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Solar cells to counter rising electricity prices

Self-consumption and profitability of solar cells for a SME in price area 2 in Sweden.

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Preface

This thesis is the completed part of my studies at the master program in Energy Engineering at the University of Gävle.

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Abstract

Increases in electricity prices in Sweden during the second half of 2021 have created a great deal of concern among companies in Sweden. Some companies report that they have stopped their production temporarily when electricity prices have been high. Several of the companies also report that future investments have been stopped and some of the companies also state that they have or are planning to move their production abroad. One of the companies that has been affected by the increased electricity prices is an SME (Small Medium Enterprise) company located in electricity area 2 in Sweden. This has caused the company to evaluate different alternatives to be able to lower their costs linked to their electricity consumption. One of the options that is being evaluated is to invest in a solar (photo voltaic) cell, a technology that has become significantly cheaper over time and solar cells installations have increased a lot in Sweden recent years.

The purpose of this study is to help the company evaluate whether it is a good option or not to install a solar cells system. The perception within the company is that the price for purchasing electricity is higher than what they would earn from selling the electricity. Therefore, the company wants to install a solar cells system which has a high proportion of self-consumption. But is that view true and, if so, to what extent and how could a solar cells system be designed to optimize self-consumption?

The result shows that by tilting and turning the solar cell panels, it is possible to change the time for production and the amount of electricity produced from a solar power system. In the current case for this study, electrical consumption is at its highest during working hours 07.00-16.00. It is also during this time of the day the solar radiation is at its most intense and the solar cells system can produce as efficiently as possible. Results showed that it was not profitable to increase self-consumption by turning and tilting the solar panels so that they produced less during the holiday season and more during other parts of the year. The view that self-consumption would increase profitability proved correct and it turned out that a smaller solar plant system is more profitable until the point that the installed power per SEK increased.

The conclusion of the work is based on the results of the best-designed solar cells system based on installation costs, previous electricity consumption, forecasted electricity prices and current STIBOR rate. The pay-off time for this solar cell system would be 8.6 years and 15.6 years discounted pay-off time. Which may certainly seem like a bad investment and therefore, one might wonder why so many solar cell plants are installed in Sweden. This can largely be explained that from 2020 there are no subsidies for the installation to apply for companies. The company is also not entitled to a tax reduction that gives 0.60 SEK for each kWh sold. This is because their main fuse exceeds the limit of 100A, which is above the limit according to one of the Swedish tax agency requirements for obtaining the tax reduction.

Keywords: SME, Solar cells, Gävleborg County, Self-consumption, Matching.

Nomenclature

Orientation	
East	-90°
South	0°
West	+90°

Letters	Descriptions
kWp	Kilo watt peak
SE1-4	Electrical price areas 1-4 in Sweden
SEK	Swedish crowns
Wp	Watt peak

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1 Introduction

Electricity consumption and its costs have become a hot topic for many companies in Sweden since prices began to rise in the second half of year 2021, as shown in Fig. 1 below. The price increases have been so significant that several companies have temporarily stopped their production when electricity prices have been high. In addition to the mentioned production stop, it has also created concern for the future of several companies, a concern that, if realized, could mean a stop for future investments and liquidation. There are also some companies that have thoughts of moving production abroad (Jagrén, 2022). As shown in the graph in Fig. 1 below, it is mainly companies in the Southern parts of Sweden (SE3-4) that have been affected by the increased electricity prices. This is due to a lack of electrical transfer capacity between electrical areas where demand is low and the price for electricity production is low (SE1-2) compared to electrical area where demand is high and electricity generation is more expensive (Energimyndigheten a, 2021). The reasons why prices increased at the end of year 2021 is due to increased electrical demand and due to lower outdoor temperature, low production from wind power, low availability of hydropower and high prices for fossil fuels, as well as high prices for emission rights (Ibid). Prices continued to rise during year 2022 which largely depends on lower availability of natural gas from Russia as a result of the ongoing war in the Ukraine. Other factors were low balance in water reservoirs for hydropower, varying availability of wind power and lower production from nuclear power than normal (Energiföretagen, 2022). One source for electrical production that increased compared to nuclear power and had significantly higher production in 2022 than the previous year was solar power, which produced 1968 GWh year 2022, which is an increase of 74.6% compared to the previous year, which corresponded to about 1.16% of Sweden's total electrical production in 2022 (Energimyndigheten a, 2023). The share of electricity production from solar power may seem small compared to the total production, but the fact is that the installed electricity capacity from solar power in Sweden has increased by 965% in 5 years (2018–2022). In 2022, there were a total of 147,691 grid-connected solar power plants with a total installed capacity of 2383.64MW (Energimyndigheten b, 2023). Considering the increased electricity prices and the fact that the price of solar cells (standard module crystalline) has decreased by 83% from SEK 27/Wp in 2010 to SEK 4.6/Wp in 2021 (Lindahl and Westerberg Oller, 2021), it should be more profitable than ever for companies to invest in solar cells and produce their own electricity.

An SME company in electricity area 2 has felt the effects of the rising electricity prices and has therefore decided to evaluate different alternatives to be able to reduce its costs linked to electricity consumption. An investment in a photovoltaic system is one of the alternatives that the company is considering. To obtain a decision-making basis for a possible investment in a solar cell system, the company has turned to the University of Gävle, which is the background to this thesis.

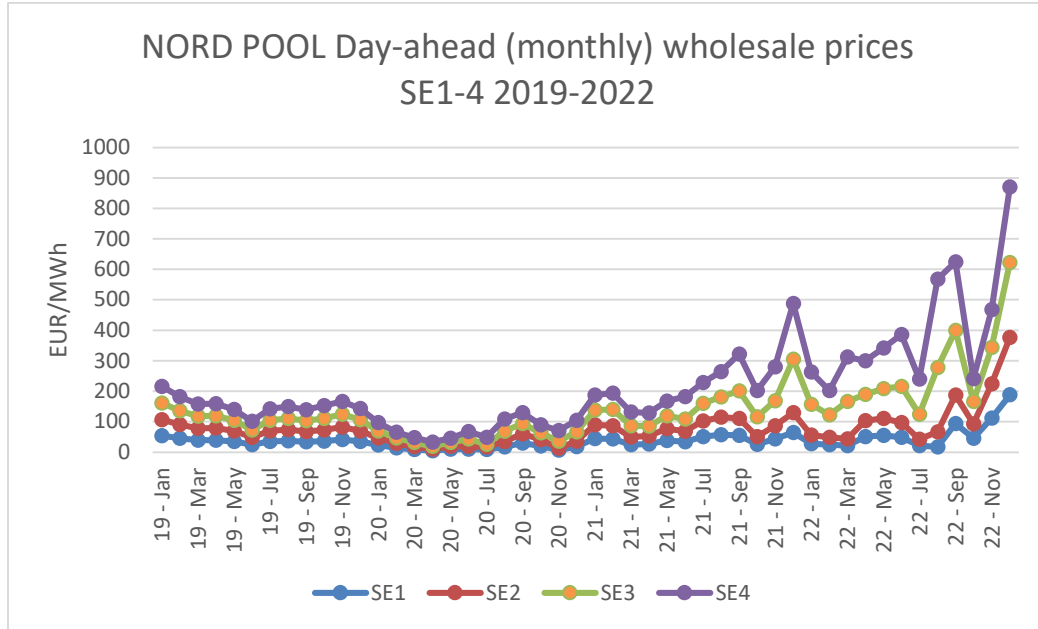


Fig.1: DAY-ahead (monthly) wholesale prices in areas SE1-4 Sweden, period 2020-2022 (NORD POOL).
Data used with permission.

1.1 Case study

The company operates within the manufacturing industry and is located in Gävleborg County, Sweden, latitude 60° . The approx. 1300 m² property consists of two parts, an office, and a factory. The property has several roofs facing Southeast (-31°). The slope of the roofs is between 3° – 7° . The local power grid, a part of the national grid, owner is Ellevio. The company is situated in electricity area 2 and has an annual electrical consumption of 300–350 MWh/year, the main fuse of the property is 400 A. Below, in Fig.2, the graph shows the company's monthly electricity consumption for the years 2020–2022. The reason why more electricity has been consumed during the winter is that the ventilation air to the production process must be heated up before entering the process. The explanation for the low consumption in July is because it is the holiday season and production is stopped. Electricity consumption will increase significantly during working hours 7.00–16.00 during Monday to Friday, as shown in Appendix. 1, which shows electricity consumption for a few weeks during the year 2022.

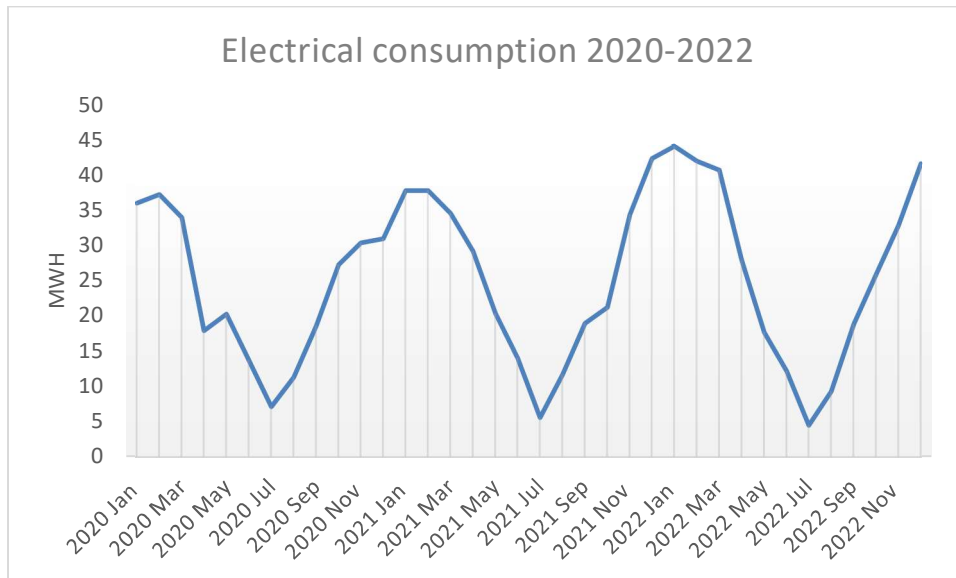


FIG.2: ELECTRICAL CONSUMPTION OF THE COMPANY 2020–2022 (MWh)

1.2 Aims

Would an investment in a solar cell system be a good solution to reduce future electricity costs? This is a question that a SME company in Gävleborg County, Sweden has been thinking about. The purpose of this thesis is to find this out based on the location's unique conditions, current tax rules and electrical prices. The answer is not simple but depends on several parameters, so before we can answer this question, two sub-questions need to be addressed.

1. What is the optimal solar panel tilt and orientation to match the company's electrical load profile?
2. How is a solar panel system designed based on maximized profitability?

