at Helsinki Metropolia University of Applied Sciences, Satakunta University of Applied Sciences and Häme University of Applied Sciences. In addition to photovoltaic system dimensioning, not many of these theses consider environmental aspects, which are considered in this work. The Veho group is a Finnish car dealership concern that also operates in the Baltics and Sweden. In 1939, Veho was founded as an importer of Mercedes-Benzes in Finland. Currently, the Veho group has several principals, and its business consists of the import of both passenger cars and commercial vehicles, retail sales and maintenance operations with related services. (Veho 1)

Currently, Veho operates in approximately 25 dealership properties (excluding Assistor and Veho rent properties) such as passenger car, van, and truck dealerships in Finland. Dealerships has services such as sales and service, taxi sales and service, spare parts service, and truck damage repair shop depending on which area the dealership focuses on (Veho retailers).

Solar energy could be one of the many solutions to reach Veho's goals. Solar energy has been studied many years and results says that it can lower the carbon footprint, lower the electricity bill, and pay back investment costs (Marsh, 2022). Veho already has solar panel systems on some of its' dealership properties. To participate in sustainable development, Veho could increase the number of solar panel systems and thereby reduce the property's electricity bill and carbon footprint.

Finland is moving towards an environmentally sustainable future, with the aim of reaching net zero emissions by 2035. One of Finland's sustainability objectives is to reduce its

dependency on imported fossil fuels by 50 % and ban the usage of coal completely in power generation by 2030. This goal of reducing imported oil will reduce emissions on a large scale. Oil is mainly used in transport sector, so the impact of reduced oil imports has implications for this sector. Finland's strategy also includes that by 2030, 10 % of cars on Finnish roads will be electric cars. (Finnish Government, 2021)

One of Veho's sustainability goal is to be CO2 emission-free till 2023. Goal also includes reducing Veho Finland's carbon footprint by 90 % from the level of 2021. With research and projects, Veho has more reliable information about from where emissions come from and what are the next targets. (Veho, 2022)

*"Also, when reducing emissions, data management pays off. The results of our carbon dioxide emissions have helped us to understand where our weaknesses are and to identify the actions that are making a big difference in the right direction."- Head of Sustainability Lia Samuelsson (Veho, 2022)*

Veho has purchased certified green electricity since 2019. Also, Veho has started to use renewable district heating from the beginning of 2022. When building or renovating properties, Veho strives to take advantage of solar panel options and renewable heating. For example, Veho's property in Vehkala is emission-free in terms of heating and electricity use. (Veho, 2022)

For years, Veho has invested in energy-saving building technologies in its Finnish properties. Optimization and automation have been used to reduce the electricity use of the properties. Veho is constantly exploring opportunities to improve energy efficiency with Veho's building performance partner. (Veho sustainability report, 2021)

In addition to dealerships for passenger cars, busses, and vans, Veho is also investing in truck dealerships in Finland, Sweden, Estonia, Latvia, and Lithuania. In 2021 in Finland, new truck registrations increased by 3.1 %, in Sweden 6.9 %, and in Estonia 59 %.

Registrations increased by 89 % in Lithuania with record-breaking for truck sales with over 3,500 new trucks delivered to the customers. In 2021, 54% of Veho's turnover was from cars, 24% from vans and 22% from trucks. (Veho annual review, 2021)

In addition to this master's thesis work, Veho has another project going on, in which the future investment program is investigated: "Green energy investment and implementation strategy". Based on this, Veho will make decisions about investments and projects. (Räsänen, 2022)

When considering charging systems, Veho will be adding systems as needed. Veho have more than 200 fixed charging points in its properties, of which about 20 are fast charging/DC stations. In addition to these, Veho have about 50 portable alternating current stations. (Räsänen, 2022)

Veho also supports its employees to switch to electric vehicles (EVs) by compensating with company cars for employees EV charging expenses and financially support employees with purchases of home charging stations. (Veho 2)

*"Ensuring that the majority of our employee and demo passenger cars are electric vehicles or plug-in hybrids by the end of 2023. Veho's vehicle policy strongly supports and incentivises a shift to electric vehicles (EVs). We compensate our employees with company cars for their EV charging expenses and financially support them with purchases of home charging stations." (Veho 2)*

Veho is a large company that currently has a stable rise in terms of sustainable development and the financial side. Also, electricity is only a fraction of Veho's total costs. The share of electricity in other business expenses was 4 % at Veho Oy Ab in the period 1-8/2022 (Räsänen, 2022). Other business expenses include non-personnel costs. When considering optimizing Veho's electricity usage, savings may remain low when thinking about the big picture.

The main goal of this work is to dimension a photovoltaic system for Veho's truck dealership property in Kokkola. As mentioned earlier, Veho is also investing in truck dealerships in Finland, Sweden, Estonia, Latvia, and in Lithuania (Veho annual review, 2021). Kokkola's dealership was chosen because it is a truck dealership, fairly -new building, it has about 10 years left on the lease, and it's a concept building, meaning Veho has similar buildings all over Finland. As a truck dealership and concept building, Kokkola gives perspective on solar panel systems in Veho's truck dealerships all over Finland.

Solar production is simulated with PVsyst software (PVsyst) in the location because it is designed to be used by architects, engineers, and researchers and is already a familiar program from university courses (PVsyst). With optimized PV system, the goal is to reduce purchased electricity from the grid with self-produced solar electricity. The optimized system is compared later between Kokkola and other Veho's dealership properties in Olari, Raasepori and in Latvia. In addition to this, a goal is to consider an EV fleet (an electric vehicle) charging through theoretical scenarios in Kokkola. Second goal is to calculate the effects in Veho's total costs after theoretically having the same optimized system size in 24 Veho's properties in Finland. The third goal is to compare emissions between grid electricity and solar electricity.

## 2 Photovoltaic system review

In this chapter technical side of a PV system is going to be explained. How the system works and what does it consists of. The benefits of a PV system related to Veho's goals will be considered and theoretical emission reduction scenario will be explained. Also, the main location of the PV system optimization in Kokkola will be reviewed.

### 2.1 PV system

Photovoltaic system generates electricity from the energy of the sunlight, more specifically from the energy of photons. (Afework et al., 2020)

*“A photon is a tiny particle that comprises waves of electromagnetic radiation. As shown by Maxwell, photons are just electric fields traveling through space. Photons have no charge, no resting mass, and travel at the speed of light.”*  
(Kennedy, 2020)

Photovoltaic system consists of solar panels, inverters and other mechanical and electrical hardwares to generate electricity as seen in the simplified sketch of a PV system in figure 1. (Afework et al., 2020)

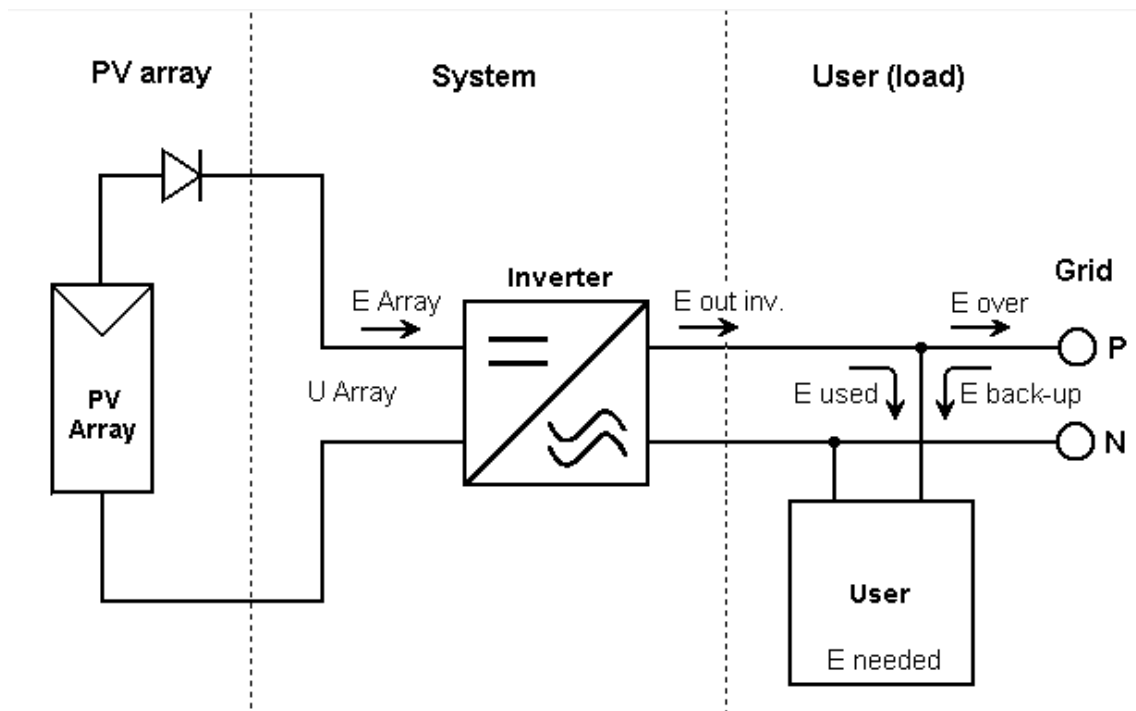


Figure 1 Simplified sketch of a PV system. (PVsyst)

Solar panel consists of solar cells which have semiconductor properties (Figure 2). (Afework et al., 2020)

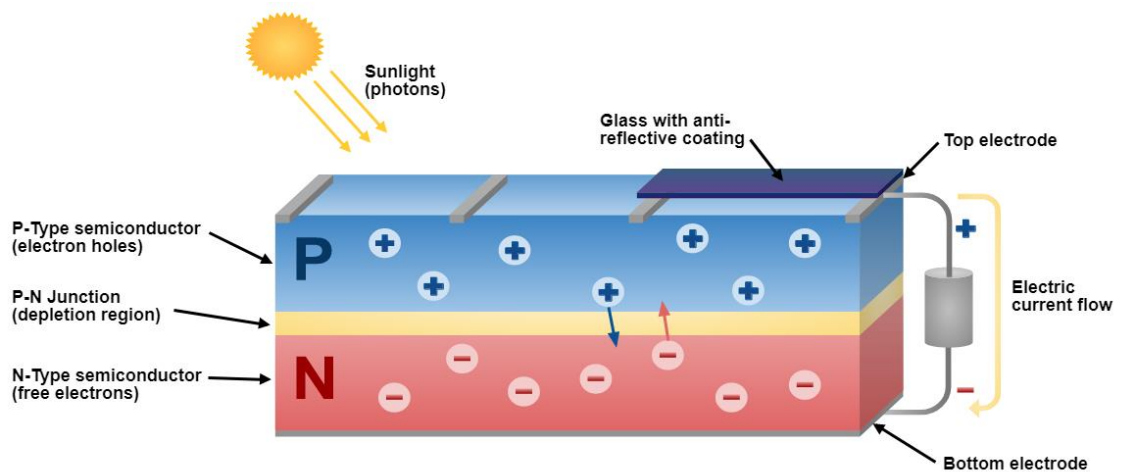


Figure 2 Solar panel's basic structure. (Hitechled 2017)

There are two layers of semiconductors on the panel (Figure 2). When photons hit the panel, they knock electrons free from atoms creating electricity with the flow of electrons. (LiveScience, 2022)

The inverter is usually considered to be the brains of the system. Inverter's task is to convert direct current DC to alternate current AC. The output of solar panel is DC, inverter changes the output to AC. Inverter uses two or more transistors to switch on and off the current extremely fast before feeding it to the transformer. In this way, direct current is converted to alternate current. In addition to DC-to-AC conversion, the inverters other tasks can include data recording and signaling, MPP tracking, and operations related to DC and AC protective devices. With advanced software, the inverter can also perform grid-supporting functions related to frequency, voltage, communication, and control. (Chintgroup, 2022) (Solarpowerworld)

## 2.2 Theoretical emission reduction of electricity

When an electricity company sells electricity, it is produced using renewable or non-renewable energy and the production may generate greenhouse gas (GHG) emissions. When an organization purchases electricity from a company which produces electricity and GHG emissions along with it, an organization is accounting these emissions in the balance of its own property. (EPA, 2021)

*“Scope 2 emissions are indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling. Although scope 2 emissions physically occur at the facility where they are generated, they are accounted for in an organization's GHG inventory because they are a result of the organization's energy use.” (EPA, 2021)*

As mentioned earlier, PV system uses renewable energy source, the sunlight (Afework et al., 2020). PV system may indirectly decrease negative effects on the environment when comparing it to the other energy sources such as purchased electricity from the grid. But

even if the panel itself is emission free when operating, there are still emissions when manufacturing the panel. As said earlier, solar panels consist of many different components such as semiconductors. These components are manufactured using materials such as rare minerals and heavy metals which must be mined and transported first. Several factors need to be considered when considering the emissions of the panel's manufacturing. What materials and how those are used when manufacturing a panel and how the panel is manufactured. (EIA, 2022) There have been done research in which greenhouse gas emissions are estimated for commercial photovoltaic systems (Mariska, 2013). Emission comparison between grid electricity and solar electricity production is done later in this work under the chapter [5.3 Justification of Kokkola's optimized PV system](#).

