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DESIGN OF A SOLAR POWER SYSTEM FOR A DOMESTIC PROPERTY

Degree Programme in Environmental Engineering
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The purpose of this thesis was to examine the conditions for a solar energy system for a domestic property in the Köyliö area, to explore solar energy options, to analyse the feasibility of these options, and to form a conclusion on the potential for solar power pertinent to the conditions and needs of the clients and their property. This paper considered the energy requirements of the clients, the natural and anthropological circumstances applicable to the location, and the technological options and the various configurations of these technologies available to satisfy a feasible solar energy installation. The paper concludes with a recommendation based on these findings.

TABLE OF CONTENTS

APPENDICES

1 INTRODUCTION

Solar energy is an increasingly important source of power as global energy requirements continue to rise. The rise in energy requirements is met with an increase in output from various sources, including fossil, nuclear, and renewable. Solar power falls into the category of renewable energy. The conjunction of the realities of climate change and the increasing demands for energy meet at a point where solar energy can provide a solution.

Solar energy technology converts solar radiation from the sun into a form of energy which can be utilised, such as heat or electricity. There are no pollutants or fuel waste, which makes solar energy very appealing to climate-conscious people, and fuel is free and available through adequate sun exposure (Kalogirou 2014, 481.)

Finland is a country not traditionally considered ‘sunny’. In spite of this, there is an increasing interest in solar energy in Finland, as demonstrated by HELEN’s (Helsinki Energia) two new solar power plants in Suvilahti – completed 2015 (Website of HELEN 2017) – and Kivikko – completed 2016 (Website of HELEN 2017), Pori’s swimming pool’s innovative solar energy system (Website of SolarForum 2017), and the approach from the clients who are the subject of this thesis to investigate and design a solar energy system for their domestic needs.

The increase in interest can be attributed to a number of factors. Climate conservation is perhaps the most obvious aspect, but the potential for energy cost savings is also an important practical consideration. It is fortunate that the heaviest cooling requirements occur at the time when photovoltaic output is at its peak, which is an added benefit when consider the many positives of solar power. The recent trend of lower costs involved in installing a solar energy system have greatly extended the affordability and appeal of solar energy to a wider potential customer base.

The aim of this thesis is to understand the energy consumption characteristics of the clients and their properties, and to use this information to determine the feasibility of the installation of a solar energy system to meet their energy consumption needs. This information will be used in combination with a study of natural conditions, financial review and research relating to solar energy to influence the design of a number of configurations of suitable solar energy systems.

2 SOLAR ENERGY PRINCIPLES AND TECHNOLOGY

2.1 Photovoltaic principles

Solar energy, as the name suggests, is energy derived from the activity of the sun. The sun generates a great deal of electromagnetic radiation, some of it in the form of visible light, although much of it is also at invisible wavelengths. The electromagnetic radiation produced by the sun is transmitted to the earth in discrete energy packets known as photons, and this is the energy used in solar power generation.

To harness this energy, a photovoltaic cell is composed of two semiconductors typically consisting of silicon. One of these is a ‘p’ type doped semiconductor, and the other is an ‘n’ type doped semiconductor. The difference between ‘p’ and ‘n’ lies in their charge: ‘p’ stands for positive, and ‘n’ stands for negative, so a ‘p’ type semiconductor has a deficit of electrons (known as a ‘hole’), and ‘n’ types have a surplus.

The term ‘doped’ refers to the fact that the semiconductor is not pure silicon. Pure silicon has four valence electrons, and thus will form covalent bonds with four adjacent silicon atoms, leaving it with no free electrons with which to carry a charge. To create an n-type semiconductor, you substitute a silicon atom with another atom which has 5 valence electrons, such as arsenic, or phosphorous; this allows for four covalent bonds with the adjacent silicon atoms and a free electron. Using the same logic, to create a p-type semiconductor, you substitute a silicon atom with an atom which has only three valence electrons, and then you are left with an electron deficit – a hole. The hole behaves like a positively charged particle, and like free electrons, is not static.

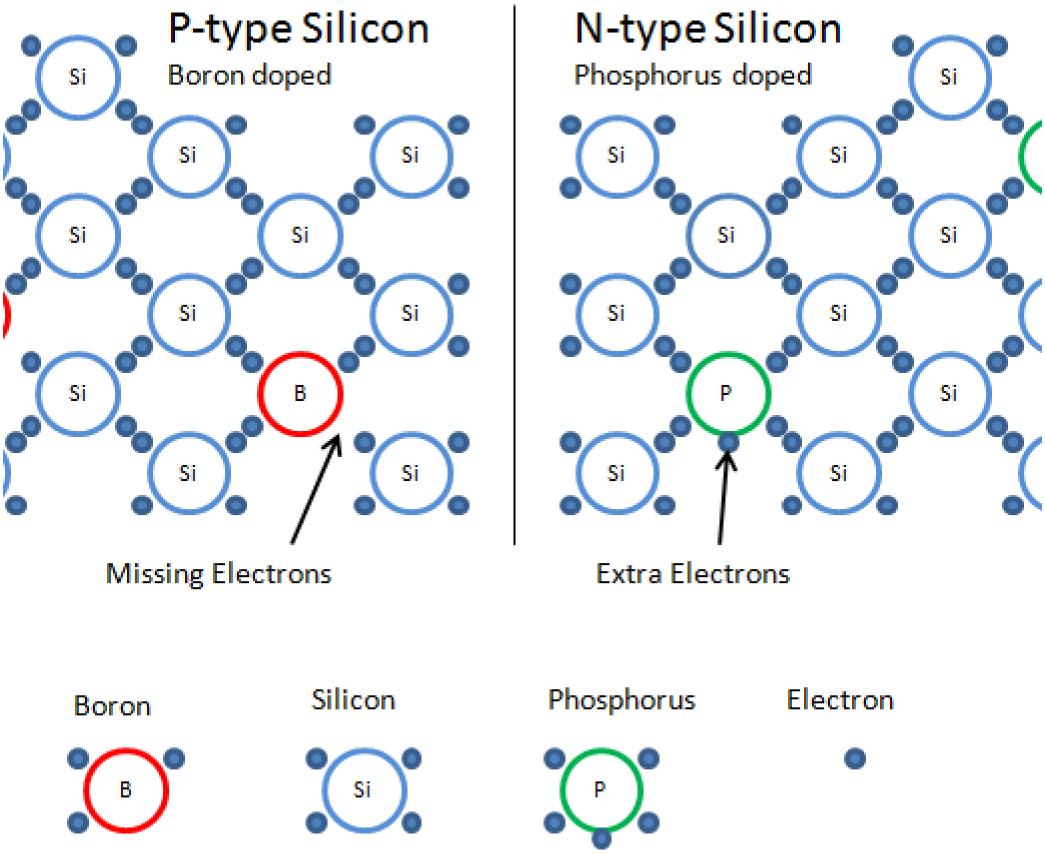


Figure 1. P- and n-type silicon, doped with boron and phosphorus respectively (Website of Solar Journey USA 2017)

When both ‘p’ and ‘n’ types are brought together, they form what is known as a p-n junction. A p-n junction has a ‘depletion zone’ at the point where the two different semiconductor materials meet. This depletion zone is effectively an insulator due to the effect which the opposite charges of the two materials have on one another. Energy from a photon can raise an electron to a higher energy state, and the electron will then have enough energy to cross the depletion zone and produce a current.

2.2 Photovoltaic technology

These scientific understandings are the underpinnings of the technology used in solar cells. Solar cells require the absorption of sunlight. Light travels in a straight path, so a solar cell has to incorporate this into its design.

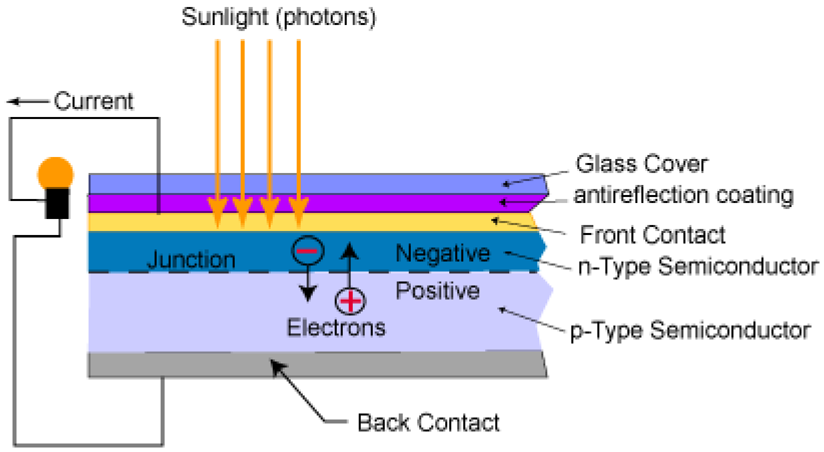


Figure 2. Lateral view diagram of a photovoltaic cell (Website of MySolarProjects 2017)

As is illustrated by the diagram in Figure 2, the outer surface is glass to protect the subsequent layers. An anti-reflective layer underneath the glass maximises the amount of sunlight that can be absorbed; the glass layer is often treated to share this characteristic. The n-layer comes next, and directly beneath this is the p-layer, and so we have the vital p-n junction. Sandwiching the p-n arrangement are current carrying contacts, negative on top and positive on the bottom, to conduct the electricity produced.

What has just been described is the simplest explanation of a solar cell. There are a number of varieties based on this design, with the main difference usually being the semiconductor material, as will be explained below.

2.2.1 Solar cells

There are two main types of PV cell appropriate to this study available today. These are crystalline silicon and thin-film cells. Crystalline silicon accounts for approximately 80% of the market, whereas thin-film effectively accounts for the approximately 20% remainder of the market.

Triple-junction cells are an up-and-coming design which have three p-n junctions which correspond to different wavelengths, expanding the range of radiation which they can utilise, resulting in up to 41.1% efficiency under laboratory conditions (Guter et al., 2009) . However, triple-junction technology will not be considered for this study as they are not quite ready for the commercial market.

Crystalline silicon

Figure 3. Polycrystalline silicon (left) and monocrystalline silicon (right) cells (Website of Silicon Solar 2017)

Crystalline silicon comes in both monocrystalline and multicrystalline forms. The advantages that monocrystalline silicon has over multicrystalline arise from the difference in structure. Monocrystalline silicon is a single continuous crystal lattice with effectively no defects or impurities, and so monocrystalline silicon has a slightly higher efficiency (~15%, up to 20%) than multicrystalline silicon (~14%, up to 17%). A disadvantage of monocrystalline silicon is the complexity of manufacturing, which drives up costs, although these have been falling in recent years. A disadvantage which both mono- and multicrystalline forms share is that of reduced efficiency as temperatures rise, which diminishes output (Kalogirou 2014, 498.)

A great deal of research into improving solar cell efficiency is pushing these efficiencies up, although at present most success is through complex laboratory testing. This means that it will still be some time before the very high efficiencies being achieved in controlled conditions are found on the market, although a general rise is nonetheless being observed in available silicon-based solar energy technologies.

Thin-film

Thin-film cells can also be silicon, but arranged in a thin homogenous layer. This layout is better able to absorb light than crystalline silicon forms, and handles higher temperatures more effectively. A further advantage is the low manufacturing costs. However, there is a catch: the efficiency is only around half that of the crystalline forms, at about 6 – 7% (Kalogirou 2014, 498), although recent lab efficiency ratings have managed to reach 21.0% (Website of Fraunhofer Institute for Solar Energy Systems, ISE 2016).

Another thin-film form is CdTe: cadmium telluride. CdTe shares the advantage of good heat tolerance, and of being cheap, but has a drawback in that cadmium is highly toxic. At around 11% efficiency, CdTe has an efficiency rating between that of crystalline silicon and thin-film silicon (Kalogirou 2014, 499), although again, in the lab, a higher efficiency – 20.5% - has been attained (Website of Fraunhofer Institute for Solar Energy Systems, ISE 2016).

A final thin-film example, and the most recent to enter the commercial market, is CIGS. CIGS stands for Copper Indium Gallium Selenide. Sharing the low cost characteristics of other thin-film examples, the efficiency lies between 10 – 13%, and the standout advantage of this particular form is that it is light in weight and does not require glass, making it applicable to a wider range of application possibilities (Kalogirou 2014, 499.)

2.2.2 PV system components

Besides the solar panels themselves, a solar power system requires periphery components to function. For example, sunlight is transformed by a photovoltaic cell into direct current electricity. DC electricity is incompatible with virtually all household appliances as they operate with alternating current (AC). In order to utilise the electricity being produced by a photovoltaic cell, a device known as an inverter is used to transform the DC electricity supplied by the solar panels into AC electricity which can be used to power household appliances (Boxwell 2011, 19.)

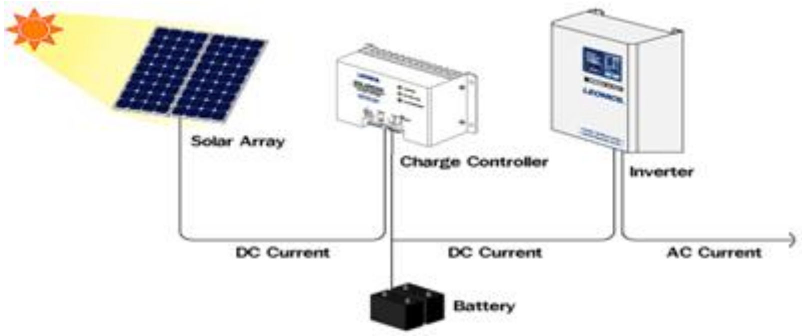


Figure 4. A basic configuration of components for an off-grid solar energy system (Website of Leonics 2017)

The components required depend on whether or not the system is connected to the grid. Off-grid, a typical setup will consist of the solar panels in a grouping known as an array connected to a controller, which regulates the flow of electricity to and from the batteries. The battery, or batteries, are more common in off-grid systems, as they store electricity for use when solar power production has dropped. Such a system is illustrated in Figure 4 above.

There are significant differences between the inverters in Figures 4 and 5. A solar inverter (Figure 5) needs to handle more parameters than an ordinary inverter. This is to deal with the inherent changes involved in harvesting energy from a solar collector as generation fluctuates throughout the day, as well as voltage range and frequency range. As a part of dealing with these, an inverter will also have safety features to handle, for example, power cuts or surges. Solar inverters are of much higher standards than ordinary inverters.

The meters in Finland are typically owned by a power company or the owner. In Figure 5 we can see ‘Watt-Hour Meter: Net metering’, known as ‘kilowatt hour meters’ on the rare occasions they are found in Finland; more often, the meter is reprogrammed to handle both the solar power system and the grid simultaneously.

It is worth noting that these ‘net meters’ are a part of some systems. As the solar power industry grows, there is the possibility of encountering such a system through the homogenisation of the global solar power landscape, so an awareness is prudent.

A final note on Figure 5: this diagram is missing a safety switch, which is an essential part of a well-designed solar power system to the point that they are mandatory in Finland.