1.3 Approach

This study has been carried out as a case study where the company's unique conditions and historical electricity consumption have been used as a basis for simulations and calculations. Hourly price data for the calculations performed in Excel has been obtained from the Nordic electricity exchange market (Nord pool), the company's electricity supplier, and from the simulation program Winsum PV.

1.4 Delimitations

The profitability calculations in this study will not consider index of energy tax, inflation or degradations of the solar panels and system losses contributed by, for example, snow cover and pollution of the solar panels. The profitability calculations will only be based on the results from the simulation program Winsum PV. Solar trackers and storage possibilities such as batteries are not included in this study.

2 Theory of solar panel systems

In Sweden, the state has long subsidized the costs of solar cell system, when the capital support was implemented in year 2005, the state could pay up to 70% of the Installations cost. But as mentioned in the introduction, the prices of solar cells has decreased a lot the recent year, which meant that the state abolished the subsidy at the end of year 2020 at that time the subsidy was just up to 20% of the installations cost (Lindahl et al., 2021). But it is not only the price of the solar cells that determines whether and how profitable it is to install solar cells system or not, it is also important to maximize electricity production from the solar cells system. The factors that affect the production from the solar cells are mainly: solar radiation, orientation, and tilt of the solar panels towards the sun, efficiency, system losses and degradation of the solar cells system (Blomqvist and Unger, 2018). Below, these five factors will be explained separately.

2.1 Solar radiation

Global solar radiation is a measure of the maximum energy from the sun that can be extracted and is measured in units of kilowatts per square meter kW/m^2 . Global solar radiation is the sum of the diffuse solar radiation, direct solar radiation and reflective solar radiation. Direct solar radiation is the radiation that hits the surface of the earth without the ray's changing direction. On a clear day, direct radiation can make up to 90% of the global solar radiation (Bengtsson et al. 2017). Diffuse radiation is the radiation whose direction has been affected in the atmosphere and it constitutes about 50% of the global solar radiation in Sweden. Reflective solar radiation is the radiation that changes direction after it has hit a surface on the earth (Lindh et al. 2020). Global solar radiation in Sweden in recent years has been approximately between 750-850 kWh/m^2 in the Northern parts and up to 1050 kWh/m^2 in the Southern parts, which gives an average in Sweden of between 900-1000 kWh/m^2 (Lindahl and Westerberg Oller, 2021).

2.2 Orientation and tilt towards the sun

To produce as much electricity as possible, the solar cells should be facing South and be perpendicular to the sun's rays. The solar height varies depending on the season, which in turn depends on the inclination of the earth's axis towards the sun, therefore there is no constant optimal tilt or orientation (Peake, 2018). In the summer, when the sun is at its highest position, the lower tilt of the solar panel is optimal and vice versa. This means that there is an opportunity to affect the electricity production from the solar cells system during the year. If the panels are tilted at the same angle as the latitudinal angle as the location, the solar cells will be linear to the sun at midday in the spring and in the autumn (Ibid.). However, annual

production is not very affected by the tilt, as can be seen in Fig.3 which shows the electricity production from South-facing panels with different tilt angles in Jönköping, Sweden, latitude 57. Tilt angles in combination with an orientation from the South will have a greater affect for the annual electrical production from the solar panel system. Fig.4 shows the annual electrical production from solar panel system with different tilt angles in combination with different orientations mounted in Jönköping, Sweden, latitude 57 (Blomqvist and Unger, 2018).

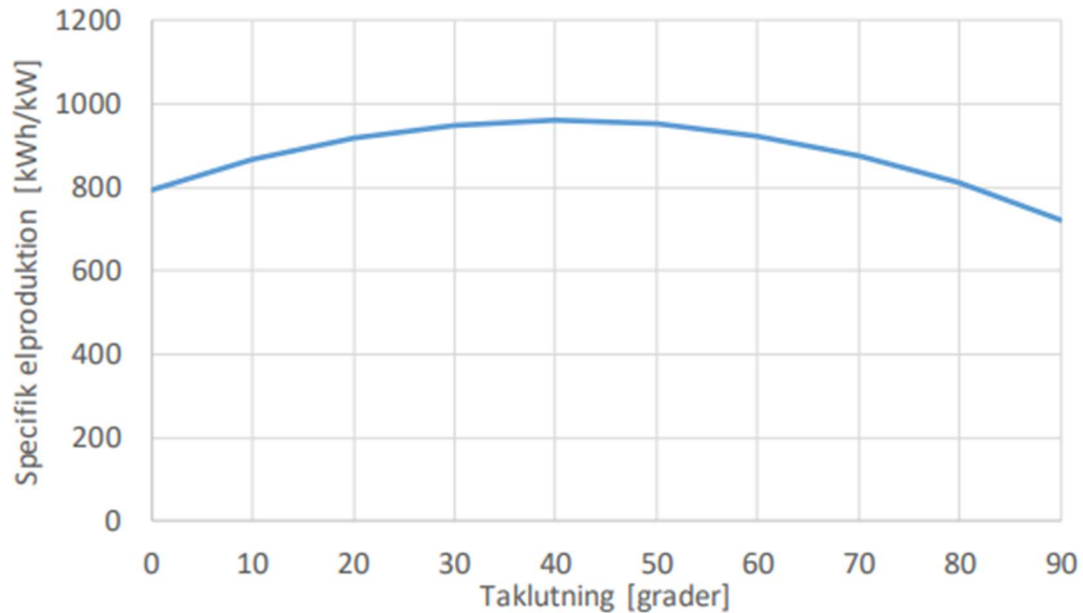


FIG. 3: SPECIFIC ELECTRICITY PRODUCTION (kWh/kW) PER YEAR FOR SOLAR CELLS ON ROOFS AT DIFFERENT TILT ANGLES⁰ (TAKLUTNING [GRADER]) (EXAMPLE CONCERNS PLACEMENT IN JÖNKÖPING (BLOMQVIST AND UNGER, 2018). USED WITH PERMISSION.

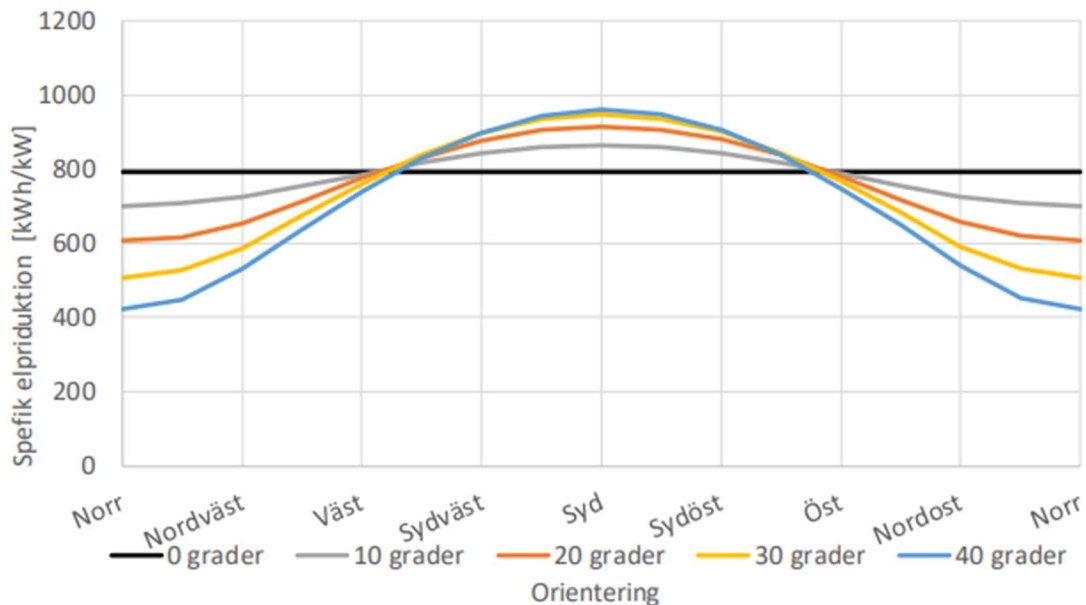


FIG. 4: SPECIFIC ELECTRICITY PRODUCTION (kWh/kW) PER YEAR FOR DIFFERENT TILT ANGLES (GRADER) AND ORIENTATIONS (EXAMPLE CONCERNS LOCATION IN JÖNKÖPING). NORR (NORTH), VÄST (EAST), SYD (SOUTH), ÖST (EAST) (BLOMQVIST AND UNGER, 2018). USED WITH PERMISSION.

Common technical terms are used to describe the position of the sun and its position in relation to the tilt and direction of the solar panels.

1. The Azimuth angle is the angle of the Sun in the horizontal plane and starts from 0° South, 90° West, -90° East and 180° North.
2. The angle of radiation (solar altitude angle) indicates the position of the sun in degrees. The angle is zero in the horizon and is 90° if sun is perpendicular to the surface of the earth (Zenith).
3. The angle of declination is the angular displacement between the sun and the equator due to the tilt of the earth's axis. As the earth spins around the sun, the angular displacement changes between -23.5° in winter and $+23.5^{\circ}$ in summer.
4. The hourly angle is 15° , which is the change of the angle of the sun in the horizontal plane for 1 hour. $360^{\circ} / 24 \text{ hours} = 15^{\circ}$.

2.3 Efficiency

The efficiency of monocrystalline solar modules is between 15–22% and for polycrystalline solar modules is 15–17% while the efficiency is slightly lower for thin film solar cells 10–16% (Energimyndigheten, 2019). The specified efficiency and rated power (Wp) of the Solar panel apply to the standardized test method STC (Standard test conditions). Test conditions are 25°C solar temperature, 1000 W/m^2 irradiance and airmass 1.5 AM (Kovács, 2019). Another result stated in the solar cell specification is the result from the standard test NOCT (Normal operating cell temperatures) which indicates the temperature of the solar cells under the test conditions 800 W/m^2 irradiation, Airmass 1.5 AM, 20°C air temperature and a wind speed of 1 m/s . The test conditions during this test are more like real conditions than test conditions during STC (Lindh et al. 2020). The efficiency of solar cells decreases when the temperature increases. The temperature of the solar cells is normally $20\text{--}30^{\circ}\text{C}$ higher than the ambient temperature. The efficiency drops by $0.3\text{--}0.4\%/^{\circ}\text{C}$ above the test value for STC 25°C . By calculating this, the efficiency is about 6–12% lower at the ambient temperature of 20°C (Hemsol, 2023). As mentioned, panel temperature is one of the biggest reasons for decreasing efficiency, especially in countries where it is significantly warmer climate than in Sweden, the solar cell temperature can rise to 70°C . One solution is to cool the solar cells by spraying water on the front of the panels, which was done in a study in UAE where the solar cell temperature was lowered by 11.3% and the efficiency then increased by 3.6% (Hachicha et al. 2015). In addition to the heating of the panel, the efficiency of the solar panel is also negatively affected by when the angle of radiation from the sun becomes too great, which increases the reflection losses of the solar panels. Another factor that negatively affects efficiency is when the

intensity of the solar radiation is too low so that the solar panels do not reach their optimal working range (Stridh, 2019). Regarding the efficiency and actual production, the Property Owners Trade Association states in their FAQ (frequently asked questions) regarding solar cells that there is a rule of thumb that the production is about 15-20% lower than compared to the kWp value measured under STC conditions (Aktea, 2018).