### 2.3 Veho Kokkola overview

Veho has a flat rooftop dealership property in Kokkola (Figure 3). The property is owned by Vehotrucks, which is focused on the sale and maintenance of trucks. The property has 14 parking lots for cars, 28 for trucks and 4 for customers total (Figure 4). (Vehotrucks)



Figure 3 Vehotrucks dealership in Kokkola.

Rooftop in the figure 4 is 42.19 m wide in horizontally and 32.48 m wide in vertically without the small overhang of the garage. The overall installation area on the rooftop is around 1370 m<sup>2</sup> for a solar panel system. According to the figure 4, there are obstacles on the roof which are not considered in this work. In practice, these obstacles would affect the type of installation.



*Figure 4 Satellite photograph of the property (picture facing north). (Google Earth)*

In the figure 4 can be seen that the building is not facing straight towards the north. This is vital information when dimensioning and installing PV system on the roof. When installing the panels to the desired direction, the angle of the building limits the length of the panel strings. Therefore, the area of the rooftop, PV system area and the angle of the building needs to be considered when installing panels to the desired direction. In this work the overall installation area is considered. The solar production simulation is done by facing the panels to the south with azimuth angle of 0° assuming that there is enough an actual installation space for the system.

In the simulations, the nominal 70 kWp PV system was the largest simulated system, because the self-sufficiency of the system is large enough for the total consumption. This system size was chosen to be the optimal with a payback-time lower than the real estate rental agreement of the property and the self-sufficiency high enough to meet the consumption and load growth in the future. The justification for this system size is later represented under the chapter [5.3 Justification of Kokkola's optimized PV system](#). 70 kWp system with generic 300 W monocrystal panels would need between a 290–390 m<sup>2</sup> area depending on the installation type. About 10 m wide vertically and 30m wide horizontally (18 modules in series and 13 strings). This size of a system would easily fit on the 1370 m<sup>2</sup> rooftop.

## 2.4 PV system criteria for the property

There are criteria for the property, when considering installing a profitable solar panel system on the roof. First, the most important factor is the location. As annual sunlight is highly dependent on this. Near the equator, the intensity of the sunlight is at its greatest. If the annual sunlight is too low, self-sufficiency decreases and pay-back time increases. (Palmetto)

The inclination and direction of the rooftop has a significant impact on the production. The highest solar production is achieved when panels are facing towards the equator. If the rooftop is flat, there is possibility to rotate the system to the south in the northern hemisphere or to the north in southern hemisphere even if the building is not facing straight towards these compass points. (Palmetto)

Trees and other obstacles create shadings on the panels reducing production of the system by blocking the sunlight. Surroundings of the building and direction of the sun needs to be considered every season of the year. (Palmetto)

Other important factors affecting solar production are temperature, fog, rain, and other weather phenomenon. Example, if there is fog in the morning, panels may be better to install at an angle for mid-day to afternoon to get the best production. (Palmetto)

The energy requirement has an impact to the size of the PV system and type of the installation. The system needs to meet the power demand of the property currently and in the future, whether the system is grid-connected or off-grid. Off-grid system would need to be more powerful than grid-connected because the grid helps in situations when there is power deficit with the PV system. (TechBullion PR)

### 3 The components of electricity price

The total electricity price consists of three distinct parts (figure 5), electrical energy price, electricity transfer price, electricity tax and value added tax (VAT). In addition to the wholesale market price of electricity, the price of the electricity also includes selling costs such as invoicing costs, marketing costs, customer service and administration costs. (Heinimäki)

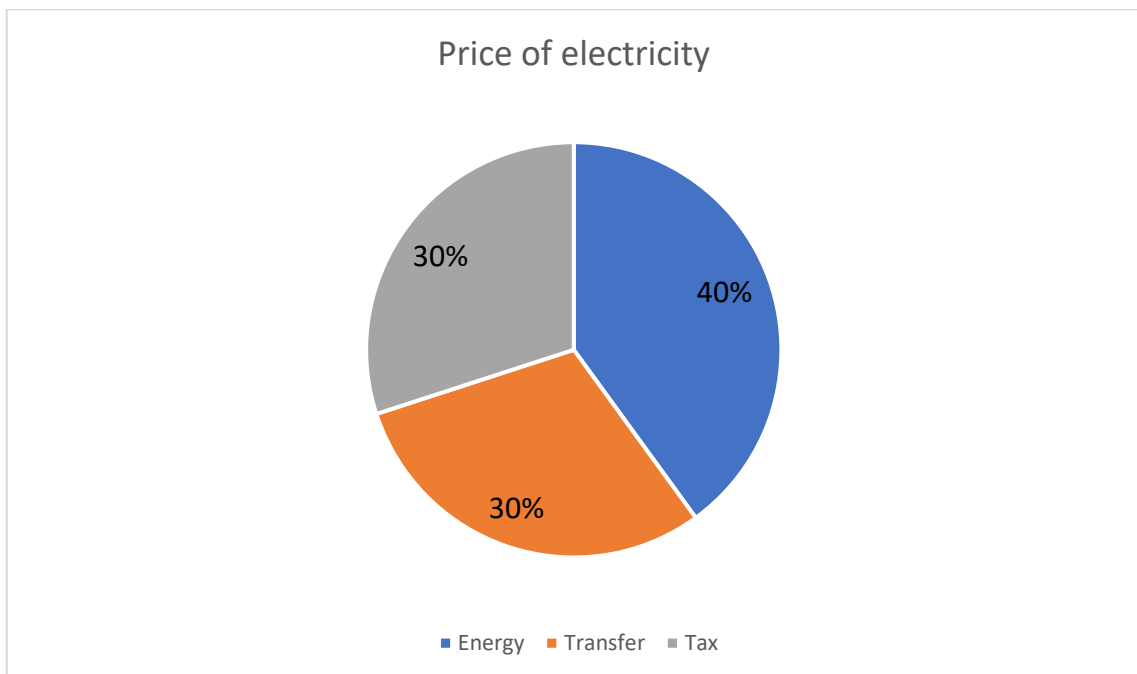


Figure 5 The components of electricity price. (Helen)

The total electricity transfer price consists of the price of electricity transfer and various taxes. The customer pays the electricity tax in the same invoice in which the customer pays for the grid service. (Heinimäki)

With the transfer price the electricity company covers the service costs related to the grid operations. Such as capital committed to the grid, maintenance, development, and renewal of the grid, as well as construction of a completely new grid. Also, service costs include

monitoring of the grid usage, fault service 24 hours around a day and repair of faults, measurement of electricity consumption, as well as customer phone and internet services. In addition, the costs include the costs of constructing and maintain the national grid. (Heinimäki)

There are many things that affects the electricity price such as the price of oil and gas, consumption, weather, emission rights prices, the amount of nuclear power generation and water reserves. For example, in the Nordic countries, hydropower is widely used to produce electricity. Dry weather conditions lower water reserves and reduces hydropower production, thereby increasing the price of electricity. Also, if the electricity production generates carbon dioxide emissions, the electricity company needs to purchase emission rights which are directly correlated to the price of electricity. (Sijoittaja, 2022)

## 4 Optimized PV system overview

In this chapter the simulations and the calculations are represented. Also, assumptions and contractual information are represented before the results. The effects of the optimized PV system in Kokkola are shown with graphs and explanations. After representing the effects in Kokkola, the PV system is then represented in Olari, Raasepori, and Kurzemes prospekts in Latvia.

### 4.1 Simulations

As mentioned earlier, solar production is simulated with PVsyst software in the location because it is designed to be used by architects, engineers, and researchers and is already a familiar software from university courses. Dimensioning the PV system in PVsyst software begins with selecting the location. System information such as panel and inverter types are entered depending on the requirements for the system (figure 6). Then the angle of the panels to the south (azimuth) and the angle between the ground and the panel (tilt) are calibrated by calculating the annual production with different angles. After the calibration the production in the location can be simulated. (PVsyst)

The following panel and inverter types were selected for the system, Generic 300 W 27 V SI-mono solar panel and 30 kW 450–700 V LF Tr 50 Hz inverter due to the availability and recommending by the software. There are 18 modules in series and 13 strings in the system. (Figure 6)



Table 1 Angle calibration parameters.

Parameter	Min	Max	Steps	Unit
Tilt	30	55	5	[deg]
Azimuth	-90	90	5	[deg]

In the figure 7 the software displays the annual maximum production with colour scaling. X-axis is tilt angle and Y-axis is azimuth angle.

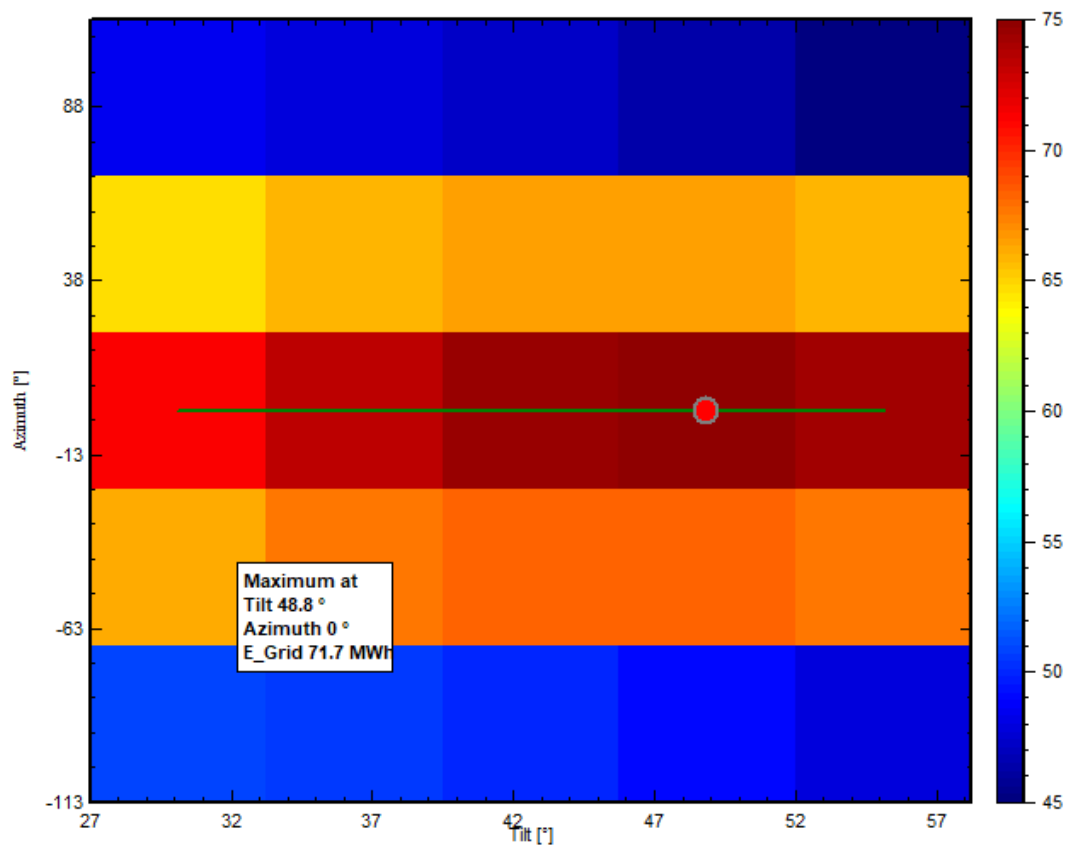


Figure 7 Kokkola angle calibration. (PVsyst)

In the figure 7 can be seen that the maximum annual production in Kokkola is achieved with the parameters: tilt = 48.8° and azimuth = 0°. This much of tilt is not typically used in a flat roof installation. This same calibration procedure is done with the other sites in Olari, Raasepori and Latvia to get the best production in the locations.

## 4.2 Assumptions and contractual information

Few noteworthy assumptions and contractual information are needed to be represented before representing the calculations and results.

Active- and reactive power consumption data were included to the calculations on a monthly level where total electricity consumption was included on an hourly level due to lack of granular data. Simulated solar electricity only decreases purchased electricity from grid on an hourly level in the calculations, which means that the solar electricity does not affect active- and reactive power transfer costs on a monthly level in the calculations. These transfer costs stay the same as there were no PV system at all. Solar electricity also most likely decreases the power peaks in practise.

Also, EV fleet charging data in Kokkola were added on a monthly level as an incomplete data. A few months' data were missing, which were duplicated from the already existing data. The reason could simply be the incomplete recording of data from the new charging stations' meters in Kokkola.