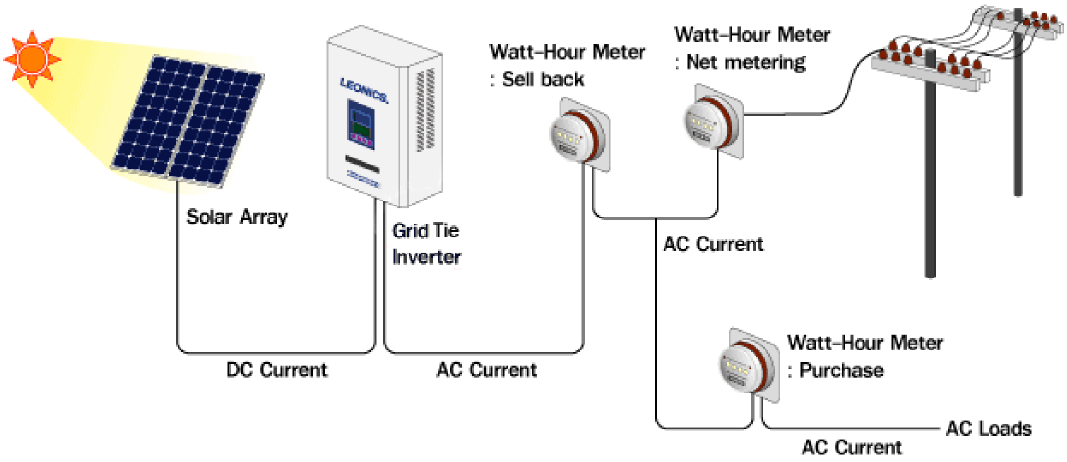


Figure 5. A basic configuration of components for an on-grid solar energy system (Website of Leonics 2017)

Solar inverters are the second most expensive pieces of equipment in a solar power system after the solar panels themselves (Website of Cenergy Power 2017), so they need to be correct for the job. An important distinction lies in the difference between off-grid inverters and on-grid inverters, usually referred to as ‘grid tie inverters’. A basic difference lies in whether the current from a solar array is converted into home-use current or is adjusted to match the grid-specification voltage and frequency (Website of Mepits.com 2017), as the grid can be affected by unregoverned tied-in solar power systems.

A solar energy system can vary in size depending on the requirements and costs. Perhaps the most obvious indicator of a system’s size is the panelling. A single photovoltaic cell is incapable of providing enough energy on its own, and so the cells are combined into a solar panel which contains many such cells. A single panel may have a rating of, for example, 260W. If 20 of these are combined the rating is increased by a factor of 20, so up to 5.2kW. These are held in a frame which supports the solar panel structure. Several of these – as many as are desired, essentially – can be put together in a series to create impressive electricity generation capabilities.

3 FINNISH ENERGY

3.1 Policies

“With its energy-intensive industries and its cold climate, Finland’s energy consumption per capita is the highest in the IEA. […] Finland notably leads all IEA member countries in terms of research and development funding for its energy sector. The focal points of the government’s energy strategy are to strengthen its energy security, to move progressively towards a decarbonised economy, and to deepen its integration in the wider European market.” (International Energy Agency, 2013, 9).

Finland is putting pressure on high-pollution industries to lower their emissions, and this includes the energy sector. Finland is committed to numerous international climate change agreements, which play a big role in the shaping of domestic energy policies (Työ- ja Elinkeinoministeriö, 2013, 5), policies which are favourable towards the expansion of pollution-free energy production in the form of renewable energy. One approach has been to increase incentives for investment into renewable energy and the removal of aid towards non-renewable energy production: “Renewable energy use will be increased to account for over 50 % of the final energy consumption in the 2020s. The long-term goal is for the energy system to become carbon neutral and be heavily based on renewable energy sources. Policy measures looking to 2030 take into account not only cost-effectiveness but also longer term needs to change the energy system.” (Työ- ja Elinkeinoministeriö, 2017, 32).

Finland regards energy security as a vital and basic prerequisite of a healthy state of affairs in which the business of the state can function to its full potential. With the increased focus on renewable energy, Finland has turned its attention towards ensuring that Finnish energy sector can sufficiently supports its aims for the future.

Finland’s energy policy has in recent years increasingly begun to promote and favour renewable energy over traditional energy sources, such as coal in particular. This has been shown in the creation of a temporary support scheme for the production of renewable energy, which is being seen as a trial towards the adoption of more permanent measures to increase renewable energy production (D&I Alert – Energy, Infrastructure & Natural Resources, 2016.)

3.2 Infrastructure

There are approximately 75 electricity retailers in Finland which produce and sell electricity (Website of Työ- ja elinkeinoministeriö 2017). This electricity is distributed across the national grid, which is owned and run by Fingrid. Fingrid handles the electricity distribution network, including international connections, ensuring that electricity has a secure means of delivery from producer to user. A typical Finnish energy bill will include the cost of energy production, grid distribution fee and taxes. Fingrid is the main operator of the Finnish electrical grid network, of which the Finnish government is a majority stakeholder (Website of Fingrid Oyj 2018), and the Finnish electrical grid is essentially leased by energy consumers to conduct the electricity their energy suppliers generate (Website of Fingrid Oyj 2018).

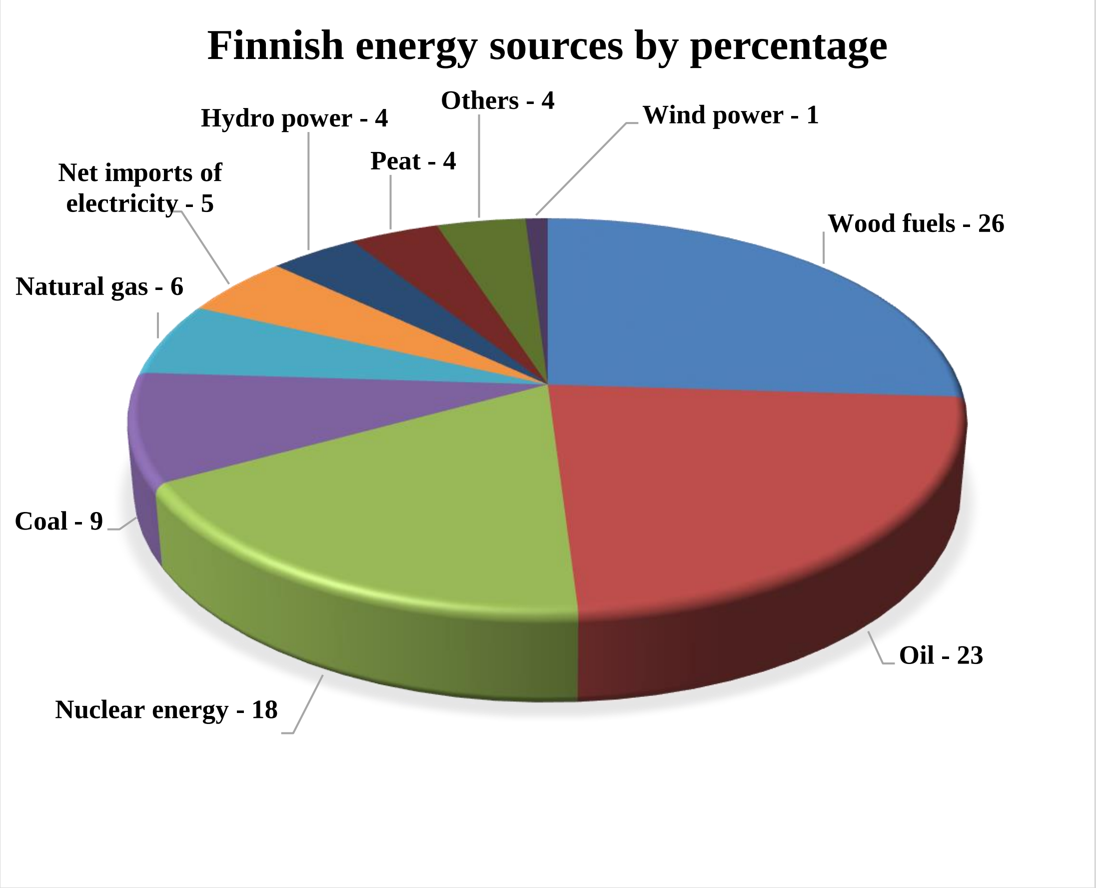


Figure 6. Pie chart showing a breakdown, in percentage, of Finnish energy sources by production type in 2016 (Official Statistics of Finland (OSF), 2017)

According to the data used in Figure 6, approximately 370 TWh of energy was consumed in Finland in 2016. Wood fuels – in particular, black liquor and forestry by-products – account for roughly a quarter of Finland's energy consumption. Combined with energy produced by oil, wood and oil represent approximately half of Finland's energy consumption sources. Regarding energy production which does not produce any greenhouse gasses, nearly 20% of Finland's energy consumption is produced through nuclear energy, and a further 5% is from hydropower (4%) and wind power (1%). In combination, this equates to nearly a quarter of Finland's energy consumption coming from clean energy sources, when including solar power, sharing the label of 'other', which amounts to 4% in total.

3.3 Economics

Nord Pool Spot is the name given to the shared energy market of the Nordic and Baltic states along with a handful of other European countries, of which Finland is a member. Nord Pool Spot acts as a marketplace for the trade of energy as a commodity between member states, and so the prices are determined by market rules of supply and demand. This system aims to increase energy security, which is highly beneficial in the case of renewable energy expansion as it acts as insurance against situations where local renewable energy production is impacted by adverse conditions. This means that energy can be bought by an energy deficient region from a member state which is producing excess energy (Website of Nord Pool Spot 2017).

4 OVERVIEW OF THE PROPERTY

4.1 Introduction

The setting for this study is Köyliö, a town within the municipality of Säkylä, in south-western Finland. The property is located within a forest area close to a number of local quarries. The forest is largely populated with pine trees which can reach nearly 30 metres in height. An area of forest was purchased and the land cleared for the construction of some properties to which this thesis applies – there are a number of structures on this property with a variety of functions. Although some of the structures are subject to shading from the surrounding forest, there are areas where shading does not occur until a point in the day where solar production is likely to be negligible anyhow. The main electric appliances are a number of fridges and freezers which includes a walk-in freezer and two deep freezers, an external two-unit HVAC system, and electrical temperature control of the swimming pool. Numerous other domestic and temporary heavy duty activities – often related to the continuing development of the clients' property – further contribute to overall energy consumption.

The electricity is supplied from the grid and heating is from pellet combustion at the outset of this thesis. The electricity plan is a one-tier system with the same price during the day as during the night.

4.2 Property overview

There are four properties of note: the main house, the indoor swimming pool, the garage, and the automobile storage hall with its attached residential wing. The pellet boiler is installed in a side building also attached to the automobile hall. These properties are privately owned by the client, and their layouts are shown in Figure 7.

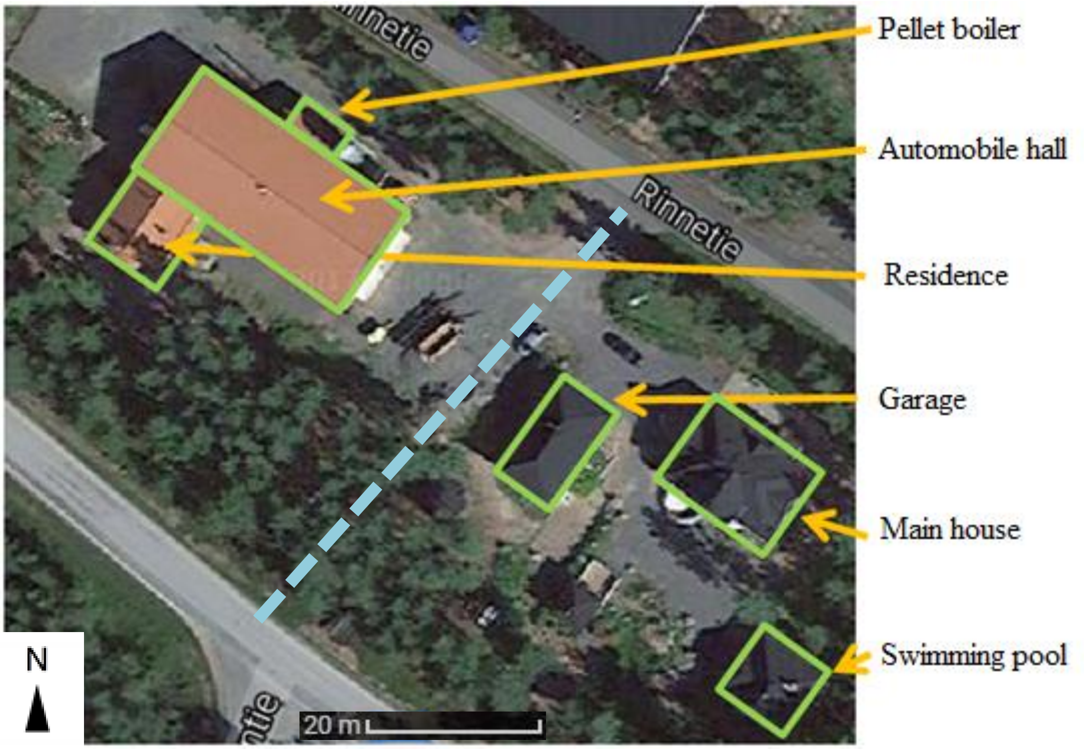


Figure 7. Overhead view of the properties which are a part of this study; the dashed line denotes the border between the addresses (Website of Google Maps 2017)

There are two residents in the main house, which is a three floor structure completed in 2010. The garage has two floors and an attic, although the attic is not heated. The swimming pool is in a standalone building, completed 2013. The pool itself has a volume of 60m^3, and is generally kept at around 15°C. The pellet system includes an external pellet silo, a pellet incinerator and boiler, and a redundant heating generator. The automobile hall has a separate address and electricity metre to the main house and will not be a part of this study, and is mentioned only because the most likely location for any solar panels will be on the roof of the automobile hall.

A direct current connection would be established between the solar panels on the automobile hall roof and the inverter, which will most likely be located within the main house, although the garage is also an option, depending on the preference of the clients. As the title to all of the properties mentioned in this thesis are held by the same person, there should be no legal issues concerning the transmission of electricity between properties with different addresses in this manner.

4.3 Structural overview and potential solar mounting options

Considering that heating requirements are currently met, it was decided to focus on electrical generation possibilities. As can be seen in the following chapters, particularly in Figure 13, there is a promising overlap of electrical consumption and PV potential during the summer. Although the initial solar energy study will focus on electricity, success with photovoltaic experiences may encourage the client to explore the possibilities of solar thermal energy as well. At this point however the focus is limited to PV.

There are two basic requirements for PV panel placement: situating a panel at as perpendicular an angle as possible to the path of the sun, and avoiding shade.

Two potentially suitable locations have been identified, namely the automobile hall and the garage.

- the garage is somewhat isolated from any other structures and trees, which allows for good sunlight cover
- the automobile hall’s roof covers a large area, is quite tall, and is largely free from shadowing

The main residence has been excluded from consideration due to the awkward shape of the roof. The swimming pool is not being considered as it is nestled in a corner of the property with significant tree surroundings, which leaves the building in a perpetual state of shadow cover.

The garage would perhaps be suitable for a very small system, as there is not a great deal of area on the roof. However, as shown in Figure 7, there is significant sun exposure bias in the morning to the east side of the garage which consequently leaves the west side in shadow. Figure 7 shows that the entire roof area of the automobile hall is bathed in sunlight, and by facing south is well oriented in relation to the path of the sun (from east to west), which means that there is a far more even distribution of sunlight exposure throughout the day. Notably, the main balance of electricity consumption occurs during the evening; this means that a PV array should favour access to sunlight when it the sun in the west (in the evening). This makes the automobile hall the preferred installation option.

Picture 1. The garage (Author, 2017)

Picture 2. The automobile hall, showing residency wing (Author, 2017)

This structure is 10.08m tall, 30m in length, 14m wide at the hall and 23.05m wide with the living quarters. The angle of the roof of the automobile hall is 20.2°.