2.4 System losses

System losses are affected by both internal and external factors. The external factors are, for example, dirt, snow and shade. The internal losses come from cables and inverters (Blomqvist and Unger, 2018). The system losses will be described below separately.

2.4.1 Pollution

Dust, leaves, moss, bird droppings, and such have a negative impact on the efficiency of solar cells system. The problems with pollution are greatest in little rainfall areas such as the desert because there are longer periods between the cleaning effect from the rain, in these areas the losses are counted to 25% while in areas with a lot of rainfall, the losses are instead estimated to be between 0-5% (Dodd et al. 2020). An experiment in Palestine compared efficiency of solar panels washed every other day with solar panels that were not washed at all for 7 months. The result showed that the solar panels that were not washed had a power reduction of 9.99% compared to solar panels that were cleaned (Juaidi et al. 2022). But in Sweden, one can pretty much purse off these losses. For the purifying effect of the rain to be as great as possible, the tilt of the panels is important, as the water drains faster at a higher tilt and therefore carries dirt more efficiently. From this point of view an optimal tilt is about 30° (Bengtsson et al. 2017).

2.4.2 Snow

Snow has both a positive and negative impact on the electrical production from solar cells. The positive consists of the reflective radiation from surrounding snow that hits the solar panels. For optimally tilted solar panels in the North part of Sweden, annual production is estimated to increase about 1%, while for vertically mounted the solar panel is higher and is between 5–6% (Van Noord, Landelius and Andersson, 2021). The negative is that the snow that get stuck on the solar panels reflects away and absorbs the solar radiation, the production decreases as the layer of snow increases; if the layer of snow is > 10 cm, the production will be zero even for sunny days (Lindh et al. 2020). However, the problem of reduced production due to snow mainly applies during the winter months when solar radiation is low, which means that snow has a small effect on annual electrical production (Bengtsson

et al. 2017). However, Sweden is a country that extends over almost 17 latitudes and has a varying amount of snow with significantly more snow-covered days in the Northern parts. For South-facing solar panels with a 30° tilt in Northern Sweden, annual electrical production can decrease by up to 30% but can also be significantly lower percent depending on how long the ground is covered with snow for the current year (Lindh et al. 2020).

2.4.3 Shading

Shade is devastating for solar cells and the shade from a leaf can reduce or stop production from unshaded parts of the solar panels. To overcome this, bypass diodes can be used either in combination with power optimizers or without.

2.4.3.1 Bypass diode

A typical solar panel consists of 60 cells which are connected in series. For each group of 20 cells there is also 1 bypass diode. The bypass diode makes it possible to disconnect the group if some of the cells become shaded, which will decrease the production for all the cells in the group. Without a bypass diode the shaded cells will decrease the total production from the solar panel instead of just a third (Bengtsson et al. 2017). There are also solar panels with multiple bypass diodes, so-called multi-diode modules. The advantage with multi-diode modules means that fewer unshaded cells need to be bypassed when parts of the solar panel are shaded (Kovács, 2019).

2.4.3.2 Power optimizers

Without the power optimizer installed on the solar panel system, it is the inverter's MPPT-function (Maximum power point tracker) that adjusts the current and voltage in the circuit of interconnected solar panel system to achieve optimal electricity production. The disadvantage of the MPPT-function is that all solar panels in the circuit for interconnected solar panels will produce according to the one with the lowest production, which could be if one or more solar panels are shaded. With a power optimizer connected to each solar panel, each individual solar panel can independently produce electricity at the optimal level. The total cost increase for installing power optimizers for each panel for a typical solar panel system for a private residence is approx. 5-10% but can be lower if the power optimizer is connected to a group of two or more solar panels (Wallnér, 2019).

2.4.4 Cables

In a properly installed solar cells system, the losses from the cables should not exceed a maximum of 2%. The losses from the cables depend on the internal resistance of the cables. The internal resistance decreases with a larger cable cross-sectional area but increases with the length of the cable. The losses in two equally long cables with a cable cross-sectional of 1.5 mm² compared to a cable with cross-sectional of 10 mm² can be up to more than 5 times as high. If a cable is undersized, losses increase, while the installation can become unprofitable because of increased costs if the cables are oversized (Ekici and Ali, 2016).

2.4.5 Inverter

The efficiency of inverters varies with their load and is therefore specified according to an agreement within the EU for the entire working area of the inverter. The EU efficiency is normally between 95–98% for modern inverters (Kovács, 2019) while the maximum efficiency is slightly higher (Solaredge, 2018). To achieve as high efficiency as possible, it is normal for an inverter with a 10-20% lower working range to be chosen than the total maximum power of the solar panel system as the electrical production almost never takes place during optimal conditions (Kovács, 2019). As mentioned earlier, heat (temperature increase) has a negative impact on the electrical production of the solar cells; an experiment also showed that the inverter's efficiency decreased because of heat. The results from the experiment showed that the efficiency decreased by 1% as the inverter for each time the inverter heat increase by 7 °C above 37 °C (Desai et al. 2021).

2.5 Degradation

The geographical location of the solar panel system is important as the efficiency of photovoltaic panels decreases over time due to high radiation and hot temperatures. In economic calculations, degradation is usually calculated in the range of 0.3 – 0.5%/year with a total lifetime of at least 30 years. The upper range is based on places with warmer climates than in Sweden. Therefore, the degradation of solar panels in Sweden should be more to the lower range (Kovács, 2019). In Brazil, which has a warmer climate than in Sweden, measurements were made on one plant when it was installed and then after 15 years in operation and the results showed that the plant had a total efficiency loss of 9.5%, which gives an average of 0.7% a year (Fonseca et al. 2019). Some of the manufacturers of solar panels guarantee a degradation of maximum of 10% for the first 10 years and then a total of maximum 20% after 25 years (Lindh et al. 2020). This corresponds to 1% per year the first 10 years and 0.8% per year in total after 25 years if the degradation were linear.

3 Economy

3.1 Profitability

Profitability assessments from solar panel systems are difficult to calculate because there are so many varied factors and conditions that are unique for each installation. The factors and prerequisites consist of economic factors such as installation costs, electricity prices, subsidies and maintenance costs, but also the choice of discount rate and economical lifetime have a significant impact on calculating profitability of solar panel system. (Blomqvist and Unger, 2018).

3.1.1 Cost of installations

Average price VAT excluded for turnkey solar panel system for year 2021 in Sweden for commercial properties in the range of 10-20 kWp costs 11.7 SEK/Wp, 20-50 kWp costs 10.1 SEK/Wp, while larger systems between 50-255 kWp cost 9.4 SEK/Wp (Lindahl and Westerberg Oller, 2021). In a cost breakdown for supplier's year 2020 of a 10 kWp turnkey roof-mounted solar cell system for private residence the solar panels and inverter is almost 50% of the total costs and labor costs accounts for 29% of the total cost (Ibid.). The prices are within the limits of the latest cost examples for companies, published on the webpage Hemsol.se that calculate an average price 9–11.6 SEK/Wp with VAT excluded for a solar cell plant with installed power greater than 50kW (Hemming, 2022).

3.1.2 Subsidies for installation

In Sweden, the state has for a long time subsidized the costs of solar cell plants. When capital support was introduced in 2005, the state could subsidize up to 70% of the total costs. As mentioned in the introduction, the prices of solar cells system have fallen since 2005, which caused the government to gradually decrease subsidies until the year 2020, when it was removed completely. In 2020 the subsidy could be up to 20% of the total investment cost (Lindahl et al. 2021). The following year, the capital subsidy was replaced instead with a green technology deduction, which is a tax deduction. The tax deduction was 15% for the material and installation cost at the time of introduction. But on the first of January year 2023 the tax deduction was increased to 20%. The largest amount of the deduction is 50 000 SEK per person and year. The green technology tax deduction only applies to private persons and for companies there is currently no subsidy from the state to apply for (Hemming, 2023).

3.1.3 Operations costs

The Property Owners' Trade Association (Aktea, 2018) writes in their FAQ regarding solar cells that there is not yet enough data to be able to calculate costs for service and repairs including loss of production, therefore a flat rate of 50–100 SEK/kW per year is used instead regardless of the installed rated power. A study based on six solar parks with an installed rated output of between 3-14 MWp states that annual fixed maintenance costs for electrical maintenance and production monitoring are in the range of 814-2861 Euro/MWp/year (average rate 2020 of 1 Euro = 10.4867 SEK), which gives an average of 1536 Euro/MWp/year (1.535 Euro/kWp/year). Solar parks with fixed tilts have no moving parts and therefore have no variable maintenance costs linked to the amount of electricity produced. In addition to these costs, costs for property management must be added (Lindahl et al. 2021). It is worth mentioning that there are more operating costs linked to production for the solar park in the current study.

3.1.4 Economic lifetime and discount rate.

The discount rate and the economic lifetime of the solar panel system have a major impact on the financial calculation and the estimated time for payback. For companies there is no standard discount rate, but it is often decided according to their requirements of return of investment. One way to set the discount rate in relation to the average saving rate for private persons or the STIBOR (Stockholm Interbank Offered Rate) +4.5% for commercial actors (Blomqvist and Unger. 2018). Another example of a discount rate used in a study to calculate the payback period for both private and commercial investments in solar cells system the interest rate was chosen at 1% for private individuals as 1% was higher than the average savings rate at that moment. For the commercial installation the interest rate was set at 2% based on the inflation target for a few years to come, the economic lifetime in the study was set to 30 years for the solar panel system (Simola et al. 2018), which is within the usual range for the choice of the economic lifetime of solar panel system which is 25-30 years (Blomqvist and Unger, 2018).

3.1.4 Price of electricity

The costs for electricity for companies are divided into 3 parts: cost for the electricity (power) grid, cost for electricity trading (to the suppliers) and taxes. Cost for the power grid refers to costs related to the transmission of electricity and are paid to the owner of the power grid. Electricity trading costs refer to costs related to the electricity consumed and are paid to the supplier (i.e., the electrical trading company) (Vattenfall a, u.å.). Costs for taxes, see heading 3.1.4.3 Other cost and income.