The Nord pool group has given a temporary access to their data for this thesis, and Helsinki-prices in ELSPOT (day-ahead market) on an hourly level were used as the wholesale price of electricity in the calculations. SPOT prices are electricity exchange purchase prices that vary hour by hour according to supply and demand and affect the price charged by the electricity company to the customer (Lumo).

Contract calculations consists of purchasing electricity with the prices in the contract and selling with the wholesale prices in the ELSPOT in 2020 and 2021. The idea behind the SPOT prices is that 2020 prices were low and 2021 were high compared to the average of a few years at that time. The low levels of 2020 SPOT prices probably won't be seen for a while, but power prices could decrease from 2021 levels as countries add more renewable

energy capacity due to especially wind power being cheap in the Nordic countries. SPOT price calculations consist of the same parts but instead of energy fee, ELSPOT prices were used. (Figure 8)

Purchase		Sale	
Contract	Spot	Contract	Spot
Energy fee	2020/2021 Elspot price	2020/2021 Elspot price	2020/2021 Elspot price
Green energy fee	Green energy fee	Sale commission	Sale commission
Electricity marginal fee	Electricity marginal fee		
Seasonal transfer fee	Seasonal transfer fee		

Figure 8 Components in electricity purchase and sale scenarios on an hourly level. Does not include VAT.

Also, every Veho's site considered in this thesis (Kokkola, Olari, Raasepori) in Finland does have their own contract information in the calculations which differ from one another. (Figure 8)

The electricity companies can charge a sale commission when the customer is selling overproduction to them (Figure 8). In Kokkola the electricity company Kokkolan Energia pays the wholesale price of electricity from which the sale commission 0.2 c/kWh is deducted when selling the overproduction (Kokkolanenergia). In another locations in Olari and Raasepori the electricity company Väre does not charge a commission (Väre).

When overproduction is fed to the grid by a small producer, distribution company can charge a service fee of a maximum of 0.07 c/kWh (VAT 0 %). Distribution companies in the

locations used in this work do not have the information on their websites that they charge for feeding to the grid, so it is assumed that there is no charge. (Motiva 2)

When small producer sells the overproduction to the electricity company occasionally, it is not considered to be an economic activity as defined in the VAT Act and Directive, and therefore no VAT is charged. The overproduced electricity must be viewed like any other good that a private operator can produce for itself and occasionally sell if there is overproduction. (KHO)

#### 4.3 Price of the PV system

The system price calculation was done using the National Survey Report of PV power applications in Finland. The reports focus on the development of the PV market in a defined country, the R&D activities, the support policies, its industry, and further information. These reports are used as a base for the annual “Trends in PV applications” report (IEA-PVPS). The report included the turnkey price intervals (excluding VAT and permitting cost) collected from Motiva and two major PV systems providers operating in Finland. Small commercial building applied photovoltaics (BAPV) 10–100 kW 0.8–1.05 eur/W category was used (excluding VAT and permitting cost). The price average 0.925 eur/W was used in the calculations although it changes logarithmically, and the system costs also vary depending on the installation method. In the table 2 can be seen the used turnkey prices in the final calculations. (Ahola, 2019)

*Table 2 Turnkey prices of different size of systems. (Excluding VAT and permitting cost)*

<b>Size (kW)</b>	<b>System price (€)</b>
18,00	16650,00
30,00	27750,00
39,90	36907,50
50,40	46620,00
60,00	55500,00
70,20	64935,00

In the table 3 can be seen calculated payback-times with the price average 0.925 eur/W used in the final calculations and in the table 2. These payback-times do not include the investment support received by the company.

*Table 3 Payback-time calculations with 0.925 eur/W average price used.*

<b>0,925 e/W</b>	<b>Paypack-time contract (y)</b>		<b>Paypack-time 2020 (y)</b>	<b>Paypack-time 2021 (y)</b>
<b>Size (kW)</b>	<b>2020 SPOT</b>	<b>2021 SPOT</b>	<b>2020 SPOT</b>	<b>2021 SPOT</b>
18,00	4,6	4,6	12,6	7,9
30,00	5,2	5,1	14,2	8,8
39,90	6,1	6,0	16,7	10,2
50,40	6,9	6,8	19,1	11,6
60,00	7,8	7,6	21,4	12,9
70,20	8,7	8,5	23,9	14,3

Although the price average 0.925 eur/W was used, the effect of the price change was also calculated. In the table 4 can be seen the lowest price 0.8 eur/W used in the payback-time calculations.

*Table 4 Payback-time calculations with 0.8 eur/W average price used.*

<b>0,8 e/W</b>	<b>Paypack-time contract (y)</b>		<b>Paypack-time 2020 (y)</b>	<b>Paypack-time 2021 (y)</b>
<b>Size (kW)</b>	<b>2020 SPOT</b>	<b>2021 SPOT</b>	<b>2020 SPOT</b>	<b>2021 SPOT</b>
18,00	4,0	3,9	10,9	6,8
30,00	4,5	4,4	12,3	7,6
39,90	5,2	5,2	14,4	8,8
50,40	6,0	5,9	16,5	10,0
60,00	6,7	6,6	18,5	11,1
70,20	7,5	7,3	20,6	12,3

In the table 5 can be seen the highest price 1.05 eur/W used in the payback-time calculations.

Table 5 Payback-time calculations with 1.05 eur/W average price used.

1,05 e/W	Paypack-time contract (y)		Paypack-time 2020 (y)	Paypack-time 2021 (y)
Size (kW)	2020 SPOT	2021 SPOT	2020 SPOT	2021 SPOT
18,00	5,2	5,2	14,3	9,0
30,00	5,9	5,8	16,2	10,0
39,90	6,9	6,8	19,0	11,6
50,40	7,9	7,8	21,7	13,2
60,00	8,8	8,7	24,3	14,7
70,20	9,9	9,7	27,2	16,4

From the previous tables can be seen that the payback-time changes between 1.2–6.6 years between the lowest 0.8 eur/W price and the highest 1.05 eur/W price. This is huge difference, which means that the eur/W price of the PV system greatly affects the payback-time.

In the figure 9 can be seen the payback-times represented earlier with a goal-line which represents the duration of the property's rental period. As represented earlier in the figure 8, contract 2020 means purchasing electricity from the grid at Veho's current contract price and selling the overproduction to the grid at 2020 SPOT prices. Contract 2021 is almost the same, but instead of selling at 2020 prices, 2021 prices are used. 2020 SPOT means purchasing and selling at 2020 SPOT prices. 2021 SPOT is the same, but at 2021 prices.

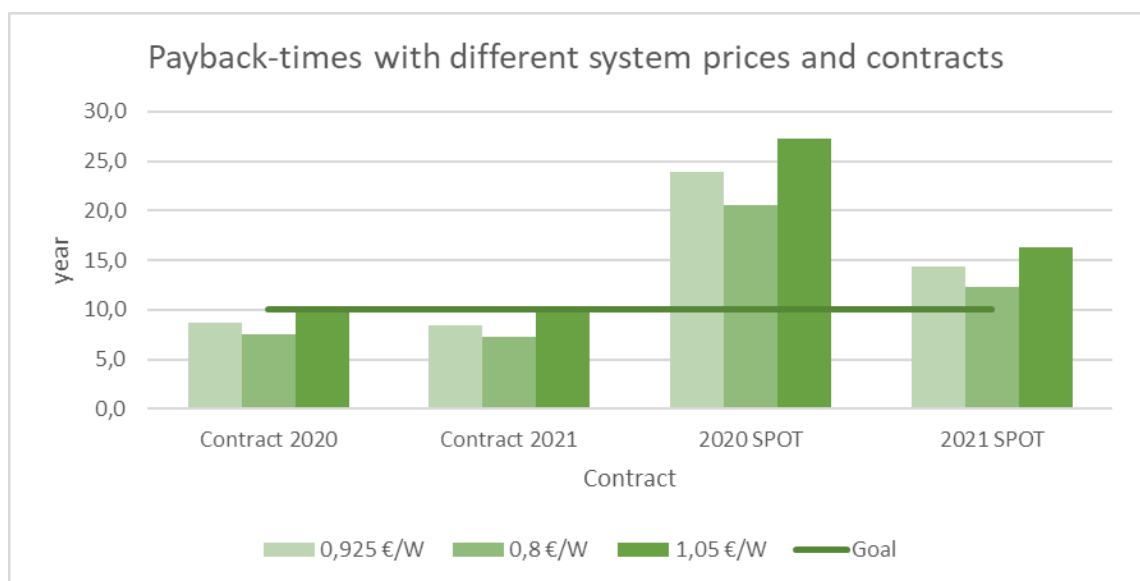


Figure 9 Payback-times with different system prices and contracts.

In the figure 9 the payback-times which stays under the goal-line are in the good area, which means that the system can pay back the investment before the rental period of the property ends. The figure 9 shows that when purchasing electricity at Veho's current contract and selling at both 2020 and 2021 SPOT prices, the payback-times stays under the goal-line. This means that the scenario is more ideal with Veho's current contract than the scenario in which purchasing and selling happens at SPOT prices.

#### 4.4 Financial effects of the PV system on property's electricity costs

As mentioned earlier in this thesis, PV system reduces purchased electricity from the grid with self-produced electricity. In the figure 10 can be seen how much the nominal 70 kWp PV system reduces the energy demand comparing to the original demand without a PV system in Kokkola. This is the basic idea with PV systems. The reduction is the most important factor when considering savings and the payback-time of the system. Overproduction sales are usually a fraction of the savings, although they do affect the savings. But the biggest benefit comes from the reduction of purchased electricity from the grid.

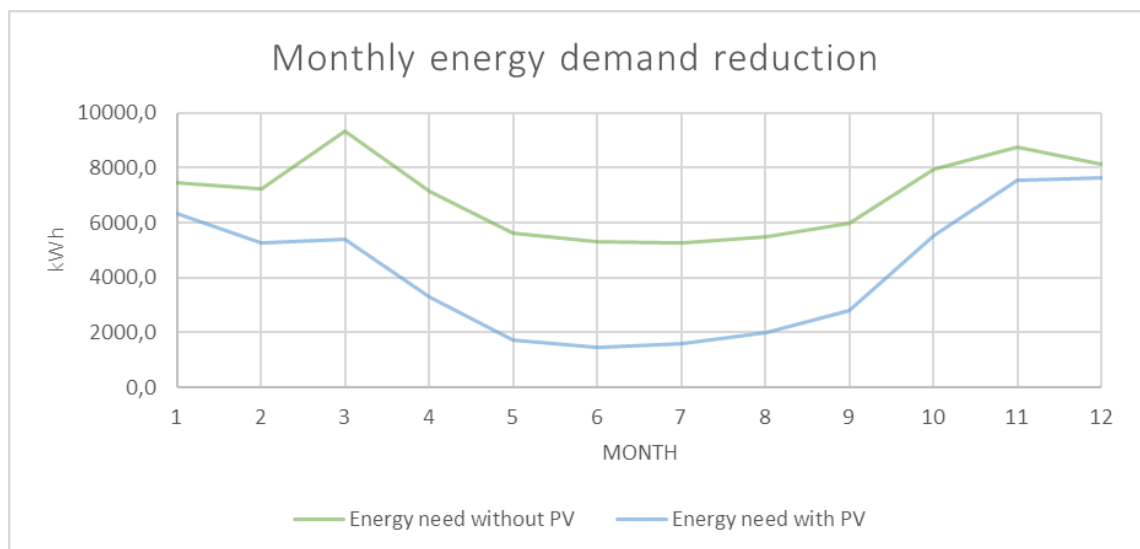


Figure 10 Monthly energy demand reduction with PV system in Kokkola.

In the figure 10 can be seen that in the summer months the reduction is greater than in the winter months due to the higher intensity of the sunlight and the production of the system in summer months.

As mentioned earlier under the chapter [4.2 assumptions and contractual information](#), electricity SPOT prices are electricity exchange purchase prices that vary hour by hour according to supply and demand and affect the price charged by the electricity company to the customer (Lumo). The difference between a SPOT price and Veho's contract energy price is that Veho's energy price is fixed. This means that if electricity supply and demand vary, SPOT prices will also vary, but Veho's contract energy price will remain unchanged.

Figure 11 shows the monthly electricity bill with Veho's contract and SPOT prices. The bill includes everything that Veho currently pays in its electricity bill in Kokkola. The idea of the figure is that electricity is purchased at fixed price in Veho's current contract and sold at the SPOT prices of years 2020 and 2021. As mentioned earlier under the chapter [4.2 assumptions and contractual information](#), 2020 prices were low and 2021 were high when compared to the average of a few years at that time.