A potential limiting factor for the size of a system is the space available for its installation. The available roof area is calculable using the angle of the roof and the width of the hall:

- two of the angles are known: 20.2° and 90°, meaning the final angle must be 69.8°
- the length of the adjacent side is known: half of 14m is 7.0m, and so the length of the hypotenuse can be calculated:

$$\frac{\sin(90°)\ \mathrm{x}\ 7.0\mathrm{m}}{\sin(69.8°)} = 7.46\mathrm{m}$$

This gives the length of one side of the roof without taking into consideration the extra width provided by the eaves which extend beyond the width of the hall. Multiplying 7.46m by the length of the hall (30.0m) gives an area of 223.8m^2 on each side for fitting solar panels.

Information from Finnwind shows that a 5kW system would require 20 panels. In a 10 x 2 configuration, this would take up an area of 10m x 3.4m for a total of 34m^2. Scaling this up means that a 10kW would require 68m^2, 15kW would require 102m^2 and 20kW would require 136m^2 of area. It can be concluded that there is sufficient area for any of the four system sizes to be installed.

5 ENERGY CONSUMPTION

5.1 Current energy sources

At the outset of this project, there were two sources of energy being used. Electrical energy is supplied from the grid, from the supplier Köyliön-Säkylän Sähkö Oy. The second source for energy is from the combustion of wood pellets in an on-site boiler. This boiler generates heat which is used to heat water; heated water is then supplied to the automobile hall and to the main house through well insulated underground pipes which run directly from the boiler room on the side of the automobile hall to the main house.

5.2 Electricity consumption

Electricity consumption data for a period of five years has been collected from the client's personal data available in the customer section of the Köyliön-Säkylän Sähkö Oy website (Website of Köyliön-Säkylän Sähkö Oy 2017). The data in Figure 8 shows electricity consumption in kWh per hour. The timeframe starts from January 1st 2012 and continues to December 31st 2016.

This data represents five years' worth of electricity consumption data, taking into account all associated structures and activities which have registered on the meter of the clients' home address; it is worth repeating once again that the automobile hall has a separate address, and any activities conducted there are not included. It can be seen from the original data that there is a sharp drop in electricity consumption in October of 2012, for reasons which are lost to time. As the data for this month is a clear anomaly which might affect the overall impression of energy consumption, the data for October 2012 has been replaced with an adjusted figure to compensate. The substitute value is an average value calculated using the values for the October months of the proceeding four years (2013-2016).

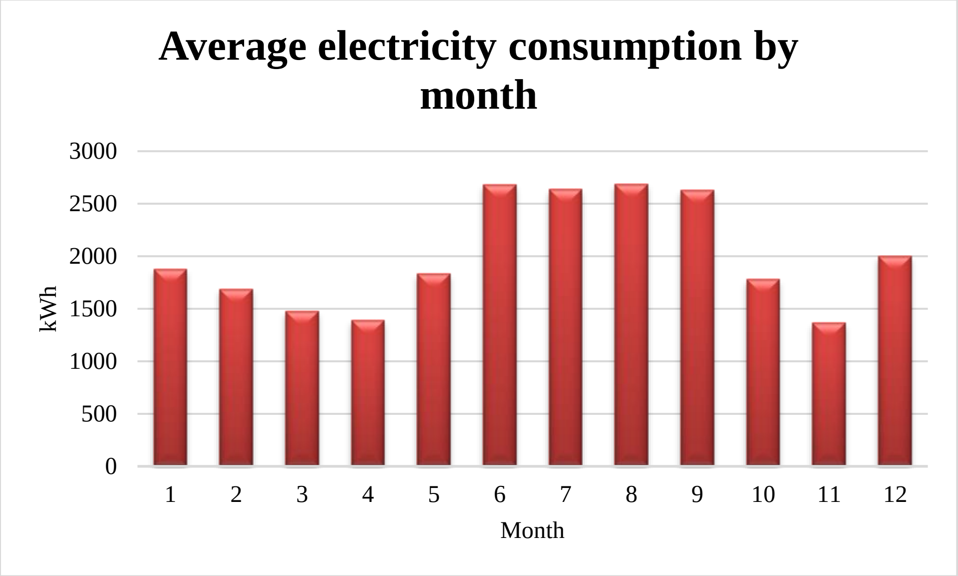


Figure 8. Bar graph showing average electricity consumption over 5 years by month, with adjusted value for October 2012 (Website of Köyliön-Säkylän Sähkö Oy 2017)

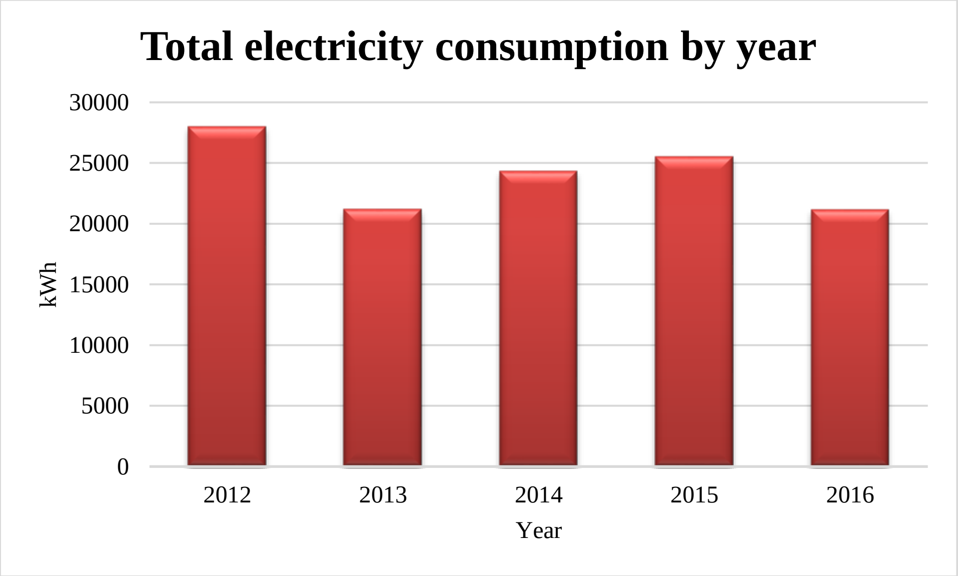


Figure 9. Bar graph showing total electricity consumption by year with adjusted value for October 2012 (Website of Köyliön-Säkylän Sähkö Oy 2017)

Figure 8 shows the average electricity consumption by month over a five year period. The months covering the summer period stand out as particularly prominent. Figure 9 shows that annual electricity consumption is over 20,000kWh and often very close to, or even passing, the 25,000kWh mark.

5.3 Analysis

The four months of June, July, August and September represent the highest monthly electricity use, ranging from an average of 2629.1kWh in September to 2685.6kWh in August. December and January are the most consumption heavy winter months – as opposed to summer and early autumn – although at a whisker over 2,000kWh for December (which is over 100kWh more than January), they do not come close to matching the 2,600+kWh consumption figures for June to September.

Adjusting the consumption value for 2012 by substituting the dataset value with an averaged value for October showed a marked difference between the data and projected use. This can be considered significant as the unadjusted data would make it appear that the ~25,000kWh values of 2014 and 2015 are at the limit of consumption. The adjusted value in Figure 9 emphasises the fact that consumption can vary well beyond 25,000kh, and calculations should take this into account when designing the solar power system.

The electricity consumption data shows that the electricity consumption is currently at between 20,000kWh and 25,000kWh per year. The months of highest consumption are September, July, June, and August, in that order, making these months the most suitable for electricity supplementation. Identifying these months as being those at which consumption is highest highlights the merits of designing a solar energy system which can support the energy demands of these months in particular.

Discussions with the client have made clear that energy-saving measures such as cutting down on use of HVAC systems, minor home modifications or changes to lifestyle were not planned or considered feasible. This is partly due to the interior outlay of the house, which is open-plan. With the sleeping quarters of the clients being on the top floor, all the heat rises and collects at the top of the building during the day which can be especially disturbing to their sleep during the warmest months, so cooling is essential.

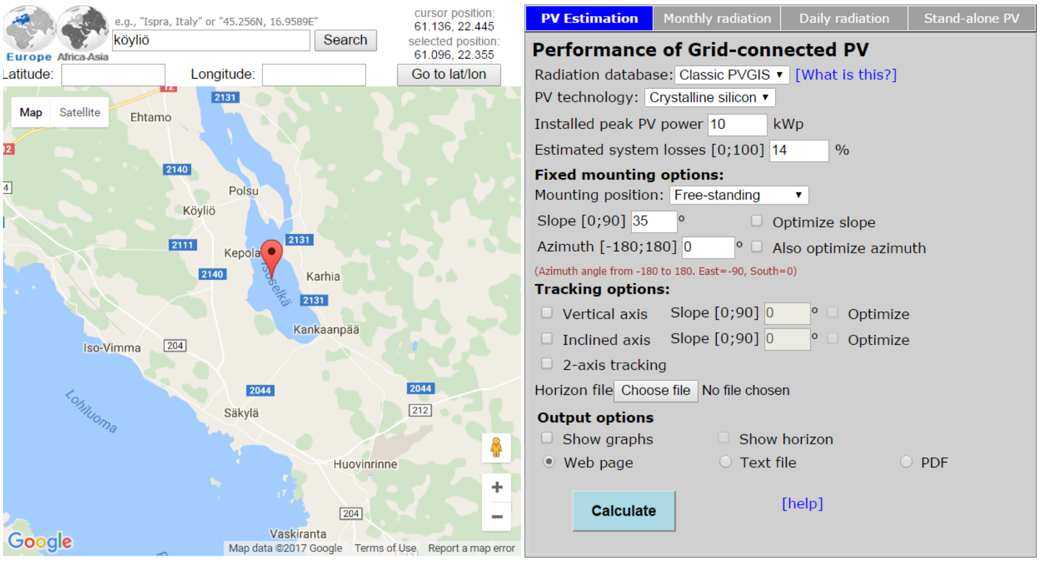
The client has not expressed any plans to expand their activities in such a way as to increase their electricity consumption, rather they wish to supplement their current consumption as much as can be considered feasible with solar energy. Owing to this, it can be assumed that any system designed to fit their needs can be formulated to fit the most recent consumption data.

6 SOLAR ENERGY CALCULATIONS

6.1 Solar energy potential in Köyliö

Due to the northerly geographical location, Köyliö, like the rest of Finland, receives typically few hours of sunlight during the winter, although this also means that the hours of available sunlight during summertime are higher than in more equatorial locations. The analyses of electricity consumption in Köyliö have highlighted that the time of the year when there is the most pronounced electrical demand occurs during the time of year with the most sunlight exposure.

It is possible when using the PVGIS online tool to pinpoint a geographical location to an accurate degree. The online program ‘PVGIS’ (Photovoltaic Geographical Information System) allows the user to input a set of variable values (Figure 10), and the algorithms produce results based on these inputs. The results include information relevant to this paper such as a calculation for “Average daily electricity production from the given system (kWh)” and “Average monthly electricity production from the given system (kWh)” using EU climatological data. (Šúri, Huld, Dunlop & Ossenbrink, 2007.) The projections were made with the inclination (‘slope’ in the program) set at 20°, and ‘azimuth’ set at 40°.



köyliö

cursor position: 61.136, 22.445
selected position: 61.096, 22.355

Latitude:
Longitude:

Performance of Grid-connected PV

Radiation database: Classic PVGIS
PV technology: Crystalline silicon
Installed peak PV power 10 kWp
Estimated system losses [0;100] 14 %

Fixed mounting options:

Mounting position: Free-standing
Slope [0;90] 35 ° ☐ Optimize slope
Azimuth [-180;180] 0 ° ☐ Also optimize azimuth
(Azimuth angle from -180 to 180. East=-90, South=0)

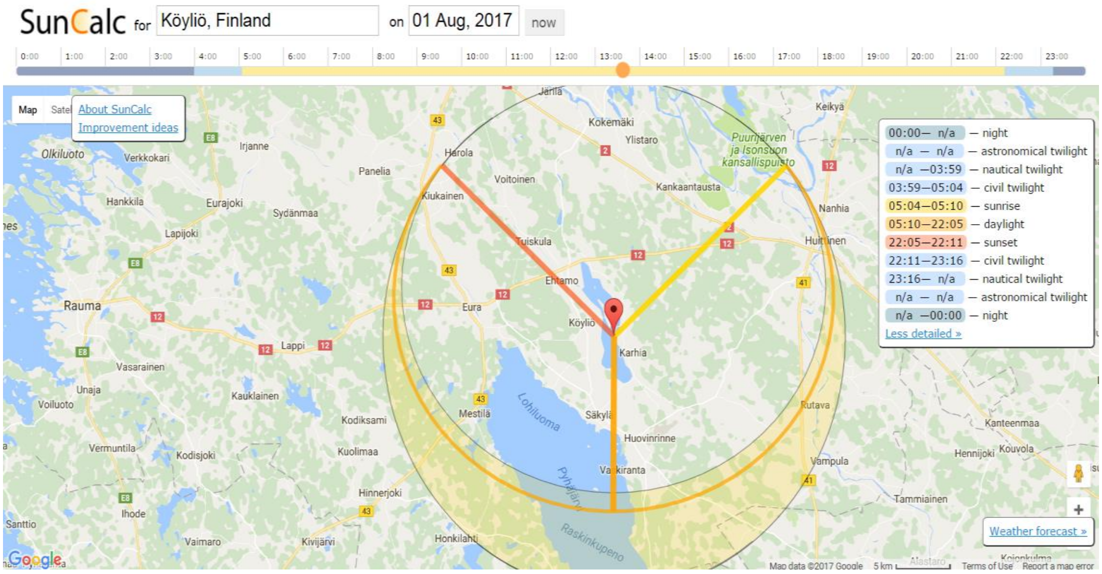
Tracking options:

☐ Vertical axis Slope [0;90] 0 ° ☐ Optimize
☐ Inclined axis Slope [0;90] 0 ° ☐ Optimize
☐ 2-axis tracking
Horizon file No file chosen

Output options

☐ Show graphs ☐ Show horizon
● Web page ○ Text file ○ PDF

Figure 10. The PVGIS program interface showing the input options (Šúri, Huld, Dunlop & Ossenbrink, 2007)


SunCalc for Köyliö, Finland on 01 Aug, 2017 now

00:00— n/a — night
n/a — n/a — astronomical twilight
n/a —03:59 — nautical twilight
03:59—05:04 — civil twilight
05:04—05:10 — sunrise
05:10—22:05 — daylight
22:05—22:11 — sunset
22:11—23:16 — civil twilight
23:16— n/a — nautical twilight
n/a — n/a — astronomical twilight
n/a —00:00 — night

Figure 11. Screenshot of SunCalc showing sun exposure for Köyliö on August 1st, 2017, GMT+2 time zone (Website of SunCalc 2017)


03:59 — dawn
05:04 — sunrise
13:38 — solar noon
22:11 — sunset
23:16 — dusk

00:00— n/a — night
n/a — n/a — astronomical twilight
n/a —03:59 — nautical twilight
03:59—05:04 — civil twilight
05:04—05:10 — sunrise
05:10—22:05 — daylight
22:05—22:11 — sunset
22:11—23:16 — civil twilight
23:16— n/a — nautical twilight
n/a — n/a — astronomical twilight
n/a —00:00 — night

Figure 12. Details from Figure 11: basic data on the left, detailed data on the right (Website of SunCalc 2017)

The SunCalc data in Figure 11 and Figure 12 show that there will be sunlight – provided weather conditions are accommodating – between the hours of 05:10 and 22:05 on August 1st 2017, with a peak at 13:38. PV output will correlate with the angle of the sun, meaning that peak irradiance is likely to occur at around 13:30, although resulting higher temperatures will likely have a negative effect on efficiency. The evidence however is favourable with regards to solar radiation availability at this location.