3.1.4.1 The grid owner

The costs for power transmission Low voltage 0.4kV (L04S) from Ellevio consist of 3 parts. A power fee for peak consumption SEK/kW (hourly power) and a fixed fee SEK/month and a fee for transmission costs SEK/kWh, note that there is a fee for peak load and other time* (Ellevio A, u.å.)

Revenues for micro production above 63A from Ellevio consist of the production compensation SEK/kWh, which refers to compensation for reduced costs for grid losses due to shorter distance for electrical transmission. The production compensation differs during peak hours and other times*. (Ellevio B, u.å.).

*Peak hours occur weekdays 06.00-22.00 from 1 November to 31 March except for New Year's Day, Epiphany Christmas, Maundy Thursday, Good Friday, Easter Monday, Christmas Eve, Christmas Day, Boxing Day and New Year's Eve which constitute other times/low loads.

3.1.4.2 Electricity supplier

The electricity purchase agreement from supplier Vattenfall consists of: An hourly spot price that is weighted over the invoice period based on spot prices from Nord pool and an hourly consumption (SEK/kWh), An electricity certificate fee (SEK/kWh), and a fixed annual fee (SEK/year) (Vattenfall e, u.å.).

The revenue for surplus production from Vattenfall for small-scale electricity production (max feed-in power installed 500 kWp) is based on Nord pool hourly spot prices minus a cost deduction of 0.4 SEK/kWh. (Vattenfall b, u.å.)

3.1.4.3 Other costs and income

- Energy tax is paid through the grid owner where 2023 tax level is 0.392 SEK/kWh (Vattenfall, 2022)
- Guarantees of origin for solar power are issued by the government after an approved application for each MWh sold and then usually sold to an electricity company that pays approximately 0.001–0.01 SEK/kWh. (Hemsol, 2022)

Other

- Previously, solar cell producers could be paid for electricity certificates, but a Stop rule has been introduced. This means that no new plants will be awarded electricity certificates after 1st January 2022. (Sveriges riksdag, 2020).

- There is a tax reduction which means that the electrical producer can receive 0.60 SEK/kWh up to 18 000 SEK/year for exported electricity. It is not relevant for the company in this study because their main fuse is greater than the limit of 100 A to be able to receive the tax reduction. (Skatteverket a, u.å.).
- Energy tax for produced electricity is not relevant for the company in this study because the solar panel system will not exceed the rated power of 500 kW, which is a lower limit for energy tax obligation for electricity production from solar panel system (Skatteverket b, u.å.).

3.1.4.4 Electricity price calculations

The electricity price calculations apply to a company with consumption of maximum 300 000 kWh/year in electricity price area 2 in agreement with the electrical grid owner based on maximum power consumption per month (L04S). The price refers to a variable contract based on a monthly average of the spot price (SEK/kWh) on the Nordic electricity exchange market Nord Pool. The calculations exclude fixed fees, power fee for peak consumption or discounts. The income from selling the electrical overproduction is calculated simply on the variable electricity price and not the hourly spot price from Nord pool, which is the correct way. Table 1 below shows the cost breakdown for electrical price. Table 2 shows revenue breakdown for electricity selling price. The bar chart in Fig.5 below shows the difference between the price for buying and selling electricity.

TABLE 1: COST BREAKDOWN OF PURCHASED ELECTRICITY

Cost item	Cost	Source
Variable electricity price*	0.6873 SEK/kWh	(Vattenfall c, u.å)
Surcharge on variable electricity price	0.06 SEK/kWh	(Vattenfall c, u.å)
Fixed electricity certificate fee	0.014 SEK/kWh	(Vattenfall c, u.å)
Variable electricity network fee	0.09 SEK/kWh**	(Ellevio A, u.å.)
Energy tax	0.392 SEK/kWh	(Vattenfall, 2022)
Total amount	1.2433 SEK/kWh	

*Based on April 2023. (Retrieved 2023-05-26)

**No cost difference for peak hours and other times.

TABLE 2: REVENUE BREAKDOWN OF PURCHASED ELECTRICITY

Revenue item	Revenue	Source
Variable electricity price*	0.6873 – 0.04 SEK/kWh	(Vattenfall c, u.å.)
Production replacement (Grid utility) *	0.054 SEK/kWh Low peak 0.062 SEK/kWh High peak	(Ellevio B, u.å..)
Guarantee of origin	0.01 SEK/kWh	(Hemsol, 2022)
Total amount	71.13 SEK/kWh Low peak 71.53 SEK/kWh High peak	

*Based on April 2023. (Retrieved 2023-05-26)

**Peak hours occur weekdays 06.00-22.00 from 1 November to 31 March except for New Year's Day, Christmas Epiphany, Maundy Thursday, Good Friday, Easter Monday, Christmas Eve, Christmas Day, Boxing Day and New Year's Eve which constitute other times/low loads.

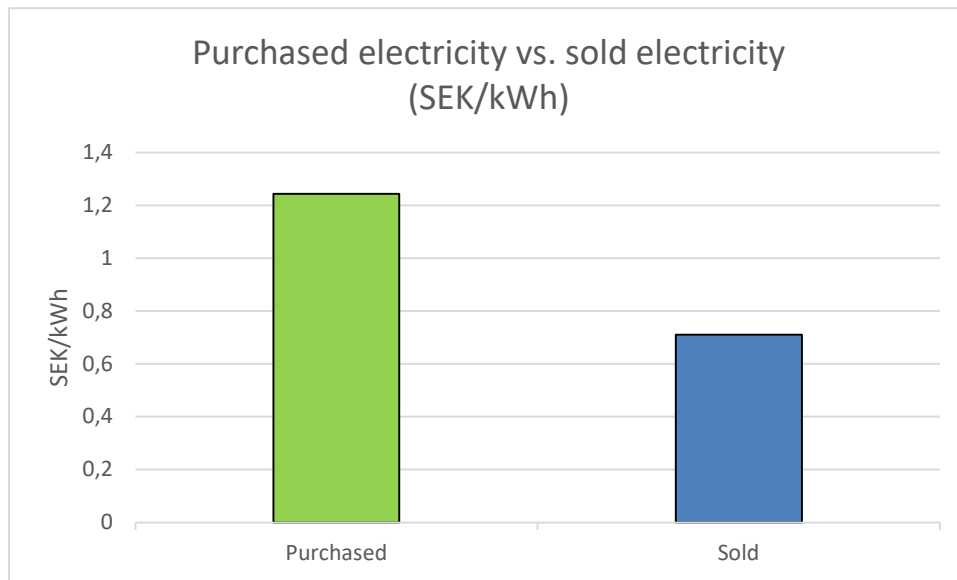


FIG. 5: PRICE FOR PURCHASED ELECTRICITY VS SOLD ELECTRICITY (SEK/kWh)

3.2 Self-consumption

In 3.1.4.4 *Electricity price calculation*, it was shown that the price for purchased electricity was about 57% higher than the revenue for the sold electricity depending on whether it is peak hour or other times. Although this only applies to this example, the difference is mostly due to the energy tax, which is 0.392 SEK/kWh but represents 31.5% of the total price. If the company in this study had been entitled to the existing tax reduction mentioned in 3.1.4.4 *Other cost and income* of 0.6 SEK/kWh the value for sold electricity would have increased significantly. Regarding the tax reduction The Swedish Energy Agency states on their website that for larger buildings with a main fuse above 100 A which cannot receive the tax

reduction is the basic principle that for larger facilities self-consumption is more profitable than selling the electricity to the electricity supplier. (Energimyndigheten, 2022). Based on this information a high degree of self-consumption is very important for the company in this study.

As to be able to increase the self-consumption The Swedish Energy Agency highlights three methods on their website (Energimyndigheten 2021, b):

1. Method 1: Matching by adapting tilt angle and orientation of solar panel.
2. Method 2: Matching using load control
3. Method 3: Matching with energy storage

Method 1: Increase self-consumption by changing the tilt angle and the orientation so that electricity production occurs when the consumption is high.

Method 2: Contrary to method 1, the time of consumption changes to when the electrical production from the solar panel system is high instead.

Method 3: Means storing electrical overproduction for later use to increase self-consumption.

3.2.1 Method 1: Matching by changing tilt and orientation of solar panels

As mentioned before, adjusting the tilt and orientation to increase self-consumption means that instead of producing maximum of electricity, the tilt and orientations are changed to produce electricity to increase self-consumption. How production can be affected by the different settings is shown in Fig.3 and Fig.4 in the 2. *Theory* section. A study that simulated different tilt and orientations of solar panels towards the sun at a farm in Southern Finland to find the best alternative to increase self-use. For solar panel systems, where the produced electricity was equal to the consumed electricity over the year, self-consumption increased most by titling half of the panels 70° Southwest and the other half 70° Southeast with a slope of 40°. However, this is because the consumption profile of the farm is highest in the morning and evening. However, the results of the simulations showed that the most profitable alternative for the solar panels system was an orientation of -10° - -5° to the South with a tilt angle between 40-45° and sell the electricity overproduction for all alternative in the test range of 10-80 kWp. (Meriläinen et al. 2022).

3.2.2 Method 2: Matching using load control

In a Swedish literature study about different techniques to change consumption to the time when there is an overproduction from the solar panel system to be able to increase the self-consumption, highlights both manual and automatic. One of the more advanced is to use algorithms to control the electrical consumption after the electricity production from the solar panel system, another is to use load limiters. A simpler and manual technique is to use a timer to start dishwasher, washing machines and other household appliances when there is electricity overproduction (Luthander et al. 2015). The simpler alternative was investigated in another Swedish study where the authors simulated an optimal use of household appliances to match the electrical production from solar panel systems and historical electricity price for 200 households. The results of the simulations for solar panels systems with installed rated power of 3, 6, 9 and 12 kWp showed that household's self-consumption over a year only increased by a few percent compare to the relative self-consumption, which corresponds to about 200 kWh/year on average. In the discussion section of the study, it is discussed why self-consumption could not be increased even more when the potential consumption that could be shifted was more than twice as high. Their conclusion was that it depends on 3 factors: 1. Some of the potential load was already optimally consumed. 2. It does not affect changing the load during the day as there is no electrical overproduction from the solar panel system for the current day. 3. Electrical overproduction is not high enough to cover power peaks of the consumption (Widén 2014). Something that was not mentioned in these two slightly older studies was the charging of electric cars. Electrical cars have increased significantly in the last years. A newer Swedish study based on simulations shows that charging the electric car at home has a positive impact on self-consumption. However, the impact is limited because electric cars are usually not at home and ready to be charged at the same time as there is an overproduction from the solar cell plant (Munkhammar, Grahm & Widén, 2013).