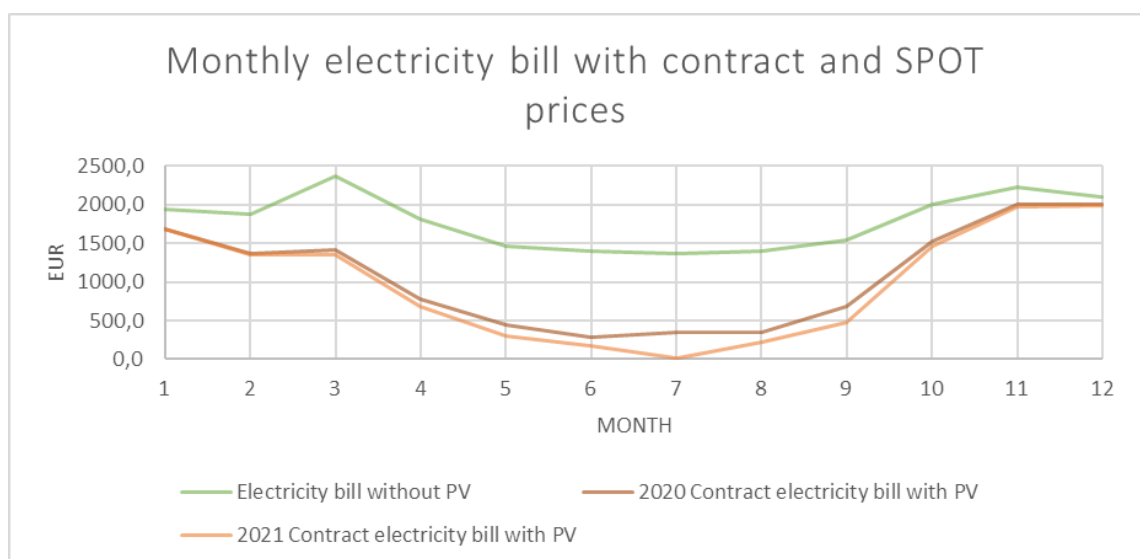


Figure 11 Monthly electricity bill reduction with contract and SPOT prices in Kokkola. The overproduction sales have been added to the reduction of the electricity bill.

Figure 11 shows that at the prices of 2021, the electricity bill is lower due to the sales at high SPOT prices when comparing to the low SPOT prices of 2020. In the figure 11 can also be seen that the electricity bill with 2021 SPOT prices is close to zero in July. This is due to high self-production in summer months which decreases the need of purchasing electricity from the grid. And the overproduction is sold to the grid at high 2021 SPOT prices, from which the monthly electricity bill is reduced with sales profits. The remaining needed energy is purchased at a fixed price according to the contract.

Figure 12 shows the monthly electricity bill with 2020 SPOT prices. Electricity is both purchased and sold at a SPOT price. The difference between purchasing and selling costs are represented earlier in the figure 8. In purchasing part, there are more cost fees and marginals than in the selling part, where the customer receives only the wholesale price of electricity. The customer also must pay the sale commission when selling overproduction to the electricity company.

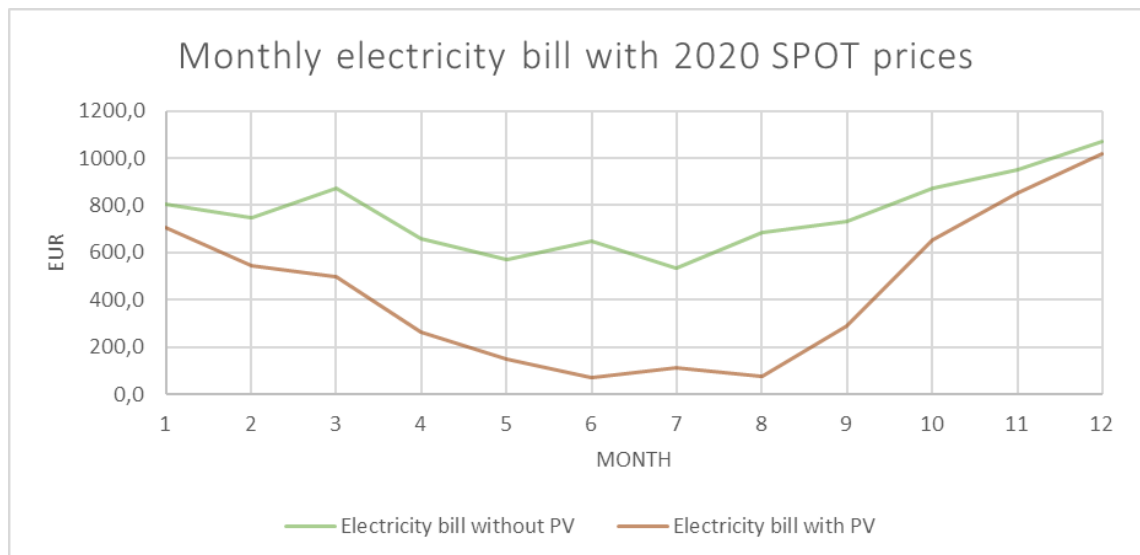
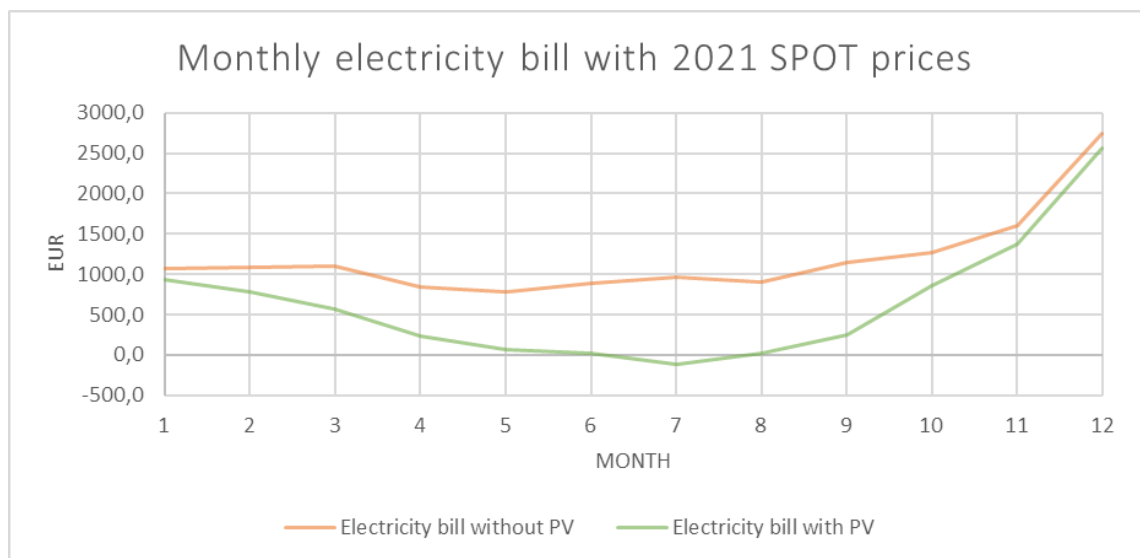


Figure 12 Monthly electricity bill reduction with 2020 SPOT prices in Kokkola. The overproduction sales have been added to the reduction of the electricity bill.

In the figure 13 can be seen the monthly electricity bill with 2021 SPOT prices. As represented earlier, 2021 was a year of high prices. The electricity is purchased and sold at a high price. Therefore, the electricity bill in the figure 13 differs from the figure 12. The figure 13 shows a sharp rise towards the end of the year. This is because the SPOT prices rose even more at the end of 2021. In the summer months, the electricity bill goes to the negative side which means that the customer is receiving more money with high overproduction sales than paying for the electricity from the grid. The customer simply remains on the winning side in terms of costs in this situation.



*Figure 13 Monthly electricity bill reduction with 2021 SPOT prices in Kokkola. The overproduction sales have been added to the reduction of the electricity bill.*

In the figure 14 can be seen the monthly electricity bill with different contracts. Figure 14 shows the earlier represented figures in a one figure. When purchasing and selling electricity at low SPOT prices of the year 2020, the monthly electricity bill is the lowest on average. At high SPOT prices of the year 2021, the electricity bill is the second lowest. This is purely because Veho has a fixed energy price in the contract, which is on average higher than the SPOT prices on average of both years.

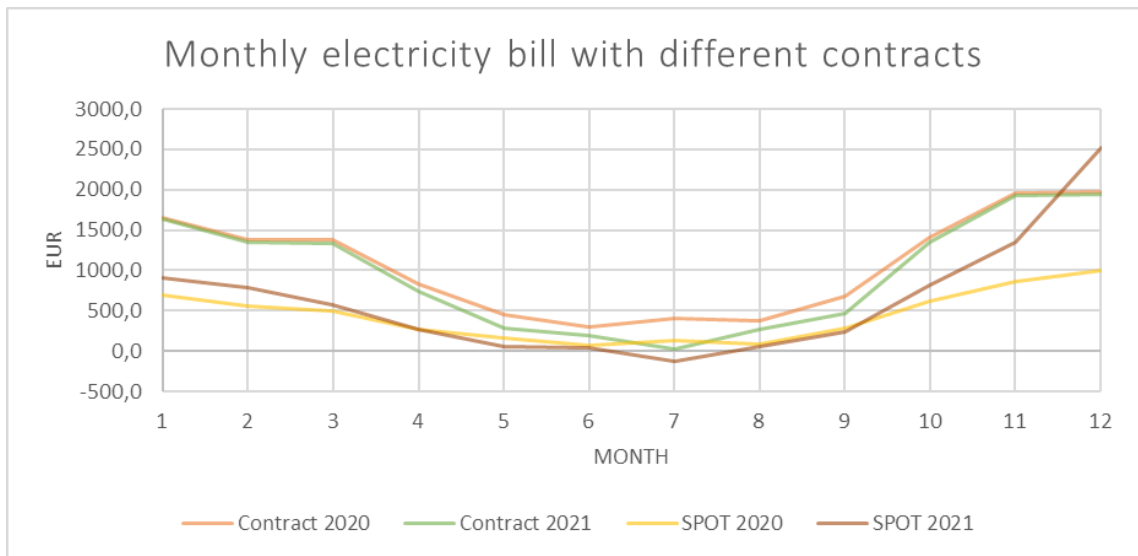


Figure 14 Monthly electricity bill with different contracts in Kokkola. The overproduction sales have been added to the reduction of the electricity bill.

In the figure 14 during the winter months, the big difference between Veho's contract electricity bill and SPOT price electricity bills is due to the low solar production and Veho's high energy price in the contract. As mentioned earlier, when there is low solar production, the need of purchasing electricity from the grid is greater.

Figure 15 shows the savings on purchased electricity with different contracts. Savings consists of the difference between electricity purchase with and without the PV system (formula 1). Sales are included in the savings. Overproduction sales are calculated using high 2021 and low 2020 SPOT prices.

$$\text{Savings} = (\text{Contract base purchase} - \text{Contract purchase}) + \text{Sales} \quad (1)$$

$$= (\text{Purchase without PV system} - \text{Purchase with PV system}) + \text{Sales} \quad (1)$$

In the figure 15 can be seen that the biggest savings comes from Veho's current contracts when sales are calculated with SPOT prices. This happens due to the high base purchase with Veho's contract without the PV system. SPOT prices have lower gap between the base purchase without the PV system and purchase with the PV system because the base purchase

is already lower compared to the Veho's contract base purchase. Also, purchase reduction with the PV system at SPOT prices is no more than at Veho's contract prices. This is purely because Veho has a fixed energy price in the contract, which is higher than the average of SPOT prices of both years.

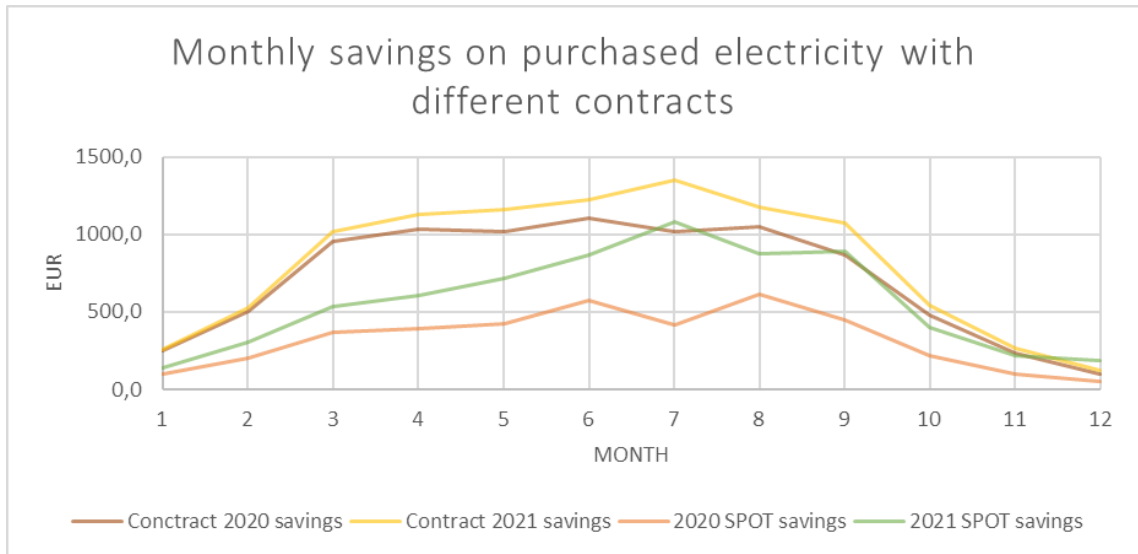


Figure 15 Savings on purchased electricity with different contracts in Kokkola. The overproduction sales have been added.