6.2 Energy required vs. energy available from a PV system

The PVGIS programme was used to obtain production estimates for systems of 5kW, 10kW, 15kW and 20kW sizes. This data was combined with consumption data to produce the graph below (Figure 13).

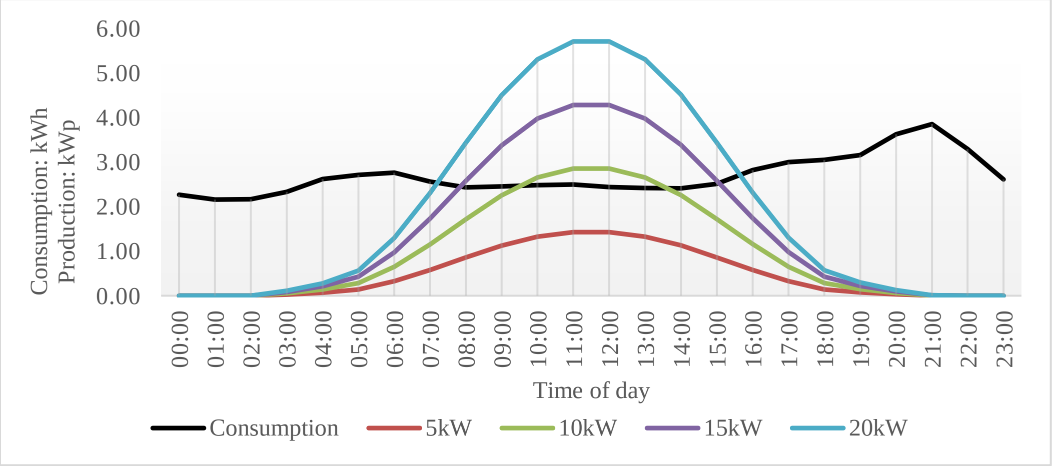


Figure 13. Graph showing average consumption by hour over a five-year period with estimated production by different systems sizes

Figure 13 shows a detailed electricity use profile which highlights those hours of the day where electrical consumption is highest. The graph shows that consumption begins to increase from around 14:00, peaking at 21:00. The hours of highest ('peak') consumption are between 19:00 and 22:00, which is when the occupants are known to be most active at home. Something worth noting is that there are times during the beginning and end of the day where there is insufficient solar energy production to cover consumption requirements, but also that there are varying degrees of surplus production which peak around midday. It is clear that both grid-sourced and solar-generated energy will be required to meet consumption needs. Peak consumption does not align well with production, and it would therefore be wise for the clients to consider if there are any activities which require electricity which currently occur after 14:00 which could be moved to an earlier time of the day when production would be higher. A possibility would be to install a simple timer on washing machines, or to set climate controls to cool the house more proactively during the day – when production is higher – so as to decrease the energy requirements for later in the day. This would increase the efficiency and thus cost-effectiveness of a solar energy system.

It is important to point out that the consumption profile in Figure 13 is the result of averaging five years' worth of hourly data – that is, 1,826 days' worth of data – without accounting for differences arising from different requirements owing to weather changes and so on. The reality is that both consumption and especially production fluctuate significantly over the course of a year. The graph is therefore merely to demonstrate some of the principles which apply to this case, and more precise calculations will require more detailed analysis which take these fluctuations into account.
To this end, the consumption data for this property, covering every hour of each day over the course of five years, was processed so as to give an average consumption for each hour of the day per month, dividing data into monthly segments. Hourly production estimates for each month from PVGIS were then compared to the consumption data. It was possible with the inclusion of PVGIS data to see how production matches consumption, highlighting periods of excess production and showing where consumption would still need to be supplemented by grid-drawn electricity. It is worth mentioning that the PVGIS data is only applicable for the first year of production, and that degradation calculations based on solar panel information supplied by the manufacturer will be applied to production data in order to provide accurate estimates for production and financial calculations beyond the first year.

Table 1. A summary of excess production, savings and remaining grid-drawn electricity requirements based on various system sizes for the first year, before any degradation of the efficiency of the systems has occurred

System size	Excess production	Remaining electricity supply deficit
5kW	56.87 kWh	19187.9 kWh
10kW	1350.93 kWh	16611.3 kWh
15kW	4238.89 kWh	15260.7 kWh
20kW	7679.55 kWh	14503.2 kWh

Calculations were made using an average yearly consumption rate of 23,616.3kWh.
An interesting aspect of Table 1 is the rate at which excess production increases with system size, especially when compared to the diminishing increases in consumption coverage. The reason for this is because consumption is relatively steady over 24 hours, whereas the production profile is a bell-shaped curve owing to the availability of solar radiation throughout the course of a day. When overlaid with one another on

a graph, the consumption line is horizontal and always above zero, whereas the production line will go from zero during hours of darkness to peaking around noon. The higher the system the rating, the higher the peak will be, sometimes rising far above the line of consumption. This is clearly illustrated in Figure 13.

6.3 Degradation

The manufacturer states that the degradation of the solar panels being considered occurs at a rate of 2.5% over the first year, with a linear 0.67% rate of degradation from that point forward (see Vikram Solar Eldora Ultima Silver Series PV panel factsheet in appendix 2). A simple calculation is all that is needed to determine the efficiency of a system after degradation by the end of the 27 year warranty:

$$2.5\% + (26 \times 0.67\%) = 19.92\% \qquad \text{(Equation 1)}$$

The result means that the solar panels are expected to be operating at around 80% efficiency after 27 years of use. However, calculating the effects this has on the financial aspect of things is not as simple. Although production can be quite easily calculated, production in relation to consumption will change, so over time the points at which production intercepts the line of consumption will change, which in turn will change the amount of excess energy generated (and thus income from selling excess production). A quick method for ascertaining whether this is true or not was to take the excel modelling for the first year, apply 27 years' worth of degradation calculations, and then compare the results to the results of applying the simple calculation above (Equation 1). The first column in Table 2 shows the calculated excess production for the first year. The second column ('Final year excess production (kWh)') shows the expected excess production after 27 years based on calculations which take into account the changes in the relationship between production and consumption over time, which can then be compared to column three ('Final year excess production using Equation 1 (kWh)') which shows the result of taking the first year's production value and subtracting 19.92% (in line with Equation 1).

Table 2. Table highlighting the disparity between calculating the relationship between production and consumption over a time period of 27 years and simply applying the calculation from Equation 1

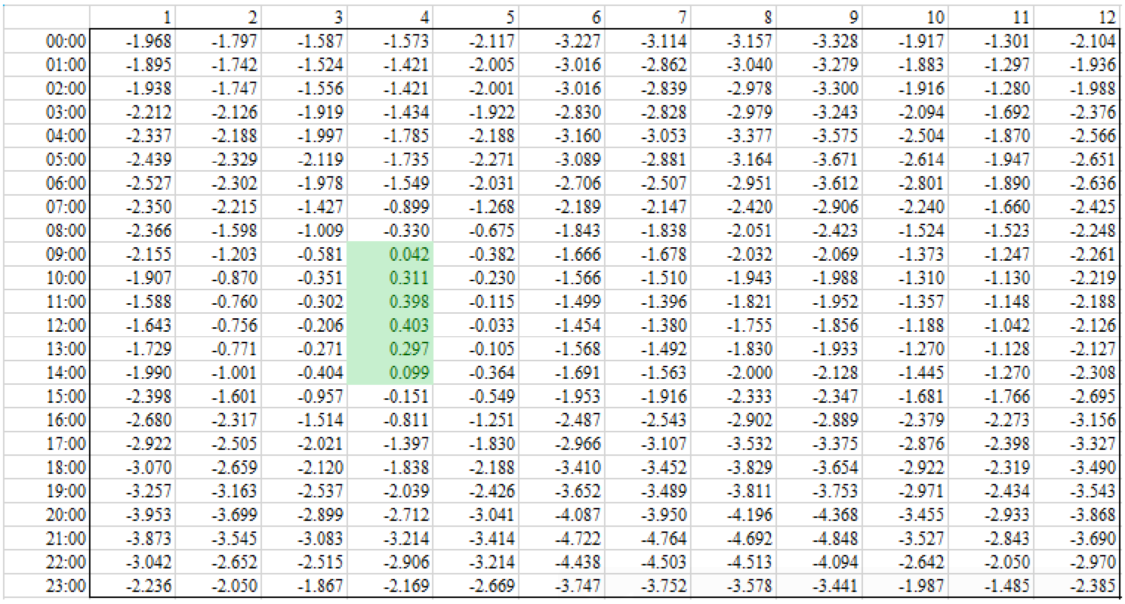
System size	First year excess production	Final year excess production	Final year excess production using Equation 1
5kW	56.87 kWh	5.78 kWh	45.54 kWh
10kW	1350.93 kWh	685.66 kWh	1081.82 kWh
15kW	4238.89 kWh	2567.09 kWh	3394.50 kWh
20kW	7679.55 kWh	5189.74 kWh	6149.79 kWh

What this means is that the characteristics of the relationship between consumption and production will change depending on the year of operation. For example, calculations show that a 5kW system would be expected to produce a total of around 56.9kWh in excess energy in the first year of operation, and only 5.8kWh of excess in the 27th year. In comparison, a 20kW system would be expected to produce a total of around 7679.6kWh in excess energy in the first year of operation, dropping to 5189.7kWh in the 27th year. Whereas the drop for a 5kW system stands at nearly 90%, the drop for a 20kW system is closer to 32%, a difference which will affect the income generated from selling excess production – and consequently the financial overview of an installation – significantly.

This can be taken into account by making calculations for each system size for each year of the expected 27 year degradation profile, and comparing the results to what is assumed to be the relatively stable consumption data. It takes some time and care to do so, but technology and programming allow for such work to be carried out at reasonable speed; specifically, these calculations were made using Microsoft Excel.

Calculating the relationship between energy demand and supply is not as simple as applying Equation 1. Solar energy generation is a bell-shaped curve on a graph, and energy consumption is a more-or-less straight line travelling horizontally across the graph. There is excess production if the dome of the bell-shaped curve rises above the line of consumption. When the dome rises above the line of consumption, there are two points of intersection: one where supply exceeds demand, and a second intersection where energy generation falls below demand. Taking into account that the area above the line of consumption represents excess production, Equation 1 does not calculate the changes that occur when the points of intersection shift as a result of changes in energy generation (Figure 13 somewhat illustrates this principle). It is for this reason that a more comprehensive approach was needed for these calculations.

Table 3. The expected electricity deficit, in kWh, for the first year of production of a 5kW system



	1	2	3	4	5	6	7	8	9	10	11	12
00:00	-1.968	-1.797	-1.587	-1.573	-2.117	-3.227	-3.114	-3.157	-3.328	-1.917	-1.301	-2.104
01:00	-1.895	-1.742	-1.524	-1.421	-2.005	-3.016	-2.862	-3.040	-3.279	-1.883	-1.297	-1.936
02:00	-1.938	-1.747	-1.556	-1.421	-2.001	-3.016	-2.839	-2.978	-3.300	-1.916	-1.280	-1.988
03:00	-2.212	-2.126	-1.919	-1.434	-1.922	-2.830	-2.828	-2.979	-3.243	-2.094	-1.692	-2.376
04:00	-2.337	-2.188	-1.997	-1.785	-2.188	-3.160	-3.053	-3.377	-3.575	-2.504	-1.870	-2.566
05:00	-2.439	-2.329	-2.119	-1.735	-2.271	-3.089	-2.881	-3.164	-3.671	-2.614	-1.947	-2.651
06:00	-2.527	-2.302	-1.978	-1.549	-2.031	-2.706	-2.507	-2.951	-3.612	-2.801	-1.890	-2.636
07:00	-2.350	-2.215	-1.427	-0.899	-1.268	-2.189	-2.147	-2.420	-2.906	-2.240	-1.660	-2.425
08:00	-2.366	-1.598	-1.009	-0.330	-0.675	-1.843	-1.838	-2.051	-2.423	-1.524	-1.523	-2.248
09:00	-2.155	-1.203	-0.581	0.042	-0.382	-1.666	-1.678	-2.032	-2.069	-1.373	-1.247	-2.261
10:00	-1.907	-0.870	-0.351	0.311	-0.230	-1.566	-1.510	-1.943	-1.988	-1.310	-1.130	-2.219
11:00	-1.588	-0.760	-0.302	0.398	-0.115	-1.499	-1.396	-1.821	-1.952	-1.357	-1.148	-2.188
12:00	-1.643	-0.756	-0.206	0.403	-0.033	-1.454	-1.380	-1.755	-1.856	-1.188	-1.042	-2.126
13:00	-1.729	-0.771	-0.271	0.297	-0.105	-1.568	-1.492	-1.830	-1.933	-1.270	-1.128	-2.127
14:00	-1.990	-1.001	-0.404	0.099	-0.364	-1.691	-1.563	-2.000	-2.128	-1.445	-1.270	-2.308
15:00	-2.398	-1.601	-0.957	-0.151	-0.549	-1.953	-1.916	-2.333	-2.347	-1.681	-1.766	-2.695
16:00	-2.680	-2.317	-1.514	-0.811	-1.251	-2.487	-2.543	-2.902	-2.889	-2.379	-2.273	-3.156
17:00	-2.922	-2.505	-2.021	-1.397	-1.830	-2.966	-3.107	-3.532	-3.375	-2.876	-2.398	-3.327
18:00	-3.070	-2.659	-2.120	-1.838	-2.188	-3.410	-3.452	-3.829	-3.654	-2.922	-2.319	-3.490
19:00	-3.257	-3.163	-2.537	-2.039	-2.426	-3.652	-3.489	-3.811	-3.753	-2.971	-2.434	-3.543
20:00	-3.953	-3.699	-2.899	-2.712	-3.041	-4.087	-3.950	-4.196	-4.368	-3.455	-2.933	-3.868
21:00	-3.873	-3.545	-3.083	-3.214	-3.414	-4.722	-4.764	-4.692	-4.848	-3.527	-2.843	-3.690
22:00	-3.042	-2.652	-2.515	-2.906	-3.214	-4.438	-4.503	-4.513	-4.094	-2.642	-2.050	-2.970
23:00	-2.236	-2.050	-1.867	-2.169	-2.669	-3.747	-3.752	-3.578	-3.441	-1.987	-1.485	-2.385

Five years' worth of hourly consumption data was processed so that for each month there was an average consumption-by-hour value. These values provide the base value in Table 3. The value is shown as a negative because these values are being represented as an energy deficit.

The production data from the PVGIS program resulted in a value which was positive, so that it could be 'overlaid' on the consumption data. Essentially, production values are being added to the consumption values to see how much of the deficit can be covered, and how much of a deficit remains. The values seen in Table 3 are the result of the consumption deficit plus the production values. If a value shown in Table 3 is a negative, it means that a supply deficit remains despite the solar energy supplied, and this must be covered by grid-drawn energy. If the value is near 0, it means that the production can be expected to generally cover the consumption needs. If the value is above 0, then there is excess energy, and this can be sold.