3.2.3 Method 3: Matching by using energy storage

In the same literature study as in method 2, two techniques for storing the overproduction from the solar cells are mentioned. The technologies mentioned are batteries and hydrogen. The battery storage capacity that was most common in the literature study had a storage capacity 0.5–1 time the installed power of the solar panel system which increased self-consumption between 10-24% (Luthander et al. 2015). Regarding hydrogen, the potential is considered to be great in the long term, but that technology is currently in its development phase. The technology to produce hydrogen is also associated with large investment costs and the process of converting electricity into hydrogen and back entails losses of about 70% (Svenska kraftnät 2022). Furthermore, the study states that it is always better to use electricity directly because regardless of the choice of storage technology it always leads to losses (Luthander et al. 2015). Another technology that is being developed is the possibility to use electric cars for storage when there is overproduction from the solar cells system and to then supply the home with electricity when consumption exceeds production. This concept is called V2G (Vehicle to the Grid) or V2H (Vehicle to the home). Some of the major car manufacturers have adopted the concept such as Nissan and Mitsubishi (Svenska kraftnät, 2022).

4 Methods

In order to answer the question in the 1.2 Aims, a case study has been chosen as a method. First, the SME company obtained the company's historical electricity consumption for the last three years from the electricity supplier. Then the data was analysed for patterns and compiled the company's load profile by month and weeks. Data, prices, and information were then collected for the parameters and variables necessary to be able to calculate the profitability of a solar panel system based on the location-unique conditions. The information gathering has mostly been taken from the internet but also from course literature. A site visit has also been carried out at the company to obtain information on the design, size, slope, and orientation for the roof of the property.

To carry out the calculations, the simulations were performed using the program Winsun PV, which is developed by the University of Gävle and RISE (Research Institutes of Sweden) with the purpose for private individuals to be able to evaluate calculations and quotes from vendors. The results from the simulations are given hour by hour and extracted in an Excel-file. Through a calculation by a self-made template in Excel, the value of self-consumption, payback time and discounted payback time for the different options is calculated according to equations 1-4 below.

$$\text{Self-consumption (\%)} = \frac{\text{Annual production} - E_{\text{exported}}}{\text{Annual production}} \quad (1)$$

$$R_{\text{annual saving}} = (E_{\text{utilized}} * P_{\text{import}}) + (E_{\text{exported}} * P_{\text{exported}}) - \text{Opex} \quad (2)$$

$$\text{Payback} = \text{Capex} / R_{\text{annual saving}} \quad (3)$$

$$\text{Discounted payback} = \frac{\ln \left(1 - \frac{\text{Capex}}{R_{\text{annual saving}}} \text{Stibor} \right)}{\ln (1 + \text{Stibor})} \quad (4)$$

Where:

E_{exported} = Electricity sold to the grid (kWh)

$R_{\text{annual saving}}$ = Total savings per year (SEK/year)

E_{utilized} = Self consumption (kWh/year)

P_{import} = Price purchased electricity (SEK/kWh)

P_{exported} = Price for sold electricity (SEK/kWh)

Capex = Installation cost for the Solar panel system (SEK)

Opex = Yearly operation cost (SEK/year)

All results from the simulations with the program Winsum PV refer to Shaded production (kWh). For the fixed values of the simulations, the program used the default settings. Standard values for ground reflection factor (0.2 Albedo) and horizon shielding (10°) and that for each kWp installed power the module area is 6m^2 . Climate data was retrieved for the postal code of the company. Orientation, slope and size of the plant are shown in the result.

4.1 Economics

The revenue for P_{export} is based on Nord pool's spot price per hour in 2022 for electricity area 2 in Sweden (was provided from Nord pool FTP-server for free). In addition to this, there is a fixed deduction of 0.04 SEK/kWh to the electricity supplier and a contribution from the electricity grid owner for the network benefit of 0.054 – 0.062 SEK/kWh depending on the time, as stated in 3.1.4.1 *The grid owner*, and 0.01 SEK/kWh for the guarantees of origin. The average price over the year for P_{export} is stated as $P_{\text{export (Average)}}$.

Costs for P_{import} consist of a fixed price of 1,449 SEK/kWh. This is based on a fixed electricity price of 0.967 SEK/kWh, which is based on a 3-year fixed electricity contract with the electricity supplier Vattenfall company valid for for the company's postcode and an annual consumption of max 300 000kWh/year (Vattenfall, d u.å.). In addition to this, there is an electricity grid fee of 0.09 SEK/kWh and energy tax of 0.392 SEK/kWh.

Capex is based on the price ranges in 3.1.1 *Cost of installation* and is reported as Capex SEK/Wp. Opex 50 SEK/kWp/year for operation cost according to 3.1.3 *Operations costs*. The calculations neglect the degradation of the solar panel system.

The calculation rate 8.21% is based according to 3.1.4 *Economic lifetime and discounting rate* on the STIBOR interest rate 3.71% + 4.5% (Dagens industri, 2023).

5 Process and results

5.1 Tilt and orientation

A solar panel system with an installed power of 1 kWp oriented to true South was simulated with different tilts to see how much impact the tilt has on annual electrical production. The result from the simulations according to Fig.6 below, the right y-axis is added to illustrate how much annual production decrease more easily from 40° tilt which was the alternative that got the highest yearly electrical production of total 982 kWh.

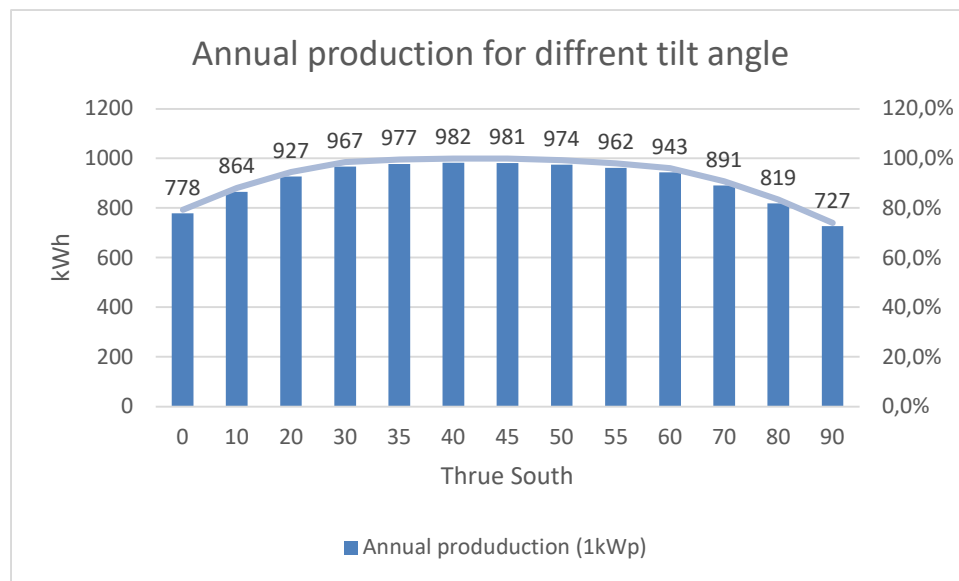


FIG.6: THE RESULT FROM THE SIMULATIONS OF DIFFERENT TILT ANGLES AND ORIENTATION TRUE SOUTH. Y-AXIS TO RIGHT SHOWS ANNUAL PRODUCTION IN kWh AND THE Y-AXIS TO THE RIGHT SHOWS ANNUAL PRODUCTION IN % COMPARED TO ONE ANOTHER.

In the next step, different orientations are added to the range -20° to the West to 20° East. 0° is true South. Table 3 shows that 40° tilt angle true South still gives the highest annual electrical production. In Appendix B, there is a table showing how the production looks month by month for these orientations and the tilt in 10° steps in the range 30-60°. The highest electricity production for all cases takes place in the period from April to August. 40° tilt true South gives the highest electricity production, although the holiday month of July is excluded from all alternatives.

TABLE 3: COLOR CHART SHOWING THE SIMULATED RESULTS OF YEARLY PRODUCTION OF 1 kWp FOR DIFFERENT TILT ANGLES (0-90°) IN COMBINATION WITH DIFFERENT ORIENTATION ANGLES (-20° - 20°)

	-20	-10	0	10	20
0	778	778	778	778	778
10	860	866	864	862	858
20	920	926	927	924	916
30	957	965	967	962	951
35	967	976	977	972	960
40	971	980	982	977	964
45	970	979	981	975	962
50	963	972	974	968	955
55	950	959	962	955	942
60	932	942	943	938	924
70	881	890	891	886	873
80	810	818	819	814	803
90	721	726	727	724	716

To achieve a high level of self-consumption, the solar panel system electricity production should be matched against the factory's load profile which has the highest consumption during the working day. Below, Fig.7-12 show the factory's electricity consumption and the electricity production from 1 kWp solar panel system on an hourly basis during 3 cloudy days 31 March, 30 June, and 30 September and 3 sunny days 29 March, 27 June, and 29 September with tilt angle 40° and orientations -45°, 0° and 45°. During cloudier days, the diffuse radiation constitutes a higher proportion of the solar radiation, which is why the curves do not differ significantly between each other. On sunny days, the direct radiation is higher, which means that the orientation of the solar cells has a greater impact on electricity production, which is why the curves differ more than for the cloudier days. In Appendix C, there is a diagram for these days showing the impact of the tilt angle (30°, 40°, 50°) on electricity production when the solar panels are facing true South. Based on these simulations, it is possible to change when production occurs during the day. Orientation true South seems to be the orientation that matches the factory's loading profile best and since the tilt angle of 40° with orientation true South gave the best electrical annual production, this application is chosen for the sizing of the solar panel system.

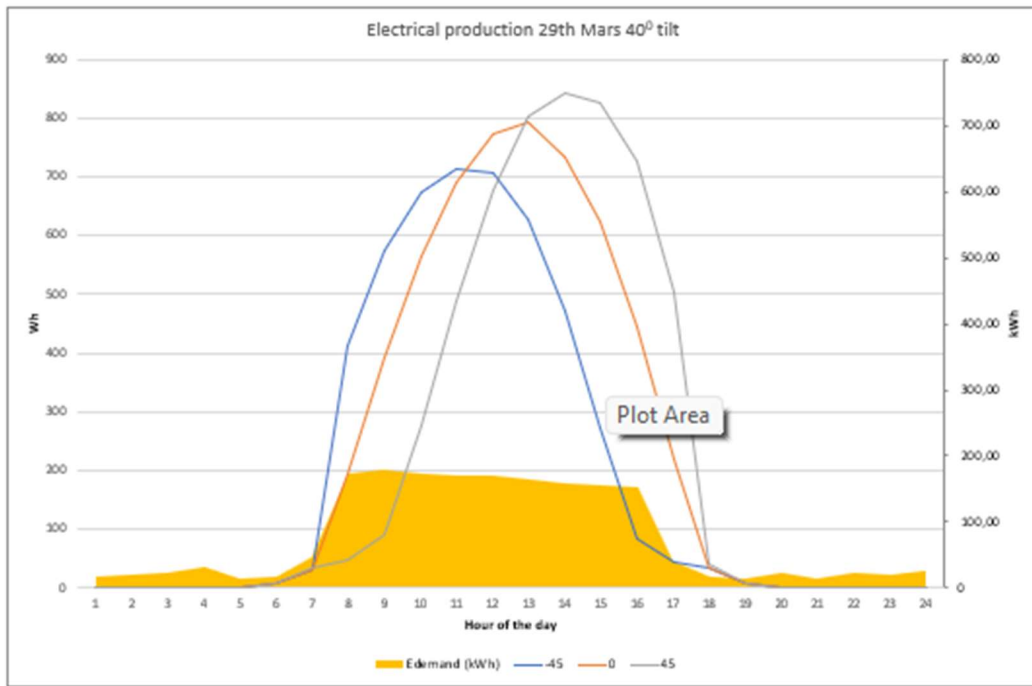


FIG. 5: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 29TH OF MARS TRUE SOUTH WITH TILT ANGLE 40° AND THE ELECTRICAL DEMAND FOR THE SAME DAY (2022).