Figure 26 shows the annual self-sufficiency with different PV system sizes in Kokkola. The annual self-sufficiency is based on hourly level in the calculations. The curve behaves logarithmically, and the increase of the self-sufficiency slows down when the system size increases.

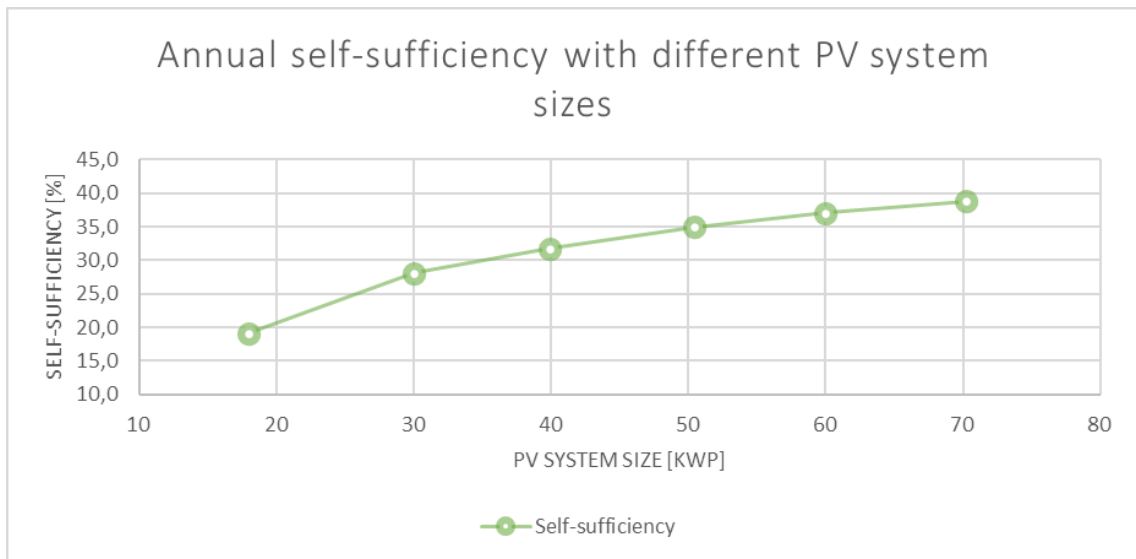


Figure 16 Annual self-sufficiency with different PV system sizes in Kokkola.

In the figure 17 can be seen the annual savings with different contracts and PV system sizes. Savings consists of the difference between electricity purchase with and without the PV system (formula 1). Sales are included in the savings.

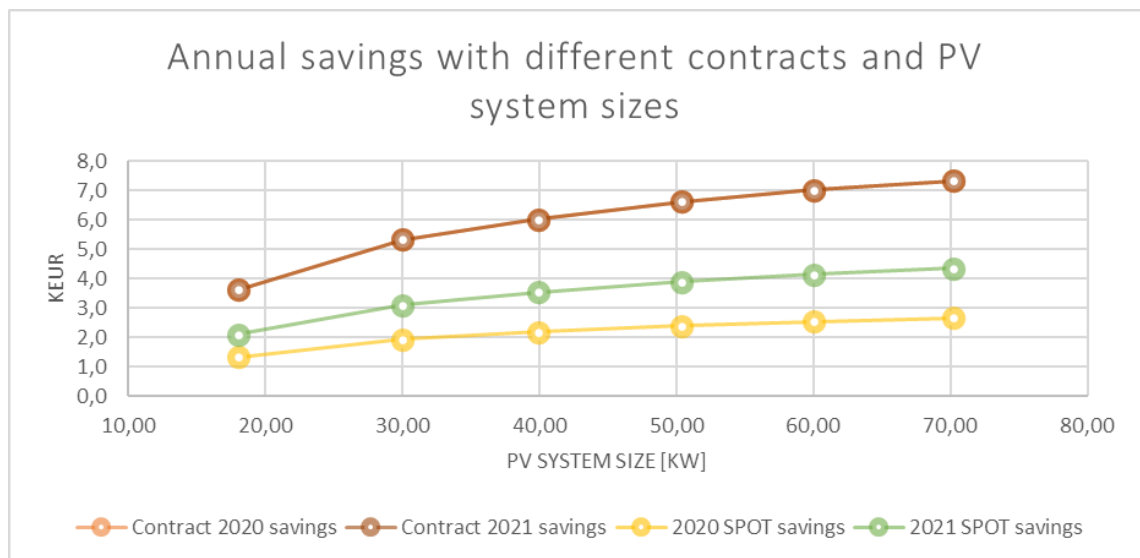


Figure 17 Annual savings with different contracts and PV system sizes in Kokkola. The overproduction sales have been added.

Figure 18 shows the payback-times with different PV system sizes in Kokkola. The payback-times are calculated with the annual savings represented above. The payback-time is the

lowest with the Veho's contract 2021, when the overproduction is sold at high SPOT price. The curves behave logarithmically and slow down the descent, even if the size of the system is reduced. As mentioned earlier, the 70 kWp system was chosen to be optimal with a payback-time lower than the real estate rental agreement of the property and the self-sufficiency high enough to meet the consumption and load growth in the future.

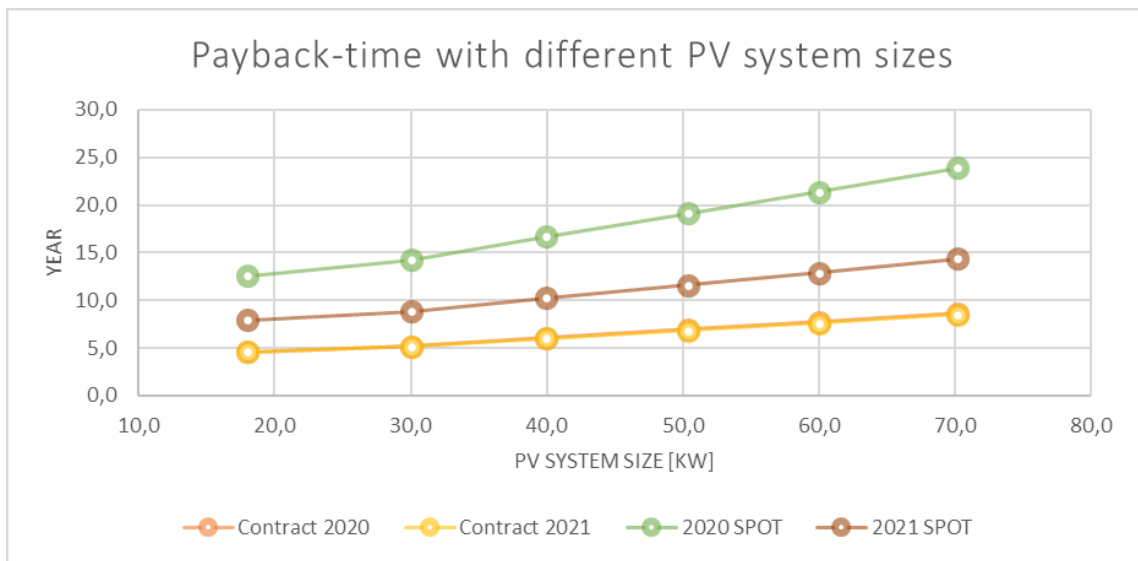


Figure 18 Payback-time with different PV system sizes in Kokkola. Table 2 system prices are used.

In the figure 19 can be seen the payback-times with calculated self-sufficiencies. Figure 19 is completely the same as earlier figure 18, but instead of system sizes, the payback-times are represented with the calculated self-sufficiencies. The large gap in the data points is due to the hard-to-obtain exactly nominal 20kWp system in the simulations.

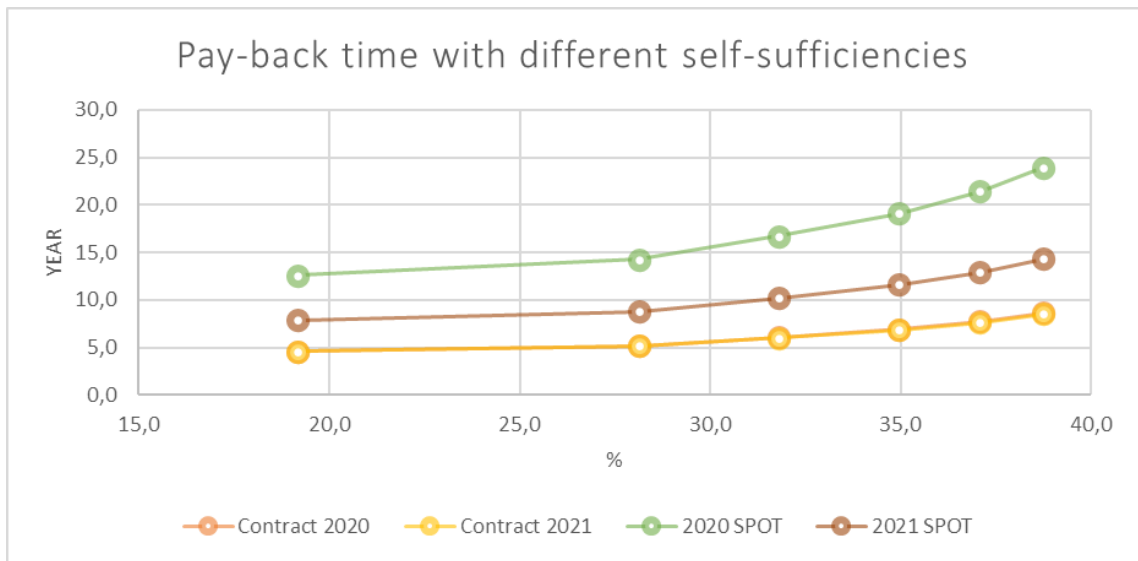


Figure 19 Payback-time with different self-sufficiencies in Kokkola. Table 2 system prices are used.

#### 4.5 Location comparison

The same nominal 70 kWp PV system in Kokkola is compared between other Veho's dealerships in Olari, Raasepori, and in Kurzemes prospekts in Latvia. The calculations are done using electricity data of each building including power transfer and contractual information, and solar production data is simulated in each location separately. A 70kWp system is not ideally sized for these locations, which results in less savings than optimal. This section demonstrates why each building will need its own carefully sized PV system. The section also demonstrates how the location impacts production due to capacity factors being higher further south. Capacity factor is a measure of how much energy is produced by PV system compared to its maximum output (NREL). As represented earlier, solar panel angles are calibrated in each location to get the maximum production throughout the year.

##### 4.5.1 Olari

In the figure 20 can be seen the effect of the PV system in Olari. Energy demand reduction is little compared to Kokkola due to the large consumption in Olari. With 70 kWp system the self-sufficiency is only about 6.7 % in Olari. Also, the location effects the sunlight intensity throughout the year.

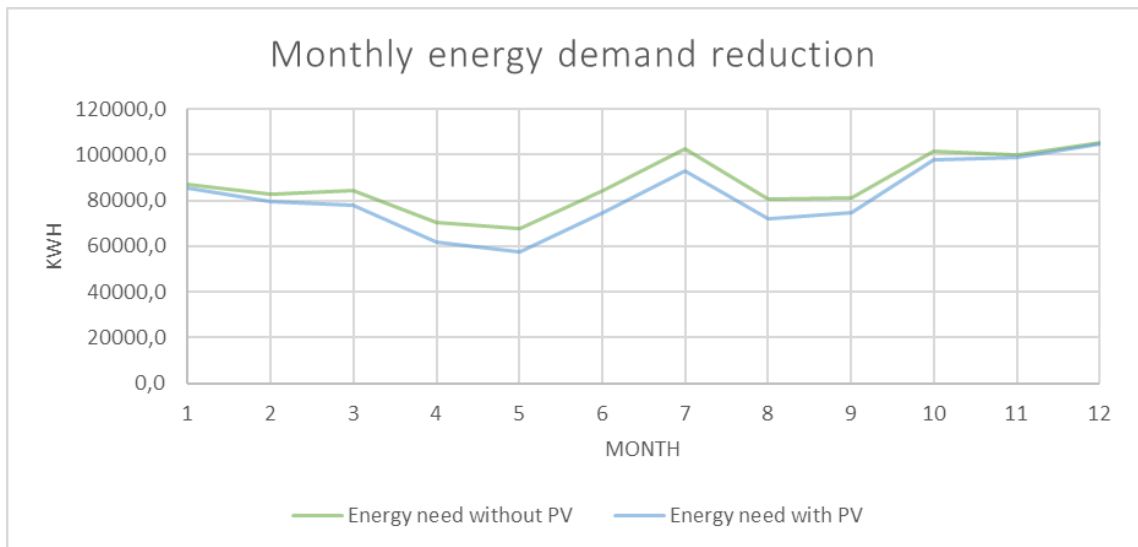


Figure 20 Monthly energy demand reduction in Olari.