As an example, in Table 3, it can be seen that for '1':'00:00', the value is -1.968. That means that with a 5kW system installed, the household is expected to still require approximately 1.968kWh of energy to be supplied from the grid between the hours of 00:00 and 01:00 in the month of January. Looking at '4':'12:00', however, it can be seen that there is a value of 0.460. This value being positive means that there is expected to be an instance of production exceeding demand, resulting in what is called 'excess production', between the hours of 12:00 and 13:00 in April.

Table 3 shows the expected situation for the first year of use. For the purposes of this study there are 27 years' worth of tables for system sizes of 5-, 10-, 15- and 20kW to match the 27 years of performance data provided in the solar panel information sheets. Each year of production is slightly different due to the deterioration in performance of the solar panels that occurs with the passage of time. Although the expected consumption rates are being assumed to be identical for each year, the production is known to be different, and this needs to be taken into account when calculating the feasibility of a given system.

Equation 1 was used to calculate the expected production in a given year by modifying it slightly:

$$\text{Production value} \times (1 - (0.025 + ((\text{year of operation} - 1) \times 0.0067))) \qquad \text{(Equation 2)}$$

Equation 2 allows the expected production of a solar energy system to be calculated for any year, which, when applied over 27 years, provides a complete calculated estimate for production over the lifetime of systems of various sizes. It also makes it simple to compare solar and grid-drawn energy supplies and requirements, and to calculate the resulting economic circumstances.

Altogether this produced data which showed the estimated surplus production and energy deficit for 27 years of solar energy production whilst accounting for expected efficiency changes. These figures could then be processed into financial information – for example, the energy deficit was multiplied by the practical price of energy (€0.13/kWh) to estimate how much the cost of grid-drawn energy would be with each systems' installation.

6.4 Photovoltaic equipment costs

Finnwind provided information on the prices for 5kW, 10kW, 15kW and 20kW systems. The costs cover the whole system but do not include service costs such as installation for systems other than the 5kW system, and as a result these costs must be estimated and factored in later.

An itemised offer for a 5kW system was given outright as €7,191.45 without VAT (Value Added Tax), which becomes €8,917.40 when the 24% VAT was included (Appendix 2), and €9,072.40 with the addition of a data card for monitoring. For larger systems, the prices given by Finnwind – including the 24% VAT – were:

- a 5kW system costs €1.74/Wp (including installation)
- a 10kW system costs €1.30/Wp
- a 15.6kW system costs €1.27/Wp
- a 20kW system costs €1.23/Wp

This gives a total equipment cost for the systems of:

- €9,072.40 for a 5kW system (including installation)
- €13,000 for a 10kW system
- €19,812 for a 15kW system
- €24,600 for a 20kW system

For 10kW, 15kW and 20kW systems, there appears to be a pattern: the pre-tax price seems to drop by €0.03/Wp for every additional 5kW increase to a system size. Using this as a template, one could infer that a 5kW system costs €1.00/Wp before installation costs are included. This would suggest that installation costs around €0.36/Wp. This can be used to inform a rough estimate as to the possible equipment-plus-installation costs of each system size (prices include VAT):

- a 5kW system costs €9,072.40
- a 10kW system costs €16,600
- a 15kW system costs €24,450
- a 20kW system costs €32,000

Since more information on actual installation costs for systems sized above 5kW is not available, these will be the estimates used in financial calculations going forward.

6.5 Projected grid-sourced energy costs

Figure 14 displays the price of electricity in Finland over 2016 and 2017, in euros per kWh, from the Nord Pool statistical archives. It shows that the average price was close to 0.030 €/kWh at the beginning of 2016, creeping up towards 0.035 €/kWh by the end of 2017, an increase of roughly 15% over two years, or around 8% annually. These are the baseline prices for electricity, and the price per kWh of electricity for the customer is in reality several times higher once additional costs are factored in. When purchasing electricity, a customer pays for the electricity, the transfer of the electricity and taxes.

The understanding to be taken from the data is that there is an upward trend in grid drawn electricity prices. This underlines the idea that grid drawn electricity prices are increasing, something which lends support towards any considerations on installing a solar energy system.

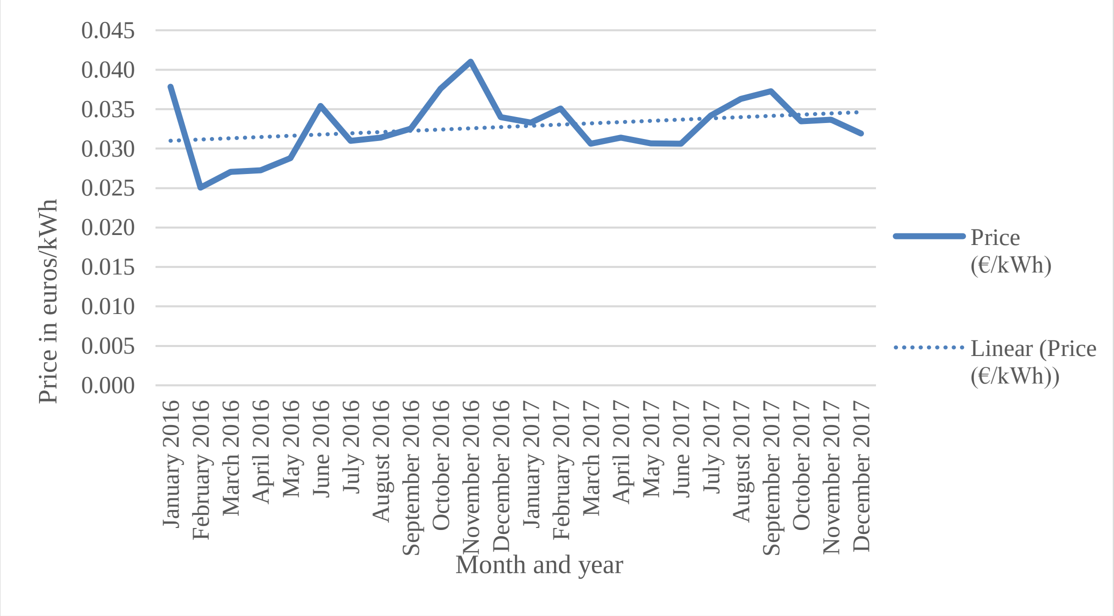


Figure 14. Finnish electricity prices showing an upward trend over the past two years, in euros per kWh (Website of Nord Pool 2018)

It is necessary to have an accurate understanding of the prices that the clients are facing for their electricity. This can be determined by looking at one of the client’s energy bills, shown in appendix 1. By taking the final sum of the bill and dividing it by

the number of kilowatt hours being charged, we find that the effective price of electricity is approximately €0.13 per kWh. This means that a customer pays around €0.10 extra per kWh in additional expenses on top of the baseline electricity price.
With the information available it is possible to compare the costs of grid-sourced and grid-plus-solar subsidised systems. The financial incentives are the savings made as a result of supplementing grid-sourced energy consumption in addition to income from selling excess generated energy to the grid. Each system would be expected to produce some quantity of excess energy which could be sold to the grid, although this appears to be negligible in the estimations for a 5kW system. For the other system sizes however, the estimated production of excess energy increases quite dramatically, although the potential income available from this must be compared to the investment costs associated with the respective larger systems.

6.6 Excess energy income

With all the system sizes under consideration, from 5kW to 20kW, there are times of the day where solar energy production will be in excess of consumption. The resulting excess energy can be sold back to the grid. Specifically, we will be looking at selling excess solar energy production to Köyliön-Säkylän Sähkö, the firm which is the current provider of electricity to the clients.
The information provided by Köyliön-Säkylän Sähkö states that they purchase excess consumption at the price of the Nord Pool SPOT rate minus 10% (Website of Köyliön-Säkylän Sähkö 2017). For example, if the SPOT rate was €0.03/kWh, the price that Köyliön-Säkylän Sähkö would pay would be €0.027/kWh. The Nord Pool SPOT price for Finland has been, on average, in the region of €0.03/kWh over the past two years, making it a fairly stable value for calculations concerning grid-drawn electricity costs for comparison with solar energy system estimates.

6.7 Payback time

It is an essential part of a solar energy system feasibility study to determine the payback time of a proposed system. This refers to how long it will take before the cumulative savings from the installation of a solar power system equal the investment cost of the solar energy system. PVGIS calculations, consumption data, Finnish grid-energy price estimations, solar energy system equipment and installation cost approximations all combine to present a picture of what can be expected from different solar energy system sizes and the associated financial details.

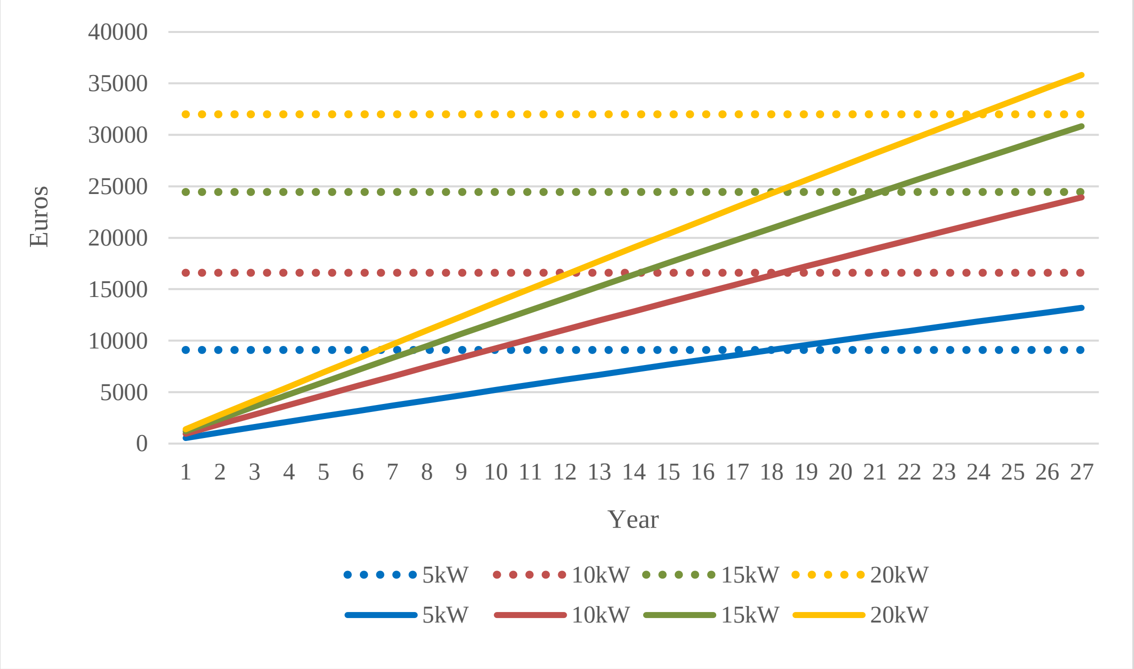


Figure 15. Graph showing the value of a solar energy system compared to the estimated costs of the various solar systems over a 27 year span. Dashed lines represent estimated system costs, and solid lines represent estimated savings plus income from excess production.

In Figure 15, the ‘value’ of a solar energy system is the combined total of savings (the energy which was supplied by the solar energy system and therefore not purchased from a grid supplier) plus the sale of excess energy, adjusted for time. As the values accumulate in Figure 15, they can be compared to the cost of the solar energy system. For a solar energy installation to be considered feasible, the savings must overtake the costs within a reasonable timeframe; after this point, the savings from a solar energy system cease to contribute towards repaying the initial investment and start to result in outright savings on energy costs.

The point of intersection in Figure 15 between the solid and dotted lines of, for example, the 5kW system, marks the point at which the system has paid for itself. Table 4 shows the estimated payback times for each system, based on Figure 15.

Table 4. Estimated payback times by system size based on Figure 15

System size (kW)	Payback time (years)
5	17
10	18
15	21
20	24

It can be seen quite clearly that the larger the system size, the longer it will take to reach a point of breaking-even, with an almost linear progression. Despite the long payback time for some systems, estimations nevertheless project that total savings will be produced by each system over the course of 27 years:

- 5kW: €5,274
- 10kW: €7,324
- 15kW: €6,389
- 20kW: €3,821

One potential issue which should be taken into account is the possibility of an increase in system price due to the addition of interest payments. Discussions with the clients suggest that it is likely that any solar energy system investment will be at least part-financed through a bank loan. There are a number of factors which make it tricky to nail down precisely what the terms of a loan would be in this case, but discussion with the clients have suggested that a likely rate of interest would be expected to be approximately 3%. This should be sufficient information to provide an estimate of how this would affect the price of a system under loan circumstances. The prices of the systems were increased by 3.5% to compensate, resulting in the information in Figure 16.

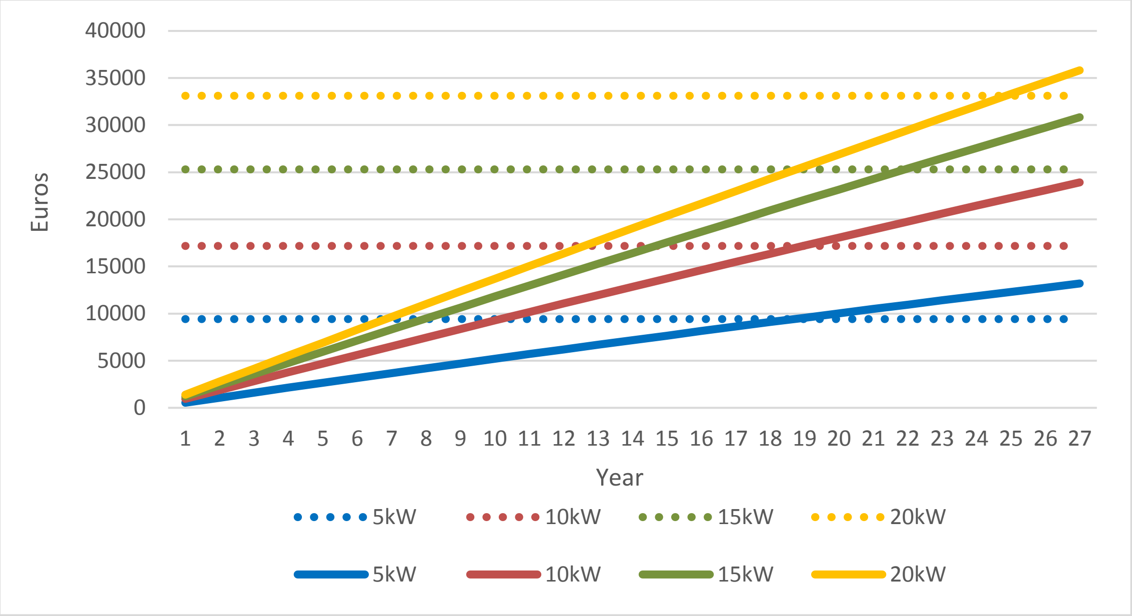


Figure 16. Identical to Figure 15 but with interest-adjusted system-cost increases, showing a higher price and longer break-even time periods

Figure 16 illustrates how an expected 3.5% increase to the overall cost of installing a solar energy system would affect the break-even point. The 3.5% increase also affects the expected total savings:

- 5kW: €4,955.50 (a drop of €318.50)
- 10kW: €6,743 (a drop of €581)
- 15kW: €5,533.25 (a drop of €855.75)
- 20kW: €2,701 (a drop of €1,120)

Table 5 is an updated version of Table 4 which reflects these developments. What it shows is that the increase in overall cost seems to affect the payback time by pushing it back by about a year.