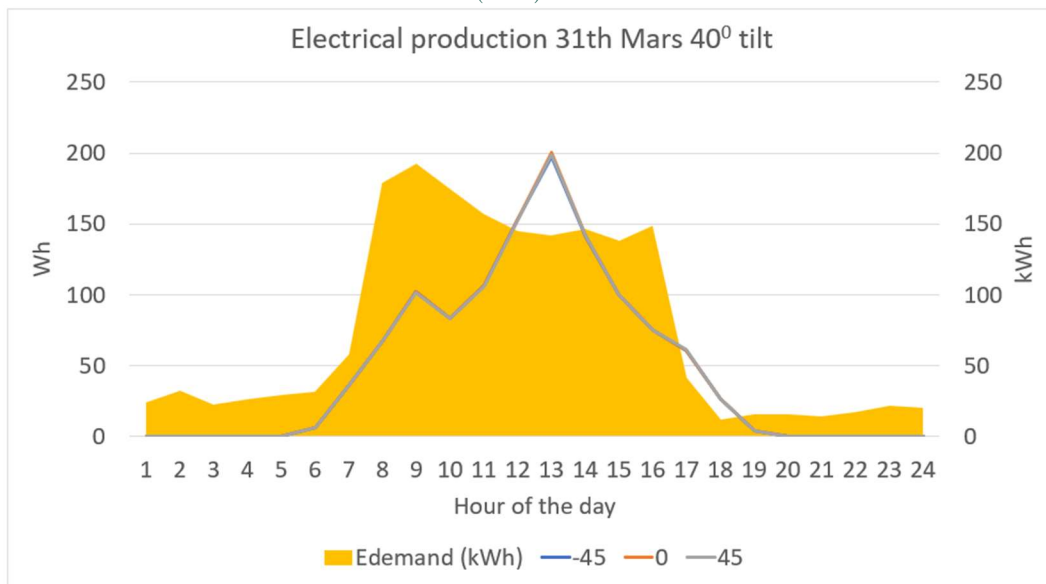


FIG. 8: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 31TH OF MARS TRUE SOUTH WITH TILT ANGLE 40° AND THE ELECTRICAL DEMAND FOR THE SAME DAY (2022).

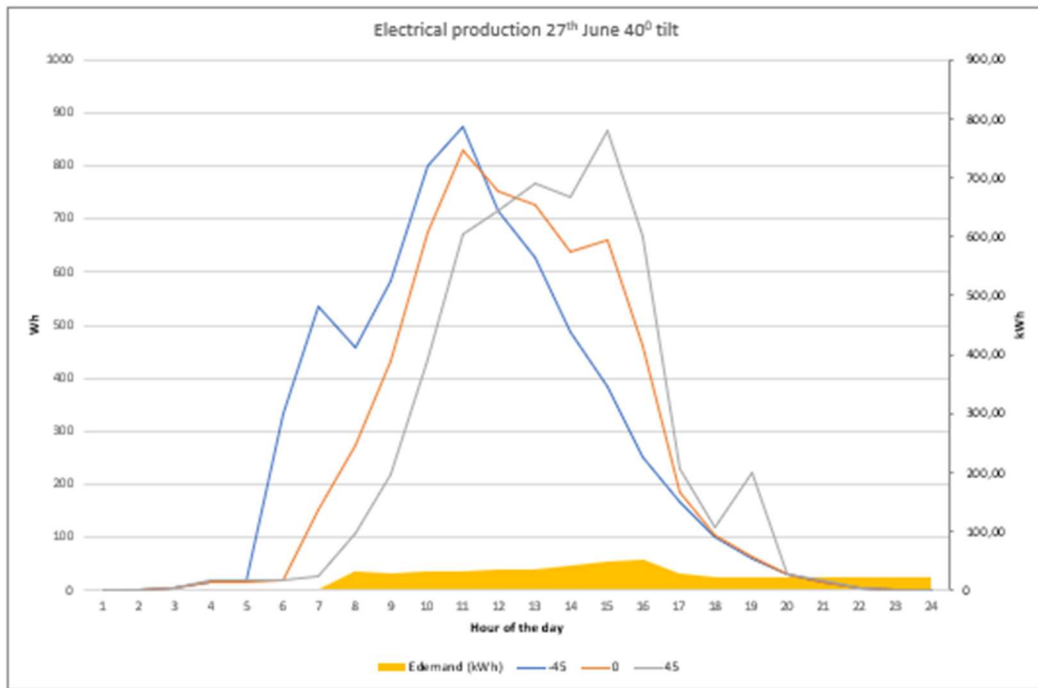


FIG.9: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 27TH OF JUNE TRUE SOUTH WITH TILT ANGLE 40° AND THE ELECTRICAL DEMAND FOR THE SAME DAY (2022).

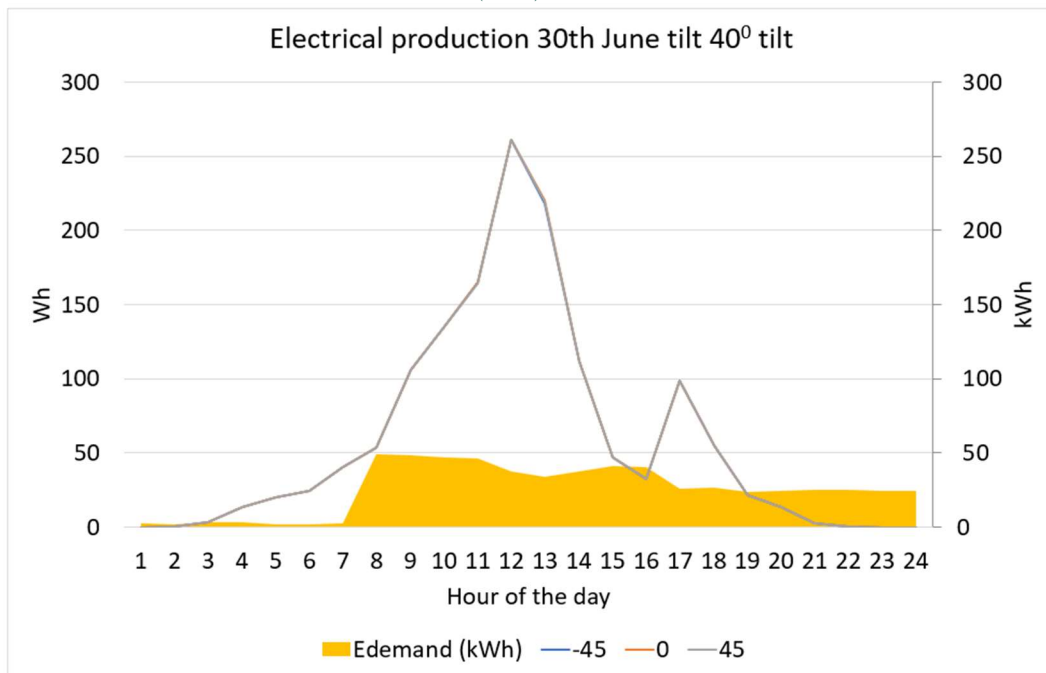


FIG.10: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 30TH OF JUNE TRUE SOUTH WITH TILT ANGLE 40° AND THE ELECTRICAL DEMAND FOR THE SAME DAY (2022).

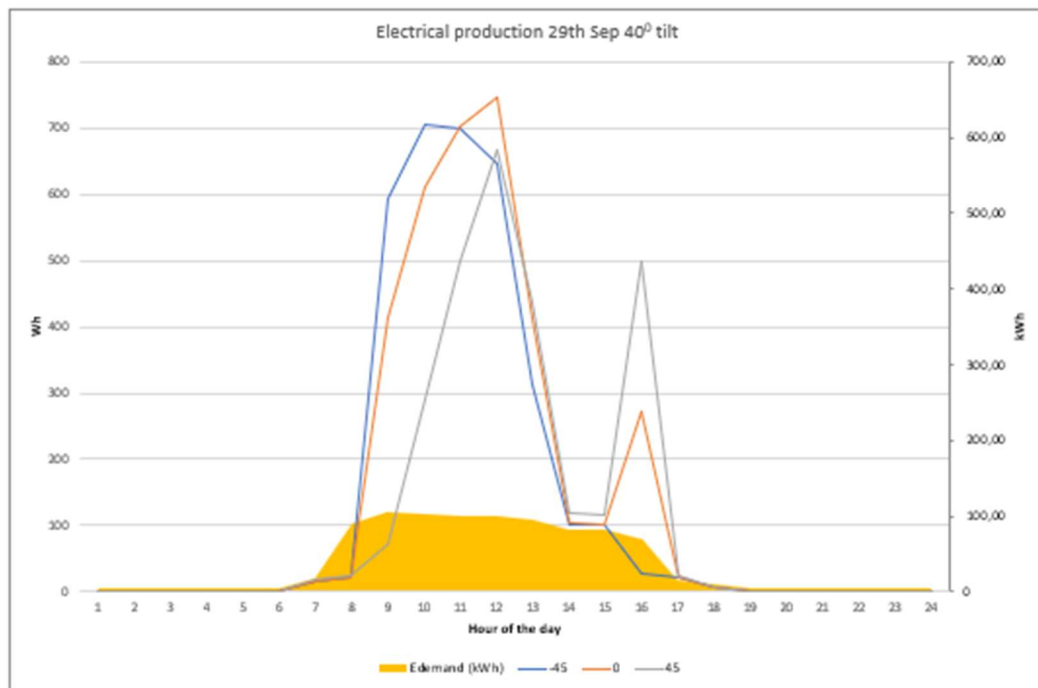


FIG. 11: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 29TH OF SEPTEMBER TRUE SOUTH WITH TILT ANGLE 40° AND THE ELECTRICAL DEMAND FOR THE SAME DAY (2022).