Figure 21 shows the monthly electricity bill with different contracts in Olari. The bills are high due to the high consumption and small PV system size. The system does not significantly affect the electricity bill in Olari. Red curve (SPOT 2021) is rising out of the figure because at the end of the year 2021, SPOT prices rose even more.

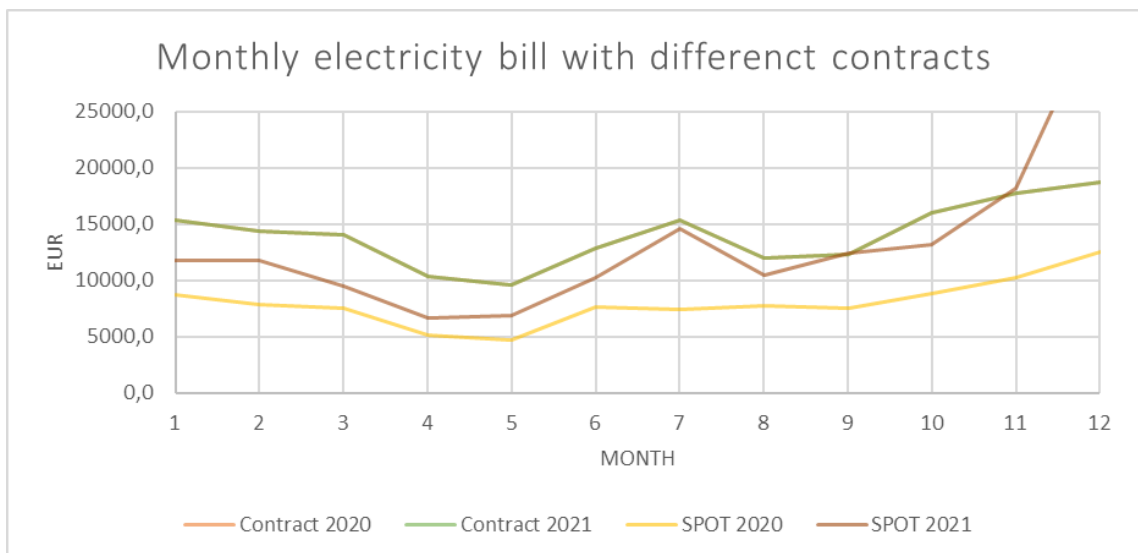


Figure 21 Monthly electricity bill with different contracts in Olari. The overproduction sales have been added to the reduction of the electricity bill.

Figure 22 shows the monthly savings on purchased electricity with different contracts in Olari. Also, savings are small due to the high consumption in Olari. In fact, the annual consumption is so big that there are no overproduction sales with 70 kWp system size in Olari. All the self-produced electricity goes to own use.

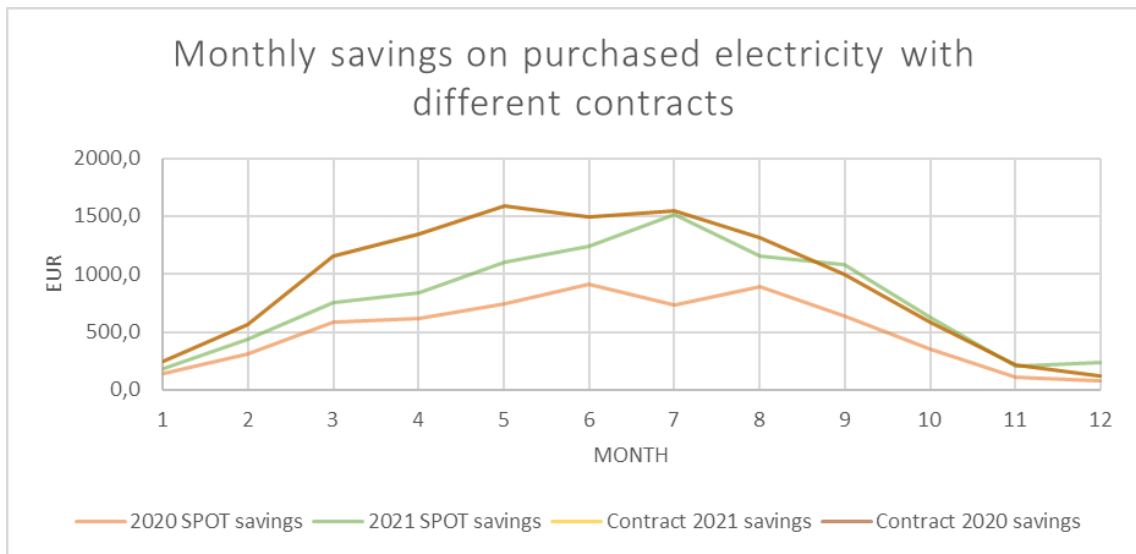


Figure 22 Savings in purchased electricity with different contracts in Olari. The overproduction sales have been added.

#### 4.5.2 Raasepori

Raasepori is one of the dealerships closest to Kokkola in terms of consumption. This can be seen in the figure 23. The 70 kWp system reduces more the energy demand compared to Olari. The annual self-sufficiency is about 21.6 % with this system size in Raasepori.

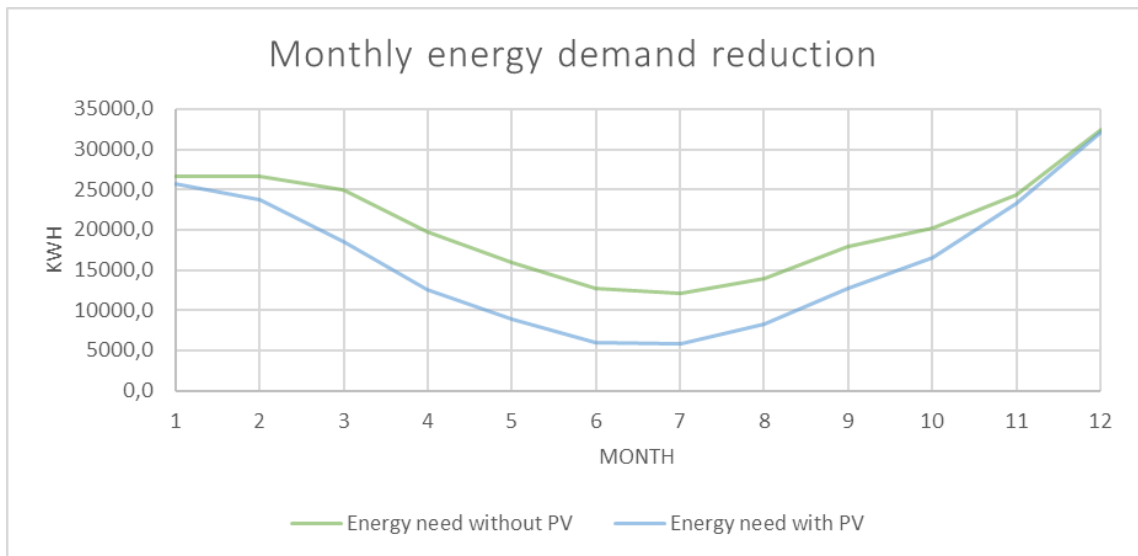


Figure 23 Monthly energy demand reduction in Raasepori.

Figure 24 shows the monthly electricity bill with different contracts in Raasepori. Because of the lower consumption than in Olari, 70 kWp system reduces the electricity bill more in Raasepori but not as much than in Kokkola. Red curve (SPOT 2021) is rising out of the figure because at the end of the year 2021, SPOT prices rose even more.

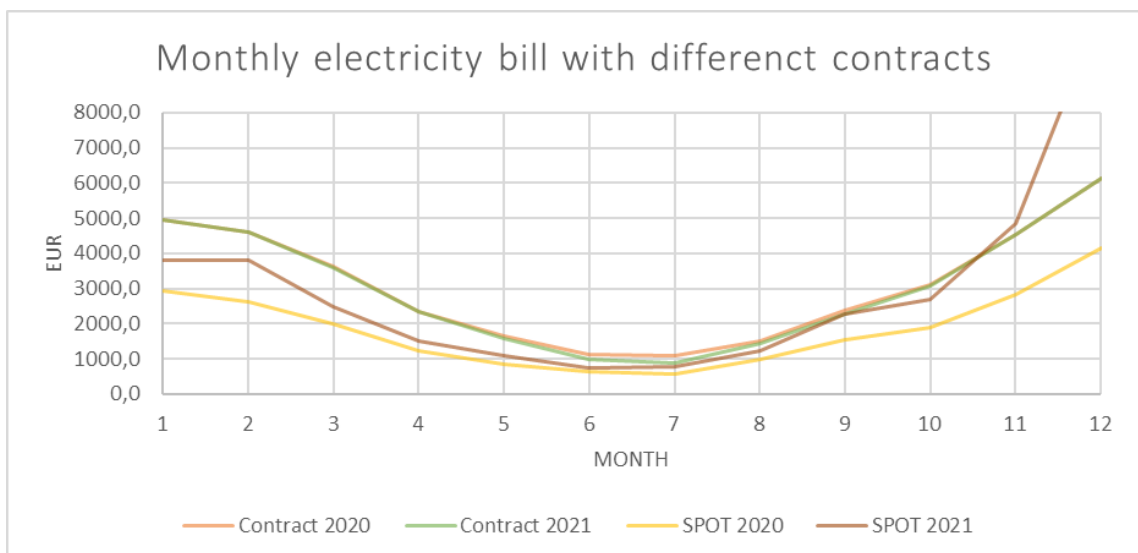


Figure 24 Monthly electricity bill with different contracts in Raasepori. The overproduction sales have been added to the reduction of the electricity bill.

Figure 25 shows the monthly savings on purchased electricity with different contracts in Raasepori. The savings are closer to Kokkola than Olari because the annual consumption is closer to Kokkola than to Olari. Also, there are overproduction sales in Raasepori due to the lower consumption of the property than in Olari where there is no overproduction at all with 70 kWp system size.

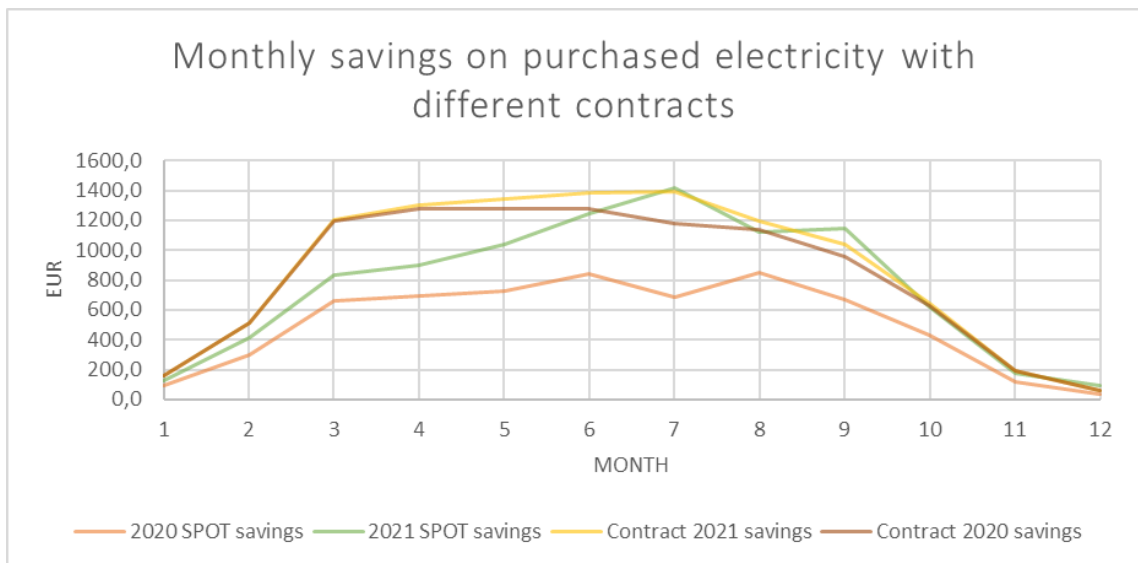


Figure 25 Savings in purchased electricity with different contracts in Raasepori. The overproduction sales have been added.