Table 5. Estimated payback times by system size based on Figure 16

System size (kW)	Payback time (years)
5	18
10	19
15	22
20	25

What if certain conditions change? Two possibilities were considered: that the price of a solar energy system would drop by 10%, and that the price of grid-drawn electricity would increase by 0.001 €/kWh a year after the first year of installation.

In the case of the price of a solar energy system's price dropping by 10%, this is simply taking into account the factors which have been behind the drop in the cost of solar energy, factors such as increased solar energy component production capacity (higher manufacturing capacity reduces costs), improvements in the underlying technologies (increasing efficiency), the increase in competition for clients in the solar energy market (leading competing businesses to make increasingly competitive offers), the ability of emerging economies to manufacture components previously only manufactured by more developed economies at a cheaper price. The effect that a 10% drop in cost would have is illustrated in Figure 17.

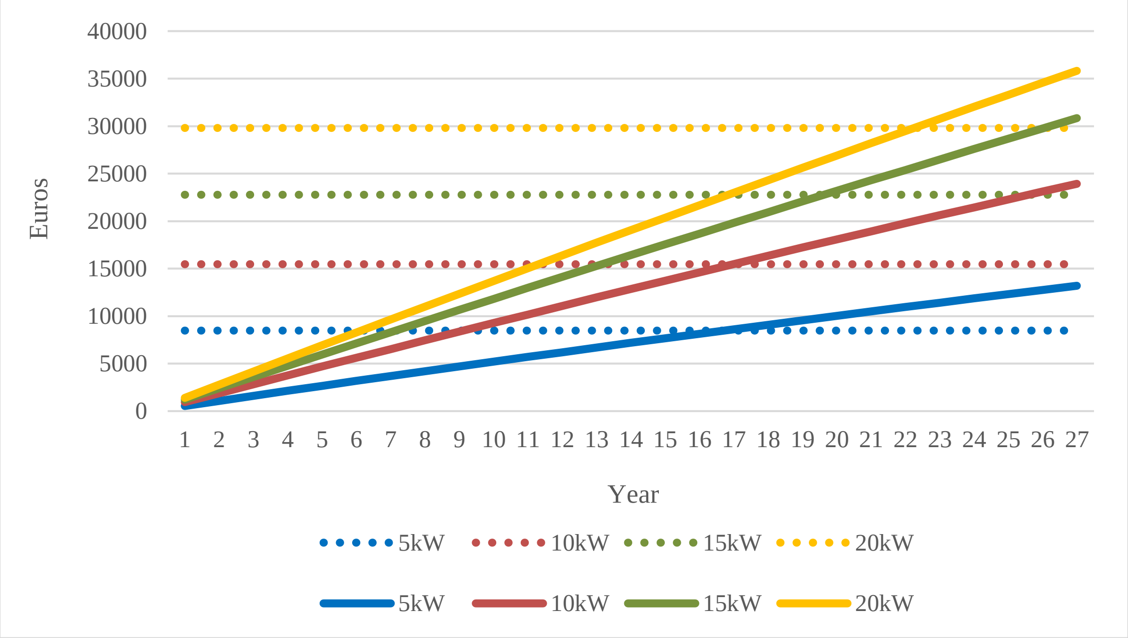


Figure 17. Identical to Figure 16 but with system costs reduced by 10%.

Table 6. Estimated payback times by system size based on Figure 17.

System size (kW)	Payback time (years)
5	16
10	17
15	20
20	22

Table 6 makes shows that payback times decrease by around a year for a 5kW system, by two years for 10- and 15kW systems, and by three years for a 20kW system. However, matters get much more interesting when referring back to Figure 14, where a general upward trend in the cost of grid-drawn electricity over two recent years can be seen. For several years now there have been warnings from various news outlets, quoting a number of respectable sources, that energy prices are expected to rise in the foreseeable future. In order to simulate this, Figure 17 was recalculated with the added factor of grid-drawn energy prices increasing by 0.001 €/kWh each year after the first year of installation. The result is presented in Figure **18**.

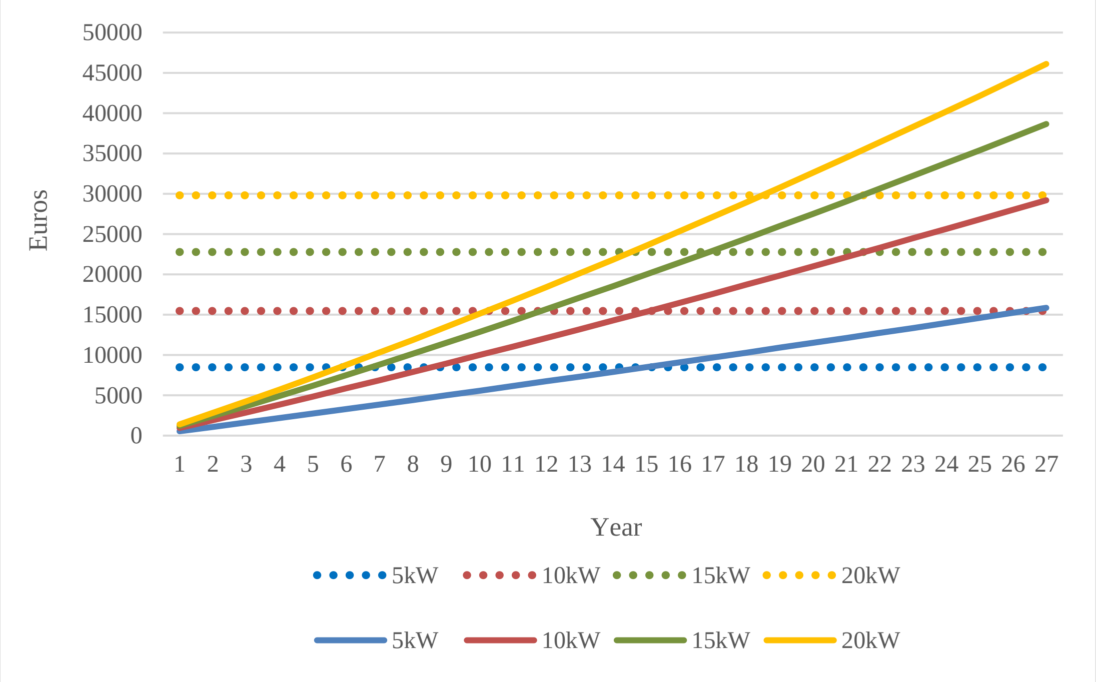


Figure 18. Identical to Figure 17 but with a linear increase in the price of grid-drawn energy taken into account

Table 7. Estimated payback times by system size based on Figure 18.

System size (kW)	Payback time (years)
5	15
10	15
15	17
20	18

Figure **18** and Table 7 make for interesting speculation. The conditions in Figure **18** are that the cost of the solar energy systems have dropped by 10% in comparison to the solar energy system prices in chapter 6.4, a loan with an interest rate of 3.5% has been included in the cost of the systems, and an increase in the price of grid-drawn energy of 0.001 €/kWh per year after the first year of installation has been applied.

The drop in system cost and increase in the price of grid-drawn energy would clearly favour the installation of a solar energy system, to the point that there is a change in perspective of the appeal of a 20kW system, which initially looks ridiculous in Figure 16, but then begins to look like a potentially profitable investment in Figure 18. In contrast, a 5kW system loses ground in terms of appeal, and it becomes more challenging to argue its case over that of the other system sizes.

Ultimately, however, it must be understood that there is no guarantee whatsoever that a 10% drop in system cost or an increase in the price of grid-drawn electricity will come to pass. As a result, although they look promising, Figures 17 and 18 cannot be considered to be based on reliable information, and they will not be discussed in the conclusion. It is however at the discretion of the clients if they wish to take Figures 17 and 18 into consideration based on their own best judgement when making a decision on the role that solar energy will have in their future.

7 CONCLUSION

It is clear that this property meets the criteria for a photovoltaic solar power system. The energy consumption is projected to be comfortably and even profitably covered by each of the solar system sizes. With such a good fit between requirements and potential, the main question is, if an investment is going to be made, which size system to choose.

It seems worth mentioning beforehand that two factors which have not been included in the final calculations may increase the appeal of the solar energy systems: potentially over-estimated installation cost figures and the effect of rising grid-drawn energy prices. Concerning the installation costs estimated for each system above 5kW, it is entirely possible – if not likely – that the installation cost will not remain equal per kWp, but will decrease conversely to kWp rating increases. Taking this into account reduces the investment cost for the systems above 5kW. Concerning increasing grid-drawn energy prices, the upward trend in prices serves to increase the value of each kWh generated by a private solar energy system; ultimately, it suggests that the value of the energy expected to be produced may increase over time. As neither of these dynamic factors have been included in calculations, it could be said that the benefits as stated in this conclusion are conservative, and that there is room for greater financial advantages than are presented. In addition to the two aforementioned factors, it is entirely possible that the interest-inflated system cost values are overestimates – for example, the clients may not take out a loan for the full cost of a system, which would decrease the actual amount of interest paid.

That being said, calculations project an estimated net profitability from each of the systems; in other words, each system is expected to repay its investment cost through the savings it provides from the energy it generates, and to then generate further savings thereafter. However, not all of the system sizes are equal in how effective they are expected to be at fulfilling these requirements.

The 5kW system has a number of advantages: the lowest investment cost, the least extensive system in terms of equipment, which also means the fewest number of components with the potential to malfunction, the quickest payback time period, and the third-highest but close to second-highest post-payback financial value. Although the 5kW system’s post-payback financial value is similar to those of the other systems, this figure increases in value when considered alongside the size of the system: a post-payback value of as-near-as-makes-no-difference €1,000/kWp system size, which is far beyond what any of the other systems can offer.

The 10kW has the second lowest investment cost, and a lower cost per Wp investment cost than the 5kW system, as well as the second the quickest payback time. The 10kW system’s main attraction however would be its post-payback financial value, which at over €6,500 is a not-inconsiderable amount.

The 15kW system provides even greater price-per-Wp investment value than the 5kW and 10kW systems, as well as the second-highest post-payback financial value, but this is offset by the long payback time. At this size, the system is also more difficult to maintain and at higher risk of malfunction compared to smaller systems with fewer components to manage.

The 20kW system’s only apparent positive aspect is that it has the lowest price-per-Wp investment cost of all the systems considered. In every other sense, however, it has the worst features: the most number of components and their associated potential problems, the longest payback time, highest investment cost and lowest post-payback financial value.

The 5kW and 10kW systems are considered to be the most attractive options. The 5kW system is most highly recommended, although should investment liquidity not be compromised, the 10kW system would also be recommended for consideration as it offers the highest post-payback value.

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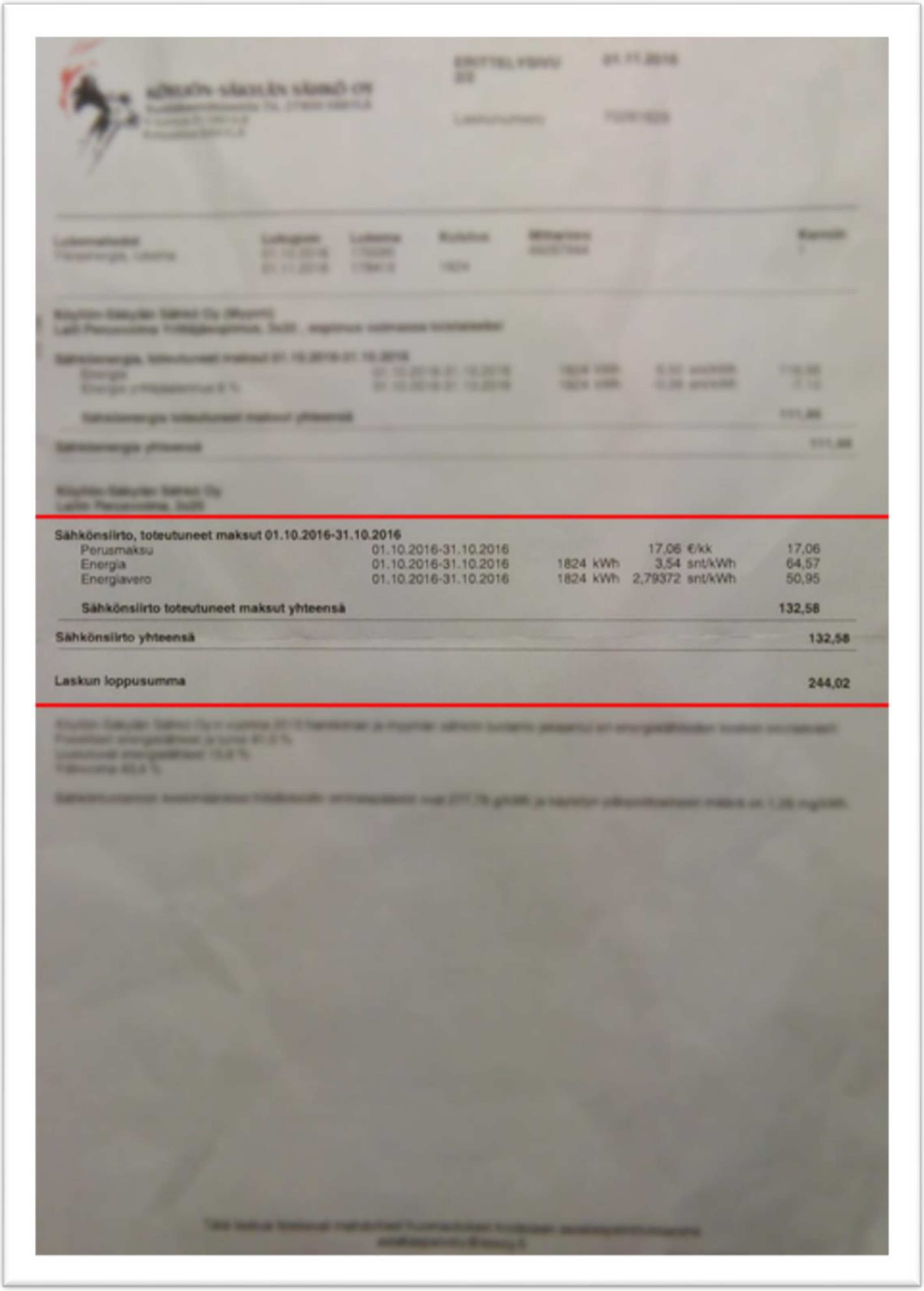
APPENDIX 1

Eräpäivä Förf.dag	15.11.2016	Euro	244,02



Sähkönsiirto, toteutuneet maksut 01.10.2016-31.10.2016

Perusmaksu	01.10.2016-31.10.2016		17,06 €/kk	17,06
Energia	01.10.2016-31.10.2016	1824 kWh	3,54 snt/kWh	64,57
Energiavero	01.10.2016-31.10.2016	1824 kWh	2,79372 snt/kWh	50,95
Sähkönsiirto toteutuneet maksut yhteensä				**132,58**
Sähkönsiirto yhteensä				**132,58**
Laskun loppusumma				**244,02**