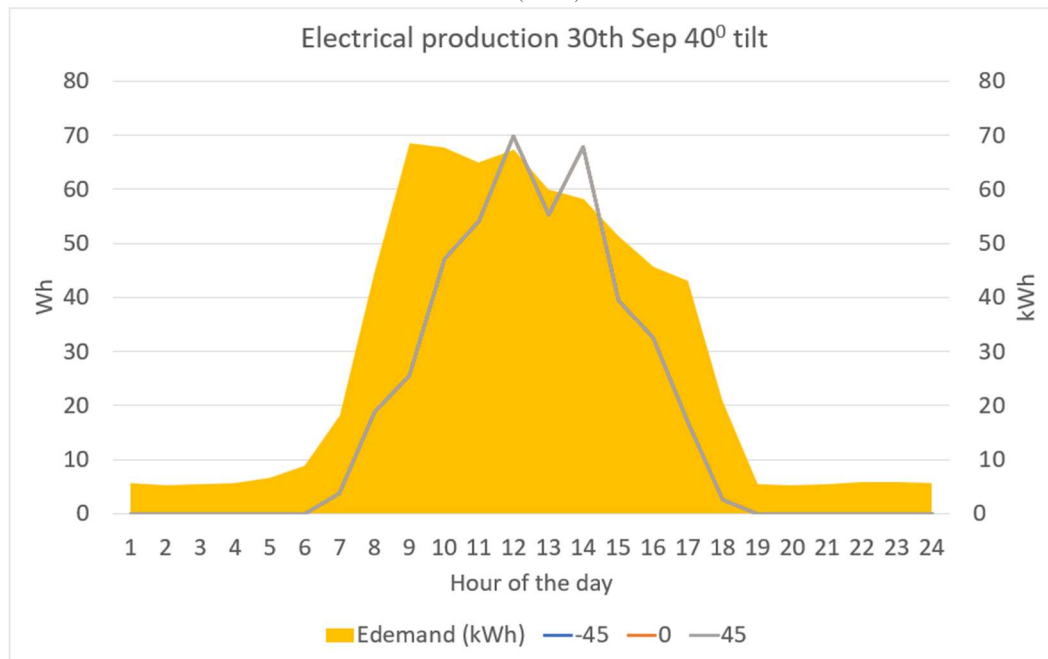


FIG. 12: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 30TH OF SEPTEMBER TRUE SOUTH WITH TILT ANGLE 40° AND THE ELECTRICAL DEMAND FOR THE SAME DAY (2022).

5.2 Sizing

The results from the simulations in 5.1 *Tilt and orientation* show that the best tilt is around 40^0 and the orientation at true South. As a starting point for the sizing, the rule of thumb in 2.3 *Efficiency* states that the actual production is 15–20% lower than solar panel systems installed kWp under real conditions. And the assumption that self-consumption is more profitable than selling electricity according to 3.2 *Self-consumption*. Electricity consumption is at its lowest during June of the days reported in 5.1 *Tilt and orientation* and is just below 50 kW during a working day. Based on this, the largest solar cell system for the simulations is chosen to 50 kWp. The results of the calculations from the simulations for the size of Solar panel systems that were simulated can be found below in Table 4. The self-consumption and discounted payback time are also shown graphically to illustrate how self-consumption affects the discounted payback time in Fig.13 below.

TABLE 4: THE RESULTS OF THE CALCULATIONS FROM THE SIMULATIONS FOR THE SIZE OF SOLAR PANEL SYSTEMS THAT WERE SIMULATED.

P _{max} (kWp)	50	40	30	25	20	15	10
Capex (SEK/Wp)	10,1	10,1	10,1	10,1	11,8	11,8	11,8
Capex (SEK)	505000	404000	303000	252500	236000	177000	118000
Opex (SEK/year)	2500	2000	1500	1250	1000	750	500
Annual production (kWh/year)	49086	39269	29452	24543	19634	14647	9817
E _{utilized} (kWh/year)	35541	29478	23137	19796	16336	12625	8907
E _{exported} (kWh/year)	13545	9791	6314	4747	3299	2022	910
Self-consumption (%)	72%	75%	79%	81%	83%	86%	91%
Self-consumption excl. July (%)	79%	81%	84%	86%	88%	90%	93%
P _{export(Average)} (SEK/kWh)	0,40	0,40	0,40	0,39	0,39	0,38	0,36
R _{annual saving} (SEK/year)	54365	44590	34525	29304	23956	18312	12731
Payback period (years)	9,3	9,1	8,8	8,6	9,9	9,7	9,3
Discounted payback (years)	18,2	17,3	16,2	15,6	21,0	20,0	18,1

Where:

P_{max}=Installed rated power of (kWp)

Capex=Total Installation cost for the Solar panel system (SEK)

Opex=Yearly operation cost (SEK/year)

E_{utilized}=Self consumption (kWh/year)

E_{exported}=Exported to grid(kWh/year)

P_{export (Average)}=Average price for sold electricity (SEK/kWh)

R_{annual saving}=Total savings per year (SEK/year)

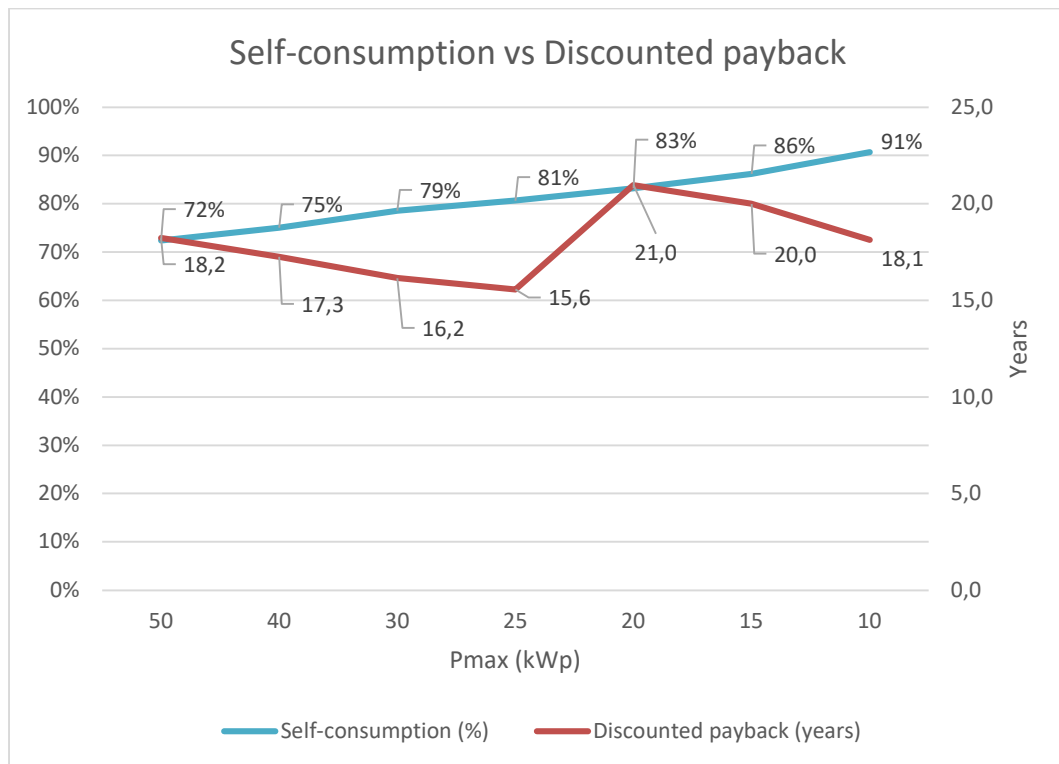


FIG. 13: SELF-CONSUMPTION (%) AND DISCOUNTED PAYBACK TIME (YEARS) FOR DIFFERENT SIZE OF SOLAR PANEL SYSTEMS (kWp). THE RESULT SHOWS THAT 25 kWp GIVES THE BEST RESULT OF 15.6 YEARS DISCOUNTED PAYBACK TIME.

5.3 Result

The results from the simulations in 5.2 *Sizing* show that a solar cell installation of 25 kWp would be the best option that gives a payback time of 8.6 years and a discounted payback time of 15.6 years and a self-consumption of 81%. The fact that the result does not improve with the increased self-consumption after 25 kWp is largely due to the cut-off limit for Capex SEK/Wp, which appear at 20 kWp.

6 Discussion

Are solar panels a good solution for an SME company in Gävleborg County, Sweden to counter the electricity costs that have risen in recent years, was one of question that was basis for this thesis. The question is still not fully answered because both future electricity prices and subsidies are unknown. But based on the result of this study, the best alternative 25kWp gives a payback period of 8,6 years which is in the range of 5-10 years which is what the company management considers a good pay-off time. Furthermore, there are values that are not monetary, installing solar cells would probably strengthen the company's sustainability profile as solar cells are environmentally friendly and are considered as a renewable energy source. It should also be mentioned that the lifetime of the solar panel system is normally much longer than the payback period and that the technology is still under development both in terms of efficiency and storage possibilities.

6.1 Cost of installation

The cost of installations in the result refer to average prices for the year 2021 and not to actual quotes from installation companies, which could potentially have a positive effect on the profitability of the investment. It should also be mentioned that devices for tilting panels 40° are not included in the price, this will probably have a significant negative impact on the profitability of the solar panel system.

6.2 The price of electricity and the payback period

The revenue for exported electricity is only based on spot prices for electricity area 2 in Sweden for the year 2022. Prices change on an hourly basis and are what could be called unpredictable for longer periods.

The costs of purchased electricity in this study are based on a 3-year fixed price agreement and what the price will be thereafter is unknown. Any future subsidy is also unknown. The calculations also do not consider changes in the energy tax which is index based.

The payback period is calculated both with the pay-off method and discounted payback period. Regarding the discount rate used to calculate the discounted payback period, it is higher than it has been in recent years because of prevailing inflation in Sweden. There is enough data in the 5.2 *Sizing* to be able to calculate with another discount rate, but the discounted payback period will not be shorter than the pay-off time as it is not affected by the discounted rate.

6.3 Tilt and orientation

Tilt and orientation were found to have some impact on both the annual electricity production and the daily electricity production, therefore there is a risk that there could be more profitable tilt and orientation of the solar panels than the ones that were simulated. If this were the case, the difference would probably not be more than marginal. Furthermore, there are other parameters than the tilt and orientation that are dynamic such as electricity prices, electricity consumption, solar radiation, which also affect the profitability of the solar panel system so the most profitably tilt and orientation will differ from year to year.

6.4 Dirt, snow and degradation

In the calculations, no account has been taken of pollution and snow, which the latter one will probably have some impact on annual electrical production if it is not removed continuously. The degradation is neither considered, which would have had a negative impact on profitability.