#### 4.5.3 Latvia

In the figure 26 can be seen the effect of the PV system in Kurzemes prospekts in Latvia. Energy demand reduction is little compared to Kokkola due to the large consumption in Kurzemes prospekts. With 70 kWp system the self-sufficiency is only about 10.7 % in Kurzemes prospekts. Also, the location effects the sunlight intensity throughout the year.

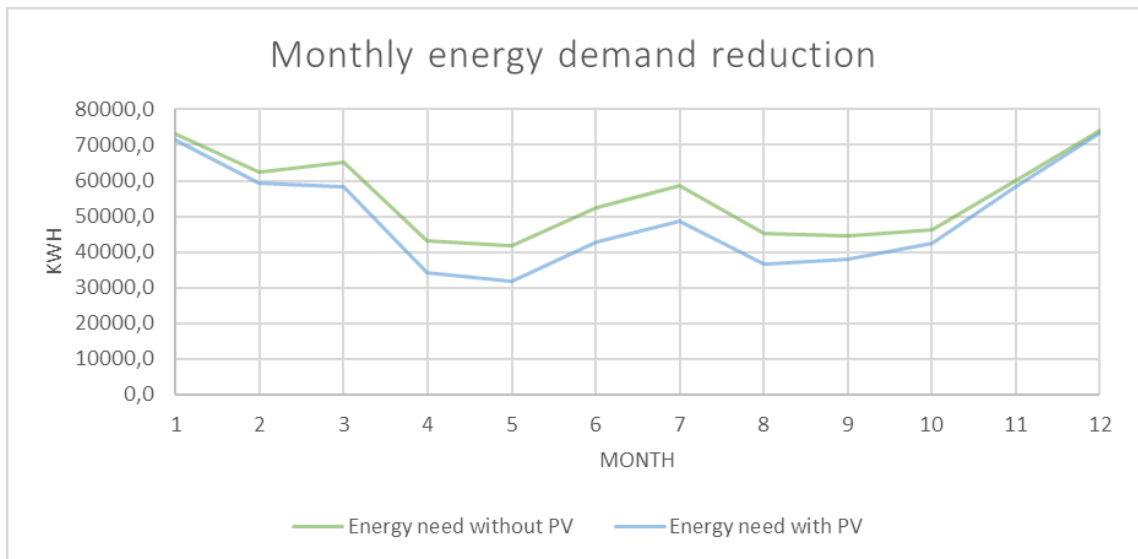


Figure 26 Monthly energy demand reduction in Kurzemes prospekts in Latvia.

When comparing Kurzemes prospekts and Olari, the energy demand reduction in Kurzemes prospekts is greater than in Olari due to the higher sunlight intensity in the location. Also, the lower consumption in Kurzemes prospekts leads to higher self-sufficiency with 70 kWp system than in Olari.

In the figure 27 can be seen the energy demand reduction with Latvia's production in Kokkola. The idea of the figure is to show how much greater the solar production is in further south. With the 70 kWp system, the self-sufficiency in Kokkola rises about 0.65 % with Latvia's solar production when comparing to the Kokkola's solar production. Also, capacity factor rises from 11.35 % to 11.44 %. As mentioned earlier, capacity factor is a measure of how much energy is produced by PV system compared to its maximum output (NREL).

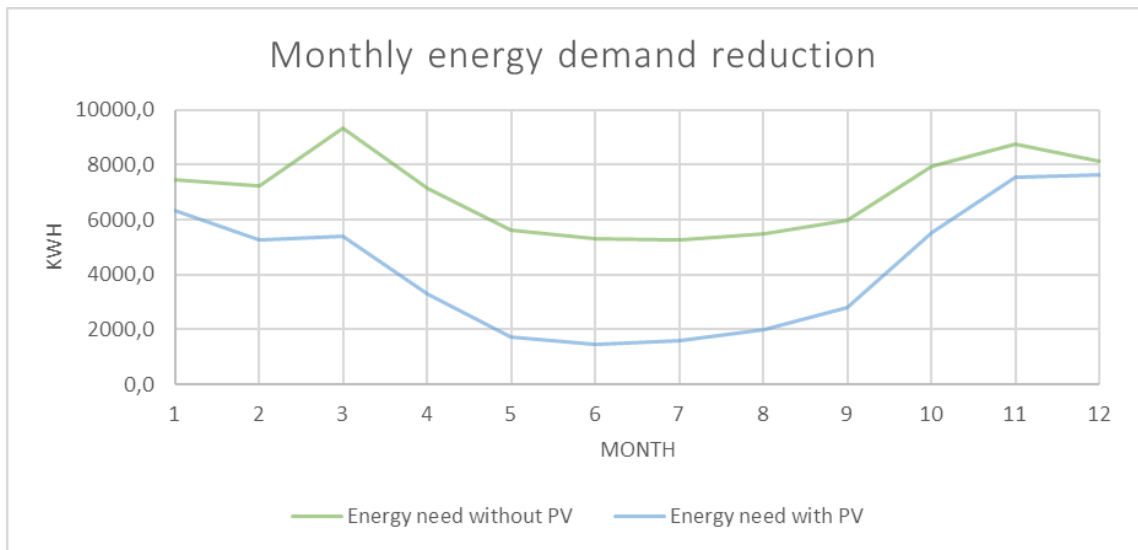


Figure 27 Monthly energy demand reduction with PV system and Latvia's solar production in Kokkola.

When comparing Kokkola's energy demand reduction in the figure 27 with Latvia's production and in the figure 10 with Kokkola's production, can be seen that the PV production is more profitable further south as mentioned earlier under the chapter [2.4 PV system criteria for the property](#). With the information represented, can be seen that it is important to optimize the PV system for each location correctly.

## 5 EV fleet charging

In this chapter, an EV fleet (an electric vehicle) charging is considered through theoretical scenarios. Also, the results of the EV fleet calculations are represented. An EV fleet is an electric vehicle which runs partly or fully by an electric motor (GEOTAB). An EV fleet has a battery from which the vehicle takes the energy needed by the electric motor to operate and are therefore a type of energy storage on wheels. Some newer types of electric vehicles have the capability to discharge electricity from their battery through so called “vehicle-to-grid” technologies such as Mitsubishi Outlander PHEV. However, as vehicle-to-grid is still an uncommon feature on electric vehicles, this type of energy storage is not considered in this thesis. (EVConnect, 2020)

### 5.1 Timing of EV charging

Optimal scenario for EV fleet charging would be at daytime when there is solar electricity production. There wouldn't be need to purchase electricity from grid with the extra price components mentioned earlier under the chapter [3. The components of electricity price](#). With the self-produced electricity, costs such as monthly fees, energy fee, and transfer fees could be saved. This scenario obviously requires large enough system producing the energy demand to be fully self-sufficient.

Depending on the electricity price, less optimal scenario is to charge at nighttime with electricity purchased from the grid or with self-produced solar electricity stored with an alternative energy storing methods. There are few options to store the self-produced energy. First, the most common is physical battery technology. Produced electricity is stored to a battery storage from which the electricity can be used later. There are countless number of batteries with varied sizes, capacities, and prices on the market. When there is no solar production, the battery can be recharged from the grid when the electricity exchange price is low and discharged when the price is high. Downside of the physical battery is its lifetime

costs. The battery needs to be replaced after the lifetime of the battery is reached. (Martikainen, 2020)

Another option for charging at nighttime is to purchase virtual battery contract from the electricity company. In this contract the customer gives the overproduction to the grid into a virtual battery (to the company). This option could be used the same way as with the physical battery. In these contracts the customer can get the same amount of electricity back with same price or a discount from the purchased electricity. Typical conditions are that the customer is charged with a contract monthly fee and there is a limit for the overproduction depending on the contract. The limit means that if the overproduction goes over the limit, the excess energy is not considered. Therefore, the customer is giving the excess energy for free to the company. The portion of the electricity tax is usually not refunded in the contract. (Martikainen, 2020)

Alternative option for the virtual battery option and physical battery option is a grid battery option where the customer has an overproduction sales contract with the electricity company. The idea is that the customer sells the overproduction to the grid and purchases it back when needed without any virtual battery contract monthly fees or limits. Therefore, the price of the electricity consists of the typical [price components](#) in the sales and purchase parts without any refund or discount agreements. The main financial difference between the virtual battery contract and the grid battery option usually is monthly fees of the virtual battery contract. (Martikainen, 2020)

In wintertime when the sunlight intensity is low, and the production of the PV system is low, there are only few options to charge efficiently. Customer can use the physical battery scenario represented above. The battery can be recharged from the grid when the electricity exchange price is low and discharged when the price is high (Martikainen, 2020). Also, the physical battery can be recharged with the low self-production at daytime and discharged at nighttime. Using the self-production by customer itself is more efficient financially than selling it to the electricity company. As represented earlier under the chapter [4.4 Financial](#)

[effects of the PV system on property's electricity costs](#) the biggest benefit comes from the reduction of purchased electricity from the grid with self-produced electricity.

Using the grid battery option represented above in wintertime might not be as efficient as the physical battery option. The self-production is low in wintertime and with the grid battery option there are typical [price components](#) in the sales and purchase parts, which lowers the benefits more compared to the physical battery option.

## 5.2 EV fleets as a load

Currently there are total of four 22 kW AC chargers in Kokkola. In 2024, EV fleet chargers will be increased by a total of two chargers. The calculations are finished with the current of 4 chargers with self-sufficiency of 38.9 % with the nominal 70 kWp PV system. The self-sufficiency will decrease when more chargers will be added in the future, which is considered when the PV system was optimized in Kokkola. When considering the future, the power load will be the biggest problem when increasing the number of chargers. Depending on the size of the chargers and the capacity of the main electrical bandwidth of the property, the capacity will be mostly likely the first limiting factor without any intelligent power control related to the chargers.

The EV fleet charging data is included in the total consumption data of Kokkola's property in calculations. In the figure 28 can be seen the ratio of the energy taken by the EV fleet chargers to the total consumption. According to the data for EV fleet charging in Kokkola, the charging happens throughout the year, but it is relatively small in the winter months that it is not shown in the figure.

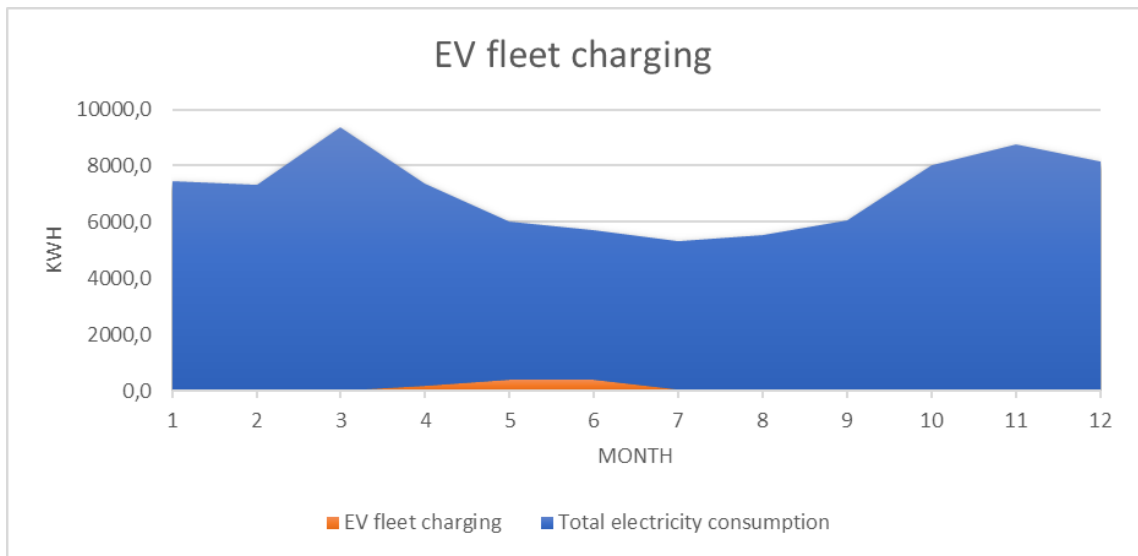


Figure 28 EV fleet charging as a part of the total electricity consumption.

As represented in the figure 28 the ratio of the chargers to the total consumption is approximately 2 %, which is currently low percentage. In some Veho's properties with a PV system, the percentage of electricity used for EV fleet charging can be close to 10 % from the total consumption, which starts to be a significant number and needs to be taken into account.

### 5.3 Justification of Kokkola's optimized PV system

The nominal 70 kWp system were chosen to be optimal in the location because of the following noteworthy information. According to the calculations, the payback-time of the system is lower than the real estate rental agreement of the property even though the system is the most expensive size in the calculations.

The self-sufficiency of the system was calculated to be 38.9 % where there is enough room for load growth in the future. With this high self-sufficiency, the system could also help with power peaks when charging the EV fleets in the future. Currently, the EV fleet charging is only about 2 % of the total electricity consumption with four of 22 kW AC chargers, as represented earlier under the previous chapter. In 2024, EV fleet chargers will be increased

by a total of two chargers, which will increase the percentage to approximately 2.5 % of the total consumption. The change will be small, but the dimensioning will also consider the following additions of chargers during the real estate rental agreement. The size is also optimized slightly upwards, considering other possible increases in the consumption.