APPENDIX 2

Tarjousnro 010278

Tarjous pvm 27-04-2017

Janos Cheshire

Toimitusosoite: Köyliö

TARJOUS

Tarjottavat tuotteet ja palvelut

Pos.	Tuote	Tuotteen kuvaus	Hinta	Määrä	Yhteensä
1	Järjestelmäsuunnittelu	Järjestelmäsuunnittelu sisältyy tuotteiden sekä asennuksen hintaan.	0,00	1	0,00
2	Aurinko E5, Fronius Light	Aurinkopaneeliteho 5200Wp, polykide aurinkopaneelit 20 kpl * 260 Wp Verkkoinvertteri Fronius Symo M Light 5kW, kaapelit, turvakytkin, sulake. EN50438 standardin edellyttämät varoitusmerkinnät Suomi ja Ruotsi. Huom! Fronius Symo Light invertteriversio ei sisällä dataliikennekorttia. Tuottotietoja voi seurata invertterin omalta näytöltä ja Light versiossa tiedonsiirtomahdollisuus muistitikulle. Dataliikennekortti saatavilla optiona.	4.722,00	1	4.722,00
3	FS-H asennusjärjestelmä harjakatolle, E5	CE-merkitty, EN1090 sertifioitu Suomen olosuhteisiin suunniteltu ja Suomessa valmistettu aurinkopaneelien asennusjärjestelmä harjakatolle lappeen myötäiseen asennukseen. Finnwind, Suomi	938,00	1	938,00
4	Aurinkovoimalan asennus, E5	Aurinkosähköjärjestelmän avaimet käteen asennus ja käyttöönotto sisältäen verkkoonliityntäilmoituksen teon.	1.306,45	1	1.306,45
5	Asennuksen pientarvikkeet, E	Asennuksen tavanmukaiset pientarvikkeet	80,00	1	80,00
6	Toimituskulut, E5	toimituskulut sis. matkakulut ja paneelit katolle nostettuna	145,00	1	145,00

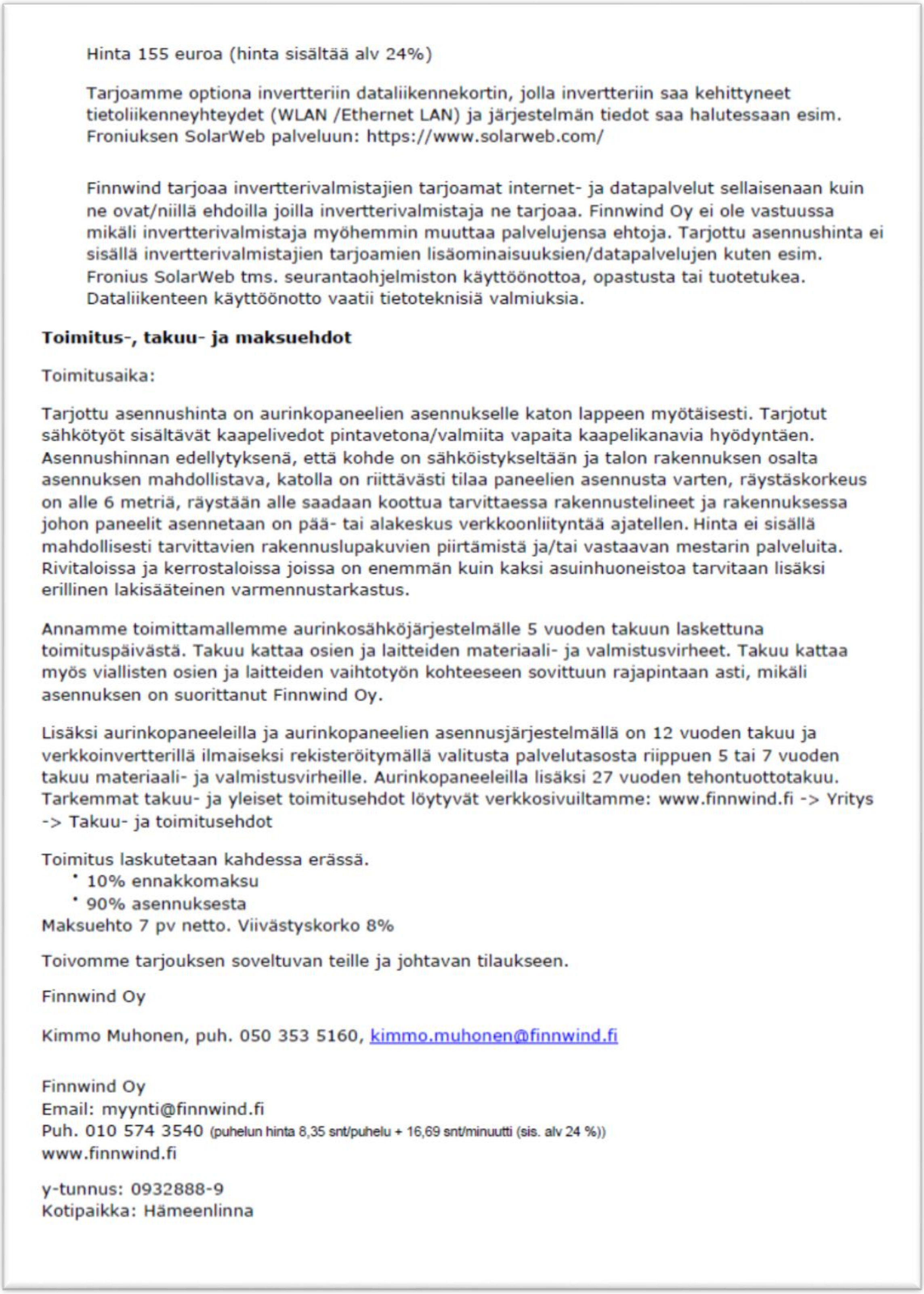
Yhteensä 7.191,45
ALV 24% 1.725,95

Yhteensä sisältäen Alv:n 8.917,40

* Tarkemmat tuotekohtaiset toimitussisällöt ja tekniset tiedot löytyvät tuote-esitteistämme: www.finnwind.fi

Tarjous on voimassa 11-05-2017

Optio: Dataliikennekortti



Hinta 155 euroa (hinta sisältää alv 24%)

Tarjoamme optiona invertteriin dataliikennekortin, jolla invertteriin saa kehittyneet tietoliikenneyhteydet (WLAN /Ethernet LAN) ja järjestelmän tiedot saa halutessaan esim. Froniuksen SolarWeb palveluun: https://www.solarweb.com/

Finnwind tarjoaa invertterivalmistajien tarjoamat internet- ja datapalvelut sellaisenaan kuin ne ovat/niillä ehdoilla joilla invertterivalmistaja ne tarjoaa. Finnwind Oy ei ole vastuussa mikäli invertterivalmistaja myöhemmin muuttaa palvelujensa ehtoja. Tarjottu asennushinta ei sisällä invertterivalmistajien tarjoamien lisäominaisuuksien/datapalvelujen kuten esim. Fronius SolarWeb tms. seurantaohjelmiston käyttöönottoa, opastusta tai tuotetukea. Dataliikenteen käyttöönotto vaatii tietoteknisiä valmiuksia.

Toimitus-, takuu- ja maksuehdot

Toimitusaika:

Tarjottu asennushinta on aurinkopaneelien asennukselle katon lappeen myötäisesti. Tarjotut sähkötyöt sisältävät kaapelivedot pintavetona/valmiita vapaita kaapelikanavia hyödyntäen. Asennushinnan edellytyksenä, että kohde on sähköistykseltään ja talon rakennuksen osalta asennuksen mahdollistava, katolla on riittävästi tilaa paneelien asennusta varten, räystäskorkeus on alle 6 metriä, räystään alle saadaan koottua tarvittaessa rakennustelineet ja rakennuksessa johon paneelit asennetaan on pää- tai alakeskus verkkoonliityntää ajatellen. Hinta ei sisällä mahdollisesti tarvittavien rakennuslupakuvien piirtämistä ja/tai vastaavan mestarin palveluita. Rivitaloissa ja kerrostaloissa joissa on enemmän kuin kaksi asuinhuoneistoa tarvitaan lisäksi erillinen lakisääteinen varmennustarkastus.

Annamme toimittamallemme aurinkosähköjärjestelmälle 5 vuoden takuun laskettuna toimituspäivästä. Takuu kattaa osien ja laitteiden materiaali- ja valmistusvirheet. Takuu kattaa myös viallisten osien ja laitteiden vaihtotyön kohteeseen sovittuun rajapintaan asti, mikäli asennuksen on suorittanut Finnwind Oy.

Lisäksi aurinkopaneeleilla ja aurinkopaneelien asennusjärjestelmällä on 12 vuoden takuu ja verkkoinvertterillä ilmaiseksi rekisteröitymällä valitusta palvelutasosta riippuen 5 tai 7 vuoden takuu materiaali- ja valmistusvirheille. Aurinkopaneeleilla lisäksi 27 vuoden tehontuottotakuu. Tarkemmat takuu- ja yleiset toimitusehdot löytyvät verkkosivuiltamme: www.finnwind.fi -> Yritys -> Takuu- ja toimitusehdot

Toimitus laskutetaan kahdessa erässä.
- 10% ennakkomaksu
- 90% asennuksesta

Maksuehto 7 pv netto. Viivästyskorko 8%

Toivomme tarjouksen soveltuvan teille ja johtavan tilaukseen.

Finnwind Oy

Kimmo Muhonen, puh. 050 353 5160, kimmo.muhonen@finnwind.fi

Finnwind Oy
Email: myynti@finnwind.fi
Puh. 010 574 3540 (puhelun hinta 8,35 snt/puhelu + 16,69 snt/minuutti (sis. alv 24 %))
www.finnwind.fi

y-tunnus: 0932888-9
Kotipaikka: Hämeenlinna

Lempäälän ja Tuusulan tuotanto- ja logistiikkavarastot:

Finnwind Lempäälä, Koiranojanrinne 4 A, 33880 Lempäälä
Finnwind Tuusula, Huoltotie 4, 04300 Tuusula

APPENDIX 3

ELDORA

HIGH EFFICIENCY SOLAR PV MODULES

vikramsolar

CREATING CLIMATE FOR CHANGE

ELDORA VSP.60.AAA.03.04| POLYCRYSTALLINE SOLAR PV MODULES | 60 CELLS | 255-280 WATT

ELDORA ULTIMA

SILVER SERIES

HIGHER OUTPUT OF MODULE POWER by reducing cell to module power loss

Designed for very **HIGH AREA EFFICIENCY** ideally suited for roof-top and ground-mounted applications

Up to +2.5 Wp **POSITIVE POWER OUTPUT TOLERANCE GUARANTEED** ensuring better ROI

Extremely **RELIABLE PRODUCT** suiting all environment conditions

Engineered to provide **EXCELLENT LOW LIGHT RESPONSE**

Extremely **NARROW POWER BINNING TOLERANCE** to reduce current mismatch loss in single string

CE PV CYCLE

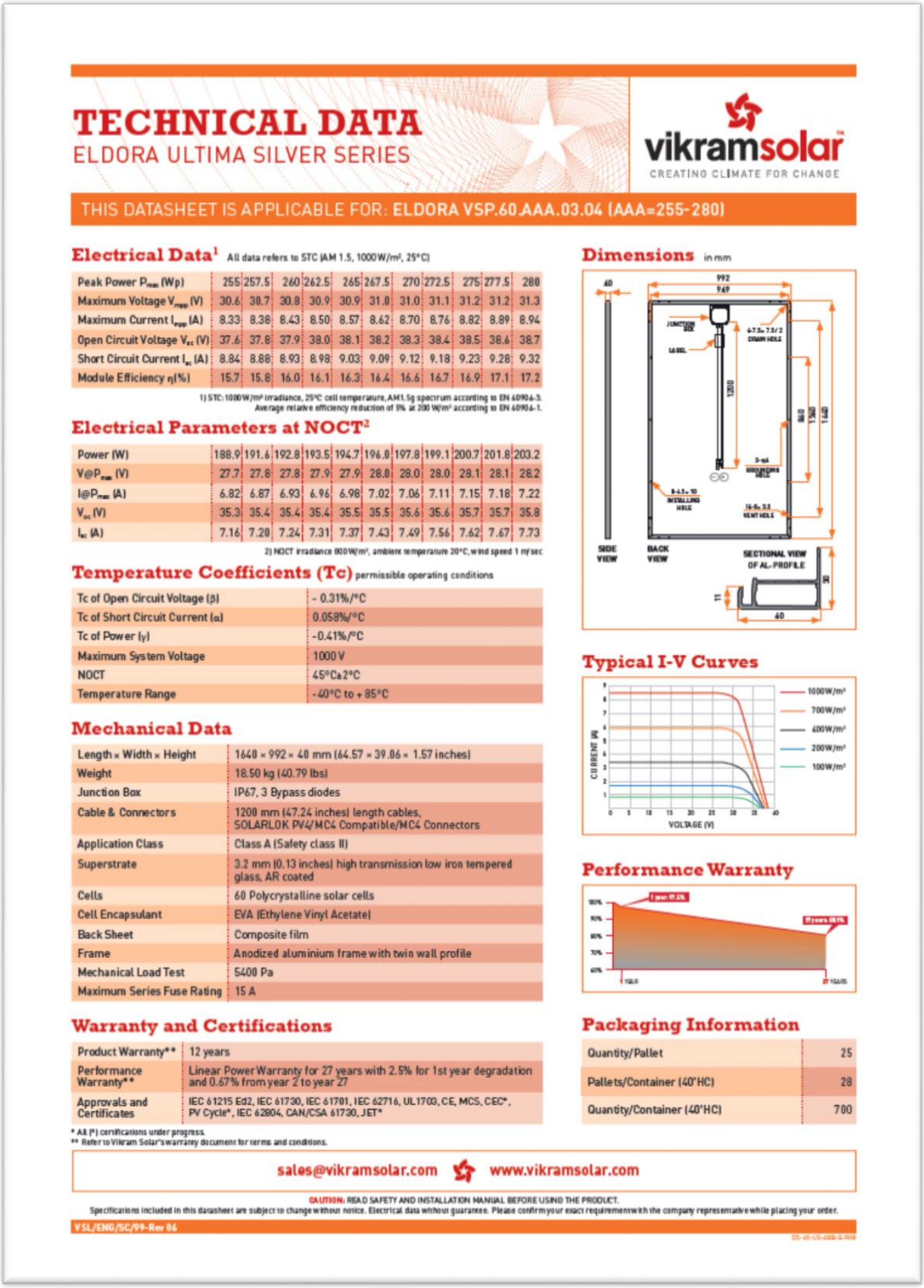
QUALITY AND SAFETY

- 27 years of linear power output warranty **
- Rigorous quality control meeting the highest international standards
- 100% EL tested to ensure micro crack free modules
- Certified for PID resistance
- Certified for salt mist corrosion resistance – severity VI
- Certified for ammonia resistance
- Compatible with K2, HILTI & Schletter structures for short and long side clamping*
- 3rd Party PAN file validated by PVEL*
- Approved by OST energy*

APPLICATIONS

- On-grid large scale utility systems
- On-grid rooftop residential and commercial systems
- Off-grid residential systems

VSL/ENG/SC/99-Rev 06 www.vikramsolar.com Email: sales@vikramsolar.com



TECHNICAL DATA

ELDORA ULTIMA SILVER SERIES

vikramsolar

CREATING CLIMATE FOR CHANGE

THIS DATASHEET IS APPLICABLE FOR: **ELDORA VSP.60.AAA.03.04 (AAA=255-280)**

Electrical Data[1]

All data refers to STC (AM 1.5, 1000W/m², 25°C)

Peak Power P_{max} (Wp)	255	257.5	260	262.5	265	267.5	270	272.5	275	277.5	280
Maximum Voltage V_{mpp} (V)	30.6	30.7	30.8	30.9	30.9	31.0	31.0	31.1	31.2	31.2	31.3
Maximum Current I_{mpp} (A)	8.33	8.38	8.43	8.50	8.57	8.62	8.70	8.76	8.82	8.89	8.94
Open Circuit Voltage V_{oc} (V)	37.6	37.8	37.9	38.0	38.1	38.2	38.3	38.4	38.5	38.6	38.7
Short Circuit Current I_{sc} (A)	8.84	8.88	8.93	8.98	9.03	9.09	9.12	9.18	9.23	9.28	9.32
Module Efficiency η(%)	15.7	15.8	16.0	16.1	16.3	16.4	16.6	16.7	16.9	17.1	17.2

1) STC: 1000W/m² irradiance, 25°C cell temperature, AM1.5g spectrum according to EN 60904-3.
Average relative efficiency reduction of 5% at 200 W/m² according to EN 60904-1.