As represented earlier under the chapter [2.3 Veho Kokkola overview](#) there is also enough installation space for the system on the roof. The available space is one of the main criteria when choosing the PV system size. If needed in the future, the PV system size can also be expanded according to the available space on the roof.

## 6 Overall effect of the PV system

In this chapter, Kokkola's 70 kWp PV system is duplicated to 24 Veho's dealerships in Finland and effect to annual electricity consumption is calculated after the reduction of 24 PV systems. The percentual reduction in annual electricity costs are calculated. Also, the total price of the 24 systems and payback-time are represented using the turnkey prices of the table 2. Emission factors between Finnish grid electricity production and solar production is compared.

### 6.1 PV system reducing Veho's total costs in Finland.

Assumptions in the calculations are that the production is taken from Kokkola's location, and Kokkola's dealership contract information is used. The main point is to represent the effects in annual consumption and annual costs when 24 Veho's dealerships have the same PV system as in Kokkola.

In the figure 29 can be seen the reduction in consumption with 24 PV systems in Veho's dealerships in 2021. The calculations are done by multiplying the overproduction of Kokkola. The production of 24 PV systems is about 13.2 % of the total annual consumption of the 24 dealerships.

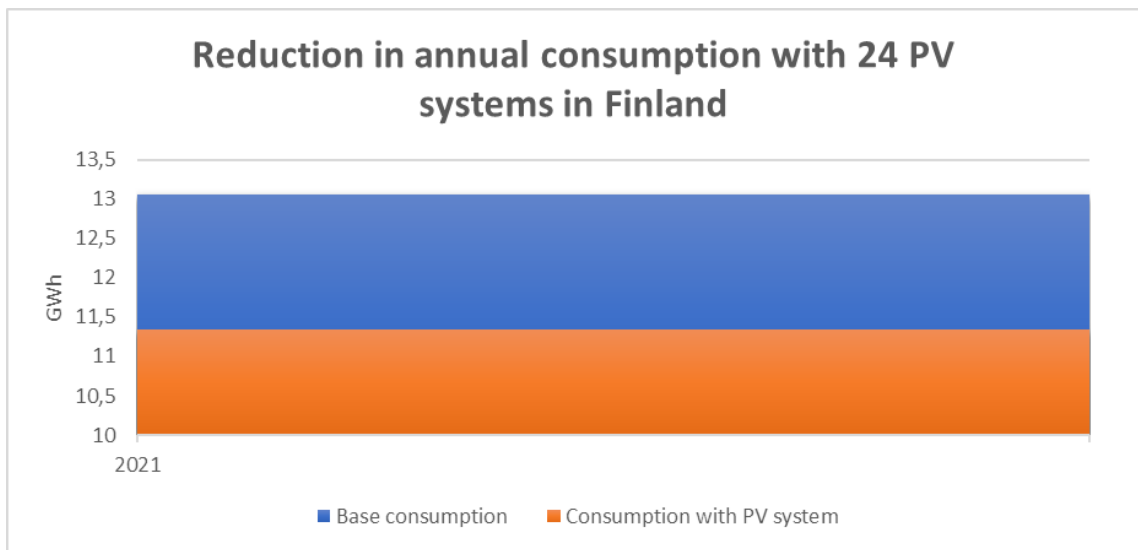


Figure 29 Effects of 24 PV systems in annual consumption in Finland.

In the figure 30 can be seen the percentual reduction in annual electricity costs with different contracts with 24 PV systems in Finland in 2021. The calculation is done by multiplying the sales and the savings. With Kokkola's current contract and 2021 SPOT prices, the reduction is the highest 9.7 %.

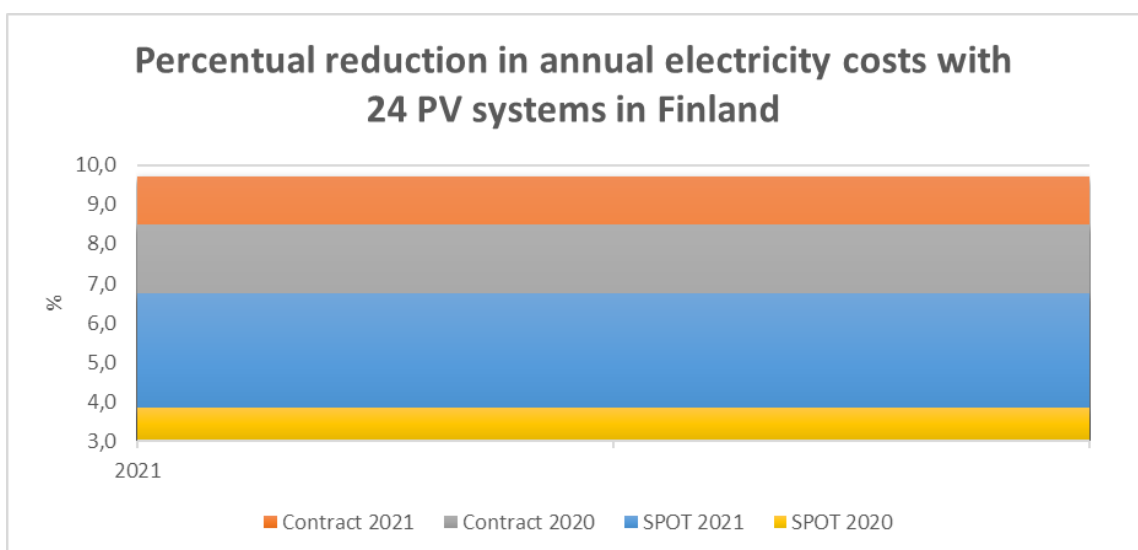


Figure 30 Percentual reduction in annual electricity costs with 24 PV systems in Finland. The overproduction sales have been added.

The total price of 24 PV systems is 1 558 440 € according to the turnkey prices in the table 2 (excluding VAT and permitting cost). The table 6 shows the theoretical payback-time of 24 PV systems. Kokkola's production and contract information is used in the calculations.

*Table 6 Payback-time calculations with 0.925 eur/W average price used.*

0,925 e/W	Paypack-time contract (y)		Paypack-time 2020 (y)	Paypack-time 2021 (y)
Size (kW)	2020 SPOT	2021 SPOT	2020 SPOT	2021 SPOT
70,2	8,7	8,5	23,9	14,3

24 PV systems could payback the investment under nine years according to the table 6. As mentioned earlier, a noteworthy information is that Kokkola's contract information and location production is used in the payback-time calculations. This means that changes in the location of properties in different parts of Finland are not considered in the calculations, which in practice would influence the payback-times.

## 6.2 Emission factors of electricity production.

According to the Finnish national statistics authority, the emission factor of electricity production in Finland was 89 gCO<sub>2</sub>/kWh as a three-year moving average (2018-2020), imported electricity is not included (Motiva 1). This emission factor typically does not include lifetime emissions for example when coal is mined and transported to Finland for the electricity production etc. The US-based National Renewable Energy Laboratory (NREL) has estimated the emission factor for solar power to be 40 gCO<sub>2</sub>/kWh throughout the life cycle of the system (Solarbay, 2020). In its research, NREL does not specify in which continent the emission factor is exactly estimated. As mentioned earlier under the chapter [2.2 Theoretical emission reduction of electricity](#), emissions with solar power happens when manufacturing the panel, it does not produce emissions when operating, producing electricity. Comparable emission factor of solar power producing electricity would be then 0 gCO<sub>2</sub>/kWh when comparing to the emission factor of electricity production in Finland 89 gCO<sub>2</sub>/kWh.

Also, while the solar panel is operating, it earns back the manufacturing CO<sub>2</sub> emissions over time. Estimated operating time is 3–4 years when the solar array finally enters the net-zero state, which means that the array has produced enough emission free energy to cancel the manufacturing energy and emissions. (Solvolaics)

## 7 Conclusions

The main goal of this work was to dimension a photovoltaic system to Veho Oy's dealership property in Kokkola to reduce electricity purchase from the grid. The effects of the PV system in Kokkola were represented with calculations, in which electric vehicle (EV) charging as a load was also considered through theoretical scenarios. The optimized system was compared between Kokkola and other Veho's dealership properties in Olari, Raasepori and Kurzemes prospekts in Latvia. Calculations were done with Veho's current electricity contracts and with years 2020 (low) and 2021 (high) SPOT prices. Main idea was to purchase electricity with 3 different prices (contract, SPOT 2020/21) and sell the self-produced overproduction to the grid with 2 prices (SPOT 2020/21).

Kokkola's dealership was chosen because it's a truck dealership, fairly new building, it has about 10 years left on the lease, and it's a concept building, meaning Veho has similar buildings all over Finland. As a truck dealership and concept building, Kokkola gives perspective on solar panel systems in Veho's truck dealerships all over Finland. The main goals for optimizing a PV system to Kokkola was to have lower payback-time than the real estate rental agreement of the property and self-sufficiency high enough to meet the consumption also in the future. According to the calculations, nominal 70 kWp PV system was economically the most optimal system size for Kokkola with the annual self-sufficiency of 38.9 % and capacity factor of 11.35 %, and with enough room for load growth in the future.

The system was found to reduce electricity purchase from the grid and to decrease electricity costs. When purchasing and selling electricity at low 2020 SPOT prices, the monthly electricity bill was found to be the lowest on average in Kokkola. At high 2021 SPOT prices, the electricity bill was the second lowest. When purchasing electricity at Veho's current contract price and selling at both 2020 and 2021 SPOT prices, electricity bills were the highest. This was found to happen purely because Veho has a fixed energy price in the contract, which is on average higher than the SPOT prices on average of both years.

According to this information, with SPOT prices, the scenario was economically more profitable for Veho.

Savings with each contract consisted of the sales and the difference between electricity purchase bill with and without the PV system. According to the calculations, the biggest savings in Kokkola came from Veho's current contracts when electricity was purchased at fixed price and sold at 2020 and 2021 SPOT prices. This happened due to the high base purchase bill with Veho's contract without the PV system and low purchase bill with the PV system. When purchasing and selling at SPOT prices, the savings were lower because of the smaller difference between the base purchase bill without the PV system and purchase bill with the PV system. The biggest savings with Veho's contract happened purely because Veho has a fixed energy price in the contract, which is higher than the average of SPOT prices of both years. This fixed price rose the base electricity purchase bill with Veho's contract.

The payback-times of the nominal 70 kWp PV system in Kokkola were calculated with the annual savings. When purchasing electricity at fixed price in Veho's contract and selling at 2021 SPOT prices, the payback-time was the lowest 8.5 years. With contract 2020, the payback-time was the second lowest 8.7 years. These two payback-times were inside the green area, which means that the system could pay back the investment before the rental period of the property ends. Also, the effects of different eur/W prices used for the PV system was calculated. The payback-time changed between 1.2–6.6 years between the lowest 0.8 eur/W price and the highest 1.05 eur/W price. This is huge difference, which means that the eur/W price of the PV system greatly affects the payback-time.

In the location comparison was found that it is important to optimize the PV system for each property with considering the electricity consumption of the building and the solar production in the location. With the 70 kWp system and with solar production of Latvia, the self-sufficiency in Kokkola rose about 0.65 % when comparing to the Kokkola's solar production. Also, the capacity factor rose from 11.35 % to 11.44 %. This shows that the PV production is more profitable further south where the sunlight intensity is higher.

When Kokkola's data with the nominal 70 kWp PV system was duplicated to 24 Veho's dealerships in Finland, was found that the production of the 24 PV systems is about 13.2 % of the total annual electricity consumption of 24 dealerships. Also, the percentual reduction in annual electricity costs with different contracts with 24 PV systems in Finland in 2021 were calculated. With Kokkola's current contract and 2021 SPOT prices, the reduction was the highest 9.7 %. With contract 2020 the reduction was the second highest 9.4 %. The total price of 24 PV systems was 1 558 440 € and these could theoretically pay back the investment under nine years.

When comparing emission factors between grid electricity production in Finland and solar electricity production was found the following. Emission factor for grid electricity production in Finland was 89 gCO<sub>2</sub>/kWh and it did not include lifetime emissions such as coal mining and import emissions. Emission factor for solar power was 40 gCO<sub>2</sub>/kWh and it included lifetime emissions. This means that the solar power has 0 gCO<sub>2</sub>/kWh emission factor compared to the emission factor of electricity production in Finland 89 gCO<sub>2</sub>/kWh. Also, was found that the PV array reaches the net-zero state in 3–4 years, where it has produced enough emission free energy to cancel the manufacturing energy and emissions.

While going through the results in this master's thesis, it is good to keep in mind that the situation lives and changes constantly because the prices change. The calculations are giving direction.

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