Electrical Parameters at NOCT[2]

Power (W)	188.9	191.6	192.8	193.5	194.7	196.0	197.8	199.1	200.7	201.8	203.2
V@P_{max} (V)	27.7	27.8	27.8	27.9	27.9	28.0	28.0	28.0	28.1	28.1	28.2
I@P_{max} (A)	6.82	6.87	6.93	6.96	6.98	7.02	7.06	7.11	7.15	7.18	7.22
V_{oc} (V)	35.3	35.4	35.4	35.4	35.5	35.5	35.6	35.6	35.7	35.7	35.8
I_{sc} (A)	7.16	7.20	7.24	7.31	7.37	7.43	7.49	7.56	7.62	7.67	7.73

2) NOCT irradiance 800W/m², ambient temperature 20°C, wind speed 1 m/sec

Temperature Coefficients (Tc)

permissible operating conditions

Tc of Open Circuit Voltage (β)	- 0.31%/°C
Tc of Short Circuit Current (α)	0.058%/°C
Tc of Power (γ)	-0.41%/°C
Maximum System Voltage	1000 V
NOCT	45°C±2°C
Temperature Range	-40°C to + 85°C

Mechanical Data

Length × Width × Height	1640 × 992 × 40 mm (64.57 × 39.06 × 1.57 inches)
Weight	18.50 kg (40.79 lbs)
Junction Box	IP67, 3 Bypass diodes
Cable & Connectors	1200 mm (47.24 inches) length cables, SOLARLOK PV4/MC4 Compatible/MC4 Connectors
Application Class	Class A (Safety class II)
Superstrate	3.2 mm (0.13 inches) high transmission low iron tempered glass, AR coated
Cells	60 Polycrystalline solar cells
Cell Encapsulant	EVA (Ethylene Vinyl Acetate)
Back Sheet	Composite film
Frame	Anodized aluminium frame with twin wall profile
Mechanical Load Test	5400 Pa
Maximum Series Fuse Rating	15 A

Warranty and Certifications

Product Warranty**	12 years
Performance Warranty**	Linear Power Warranty for 27 years with 2.5% for 1st year degradation and 0.67% from year 2 to year 27
Approvals and Certificates	IEC 61215 Ed2, IEC 61730, IEC 61701, IEC 62716, UL1703, CE, MCS, CEC*, PV Cycle*, IEC 62804, CAN/CSA 61730, JET*

* All (*) certifications under progress.
** Refer to Vikram Solar's warranty document for terms and conditions.

Dimensions

in mm

Typical I-V Curves

Performance Warranty

Packaging Information

Quantity/Pallet	25
Pallets/Container (40'HC)	28
Quantity/Container (40'HC)	700

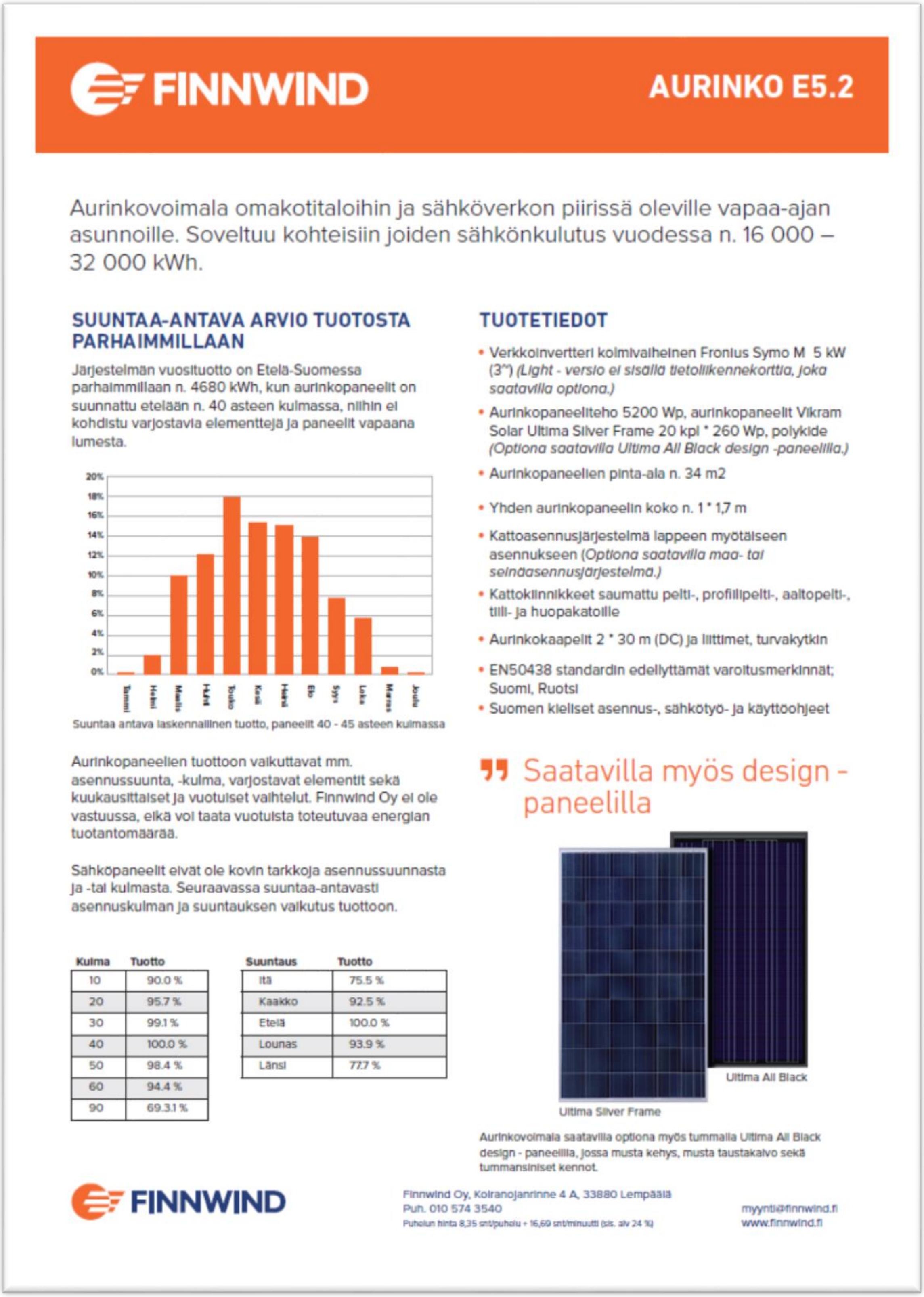
sales@vikramsolar.com www.vikramsolar.com

CAUTION: READ SAFETY AND INSTALLATION MANUAL BEFORE USING THE PRODUCT.

Specifications included in this datasheet are subject to change without notice. Electrical data without guarantee. Please confirm your exact requirement with the company representative while placing your order.

VSL/ENG/SC/99-Rev 06

APPENDIX 4



FINNWIND

AURINKO E5.2

Aurinkovoimala omakotitaloihin ja sähköverkon piirissä oleville vapaa-ajan asunnoille. Soveltuu kohteisiin joiden sähkönkulutus vuodessa n. 16 000 – 32 000 kWh.

SUUNTAA-ANTAVA ARVIO TUOTOSTA PARHAIMMILLAAN

Järjestelmän vuosituotto on Etelä-Suomessa parhaimmillaan n. 4680 kWh, kun aurinkopaneelit on suunnattu etelään n. 40 asteen kulmassa, niihin ei kohdistu varjostavia elementtejä ja paneelit vapaana lumesta.

Suuntaa antava laskennallinen tuotto, paneelit 40 - 45 asteen kulmassa

Aurinkopaneelien tuottoon vaikuttavat mm. asennussuunta, -kulma, varjostavat elementit sekä kuukausittaiset ja vuotuiset vaihtelut. Finnwind Oy ei ole vastuussa, eikä voi taata vuotuista toteutuvaa energian tuotantomäärää.

Sähköpaneelit eivät ole kovin tarkkoja asennussuunnasta ja -tai kulmasta. Seuraavassa suuntaa-antavasti asennuskulman ja suuntauksen vaikutus tuottoon.

Kulma	Tuotto
10	90.0 %
20	95.7 %
30	99.1 %
40	100.0 %
50	98.4 %
60	94.4 %
90	69.3.1 %

Suuntaus	Tuotto
Itä	75.5 %
Kaakko	92.5 %
Etelä	100.0 %
Lounas	93.9 %
Länsi	77.7 %

TUOTETIEDOT

- Verkkoinvertteri kolmivaiheinen Fronius Symo M 5 kW (3~) *(Light - versio ei sisällä tietoliikennekorttia, joka saatavilla optiona.)*
- Aurinkopaneeliteho 5200 Wp, aurinkopaneelit Vikram Solar Ultima Silver Frame 20 kpl * 260 Wp, polykide *(Optiona saatavilla Ultima All Black design -paneelilla.)*
- Aurinkopaneelien pinta-ala n. 34 m2
- Yhden aurinkopaneelin koko n. 1 * 1,7 m
- Kattoasennusjärjestelmä lappeen myötäiseen asennukseen *(Optiona saatavilla maa- tai seinäasennusjärjestelmä.)*
- Kattokiinnikkeet saumattu pelti-, profiilipelti-, aaltopelti-, tiili- ja huopakatoille
- Aurinkokaapelit 2 * 30 m (DC) ja liittimet, turvakytkin
- EN50438 standardin edellyttämät varoitusmerkinnät; Suomi, Ruotsi
- Suomen kieliset asennus-, sähkötyö- ja käyttöohjeet

> „ Saatavilla myös design -paneelilla

Ultima All Black

Ultima Silver Frame

Aurinkovoimala saatavilla optiona myös tummalla Ultima All Black design - paneelilla, jossa musta kehys, musta taustakalvo sekä tummansiniset kennot.

FINNWIND

Finnwind Oy, Koiranojanrinne 4 A, 33880 Lempäälä
Puh. 010 574 3540
Puhelun hinta 8,35 snt/puhelu + 16,69 snt/minuutti (sis. alv 24 %)

myynti@finnwind.fi
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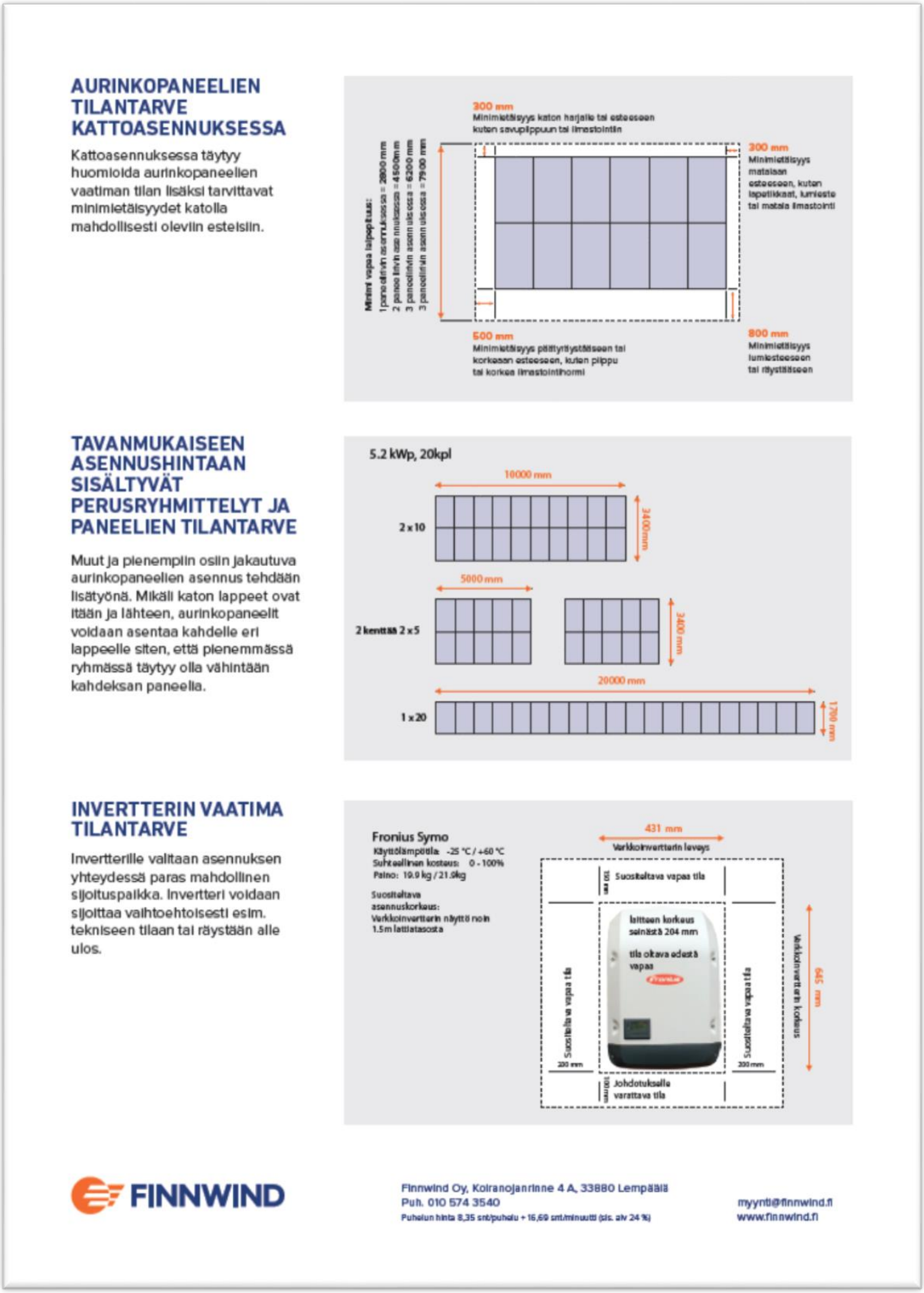

AURINKOPANEELIEN TILANTARVE KATTOASENNUKSESSA

Kattoasennuksessa täytyy huomioida aurinkopaneelien vaatiman tilan lisäksi tarvittavat minimietäisyydet katolla mahdollisesti oleviin esteisiin.

TAVANMUKAISEEN ASENNUSHINTAAN SISÄLTYVÄT PERUSRYHMITTELYT JA PANEELIEN TILANTARVE

Muut ja pienemplin osiin jakautuva aurinkopaneelien asennus tehdään lisätyönä. Mikäli katon lappeet ovat itään ja länteen, aurinkopaneelit voidaan asentaa kahdelle eri lappeelle siten, että pienemmässä ryhmässä täytyy olla vähintään kahdeksan paneelia.

INVERTTERIN VAATIMA TILANTARVE

Invertterille valitaan asennuksen yhteydessä paras mahdollinen sijoituspaikka. Invertteri voidaan sijoittaa vaihtoehtoisesti esim. tekniseen tilaan tai räystään alle ulos.

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