6.5 Approach

The simulations are based on climate data for the company's postal code in the simulation program Winsum PV, so the future electricity production should be quite consistent even if the climate may differ slightly from year to year. The company's consumption does not differ so much monthly for the 3 years that the data was collected. However, the calculations are only based on the company's hourly electricity consumption for the year 2022. Furthermore, electricity production from solar cells system mostly takes place during working hours when consumption is at its highest, however, periods such as weekends and the holiday month of July with low electricity consumption will make it difficult to achieve close to 100% self-consumption. The result of this study should be within a reasonable margin of error and should be applied to similar companies at the same latitude and electricity area in Sweden.

7 Conclusions

7.1 Study results

It is possible to influence the electricity production from the solar cells by turning and tilting the solar panels, but when the sun is shining cannot be influenced. The results of the simulations in this study showed that the direction true South with 40° tilts gave the highest annual production and highest self-consumption, this even in the case that the holiday month of July was excluded from the all the simulated alternatives. Furthermore, the factory's electrical consumption is at its peak during working hours, 07:00-16:00 Monday-Friday, which is also the time of the day when the electrical production from the solar panels system is at its highest. Unfortunately, the degree of self-consumption is negatively affected by the holiday and non-working days.

A higher proportion of self-consumption offers better profitability until installation costs SEK/Wp increase when the solar panel systems installed power decreases. The most profitable alternative with the installed power of 25 kWp had an 81% self-consumption and a payback period of 8.6 years and a discounted payback period of 15.6 years when the STIBOR + 4.5% was used as discounted rate. It should also be mentioned just like in the discussion section that devices for tilting the PV panels to 40° are not included in the calculation of installation costs and are likely to significantly negative impact of the profitability.

7.2 Outlook

The continuation of this thesis could be to calculate how a battery storage possibility would affect the profitability. It would also have been interesting to analyze an alternative where the solar panels were mounted direct on the low-sloping roof of the factory. And it also been interesting to calculate how profitability would been affected if the company had been entitled to existing subsidies.

7.3 Perspectives

The focus of this study has not been to study solar cells from a sustainability perspective, but from a profitability perspective. From a sustainability perspective, solar cells are considered a renewable energy source and thus contribute to ecological sustainability, which is one of three dimensions of sustainable development. The other dimensions are social sustainability and economic sustainability, which is met by self-production of electricity from solar cells reducing the proportion of purchased electricity which reduces sensitivity to fluctuating prices affected by external factors such as the war in Ukraine. The reduced sensitivity to high electricity prices means a competitive advantage which can thereby secure local jobs which is important for people's well-being.

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Appendix. A: Weekly electrical consumption

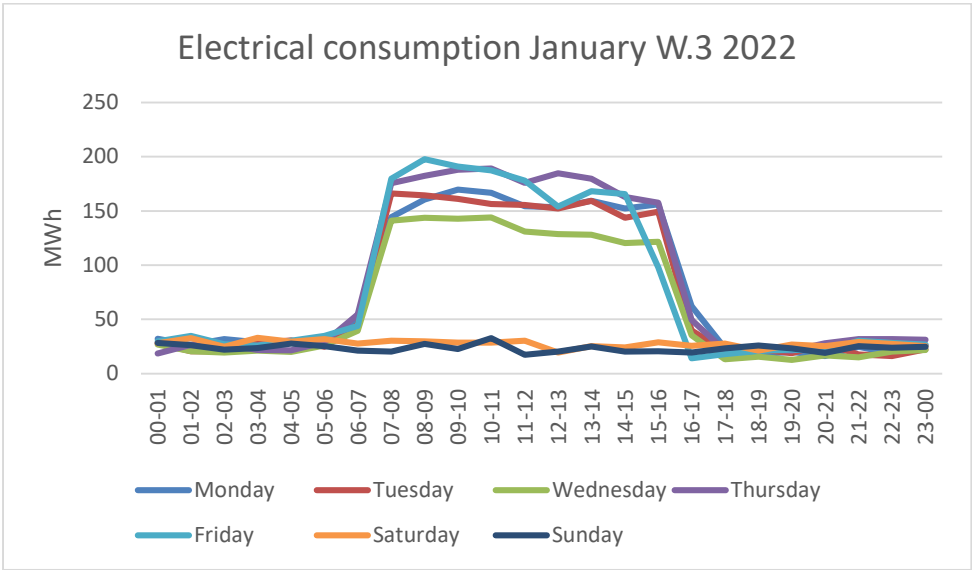


FIG. 14: THE ELECTRICITY CONSUMPTION OF THE COMPANY DAY BY DAY DURING W.3 2022.

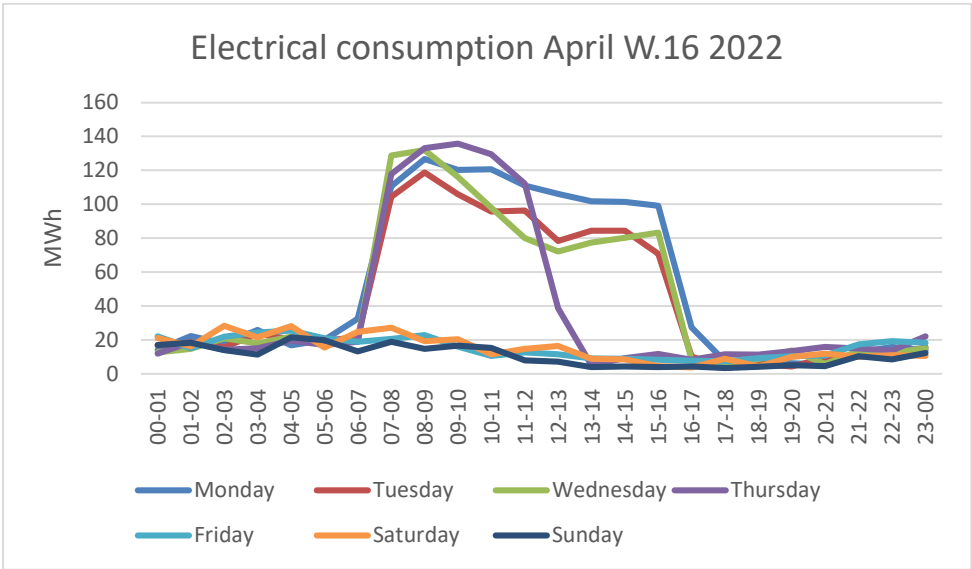


FIG. 15: THE ELECTRICITY CONSUMPTION OF THE COMPANY DAY BY DAY DURING W.16 2022.

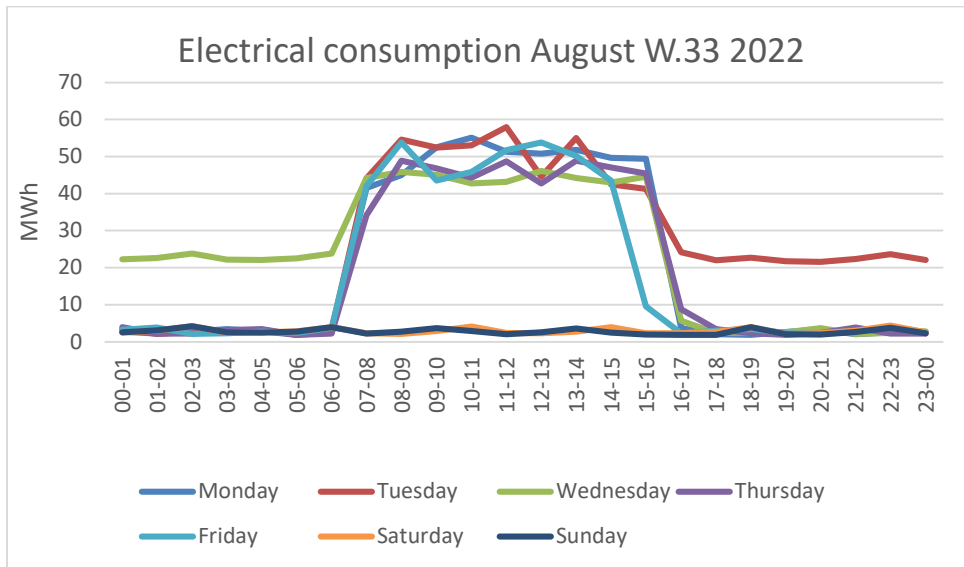


FIG. 16: THE ELECTRICITY CONSUMPTION OF THE COMPANY DAY BY DAY DURING W.33 2022.

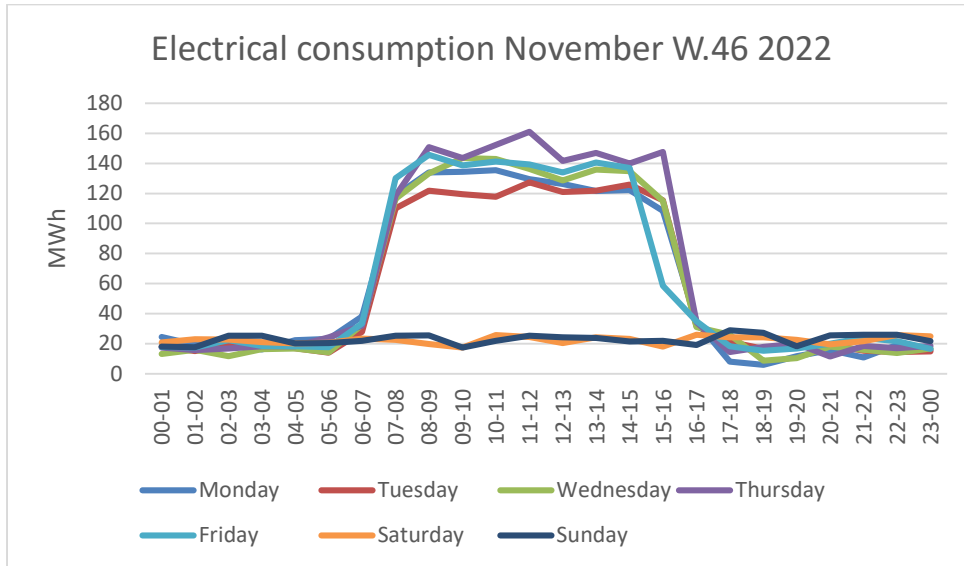


FIG. 17: THE ELECTRICITY CONSUMPTION OF THE COMPANY DAY BY DAY DURING W.46 2022.

Appendix. B: Color diagram of simulations

TABLE 5: SIMULATION MONTH BY MONTH FOR TILT ANGLES IN 10⁰ STEPS IN THE RANGE 30-60⁰ IN COMBINATION WITH ORIENTATIONS 10⁰ STEPS IN THE RANGE -20 - 20⁰. THE HIGHEST ELECTRICITY PRODUCTION FOR ALL CASES TAKES PLACE IN THE PERIOD FROM APRIL TO AUGUST. 40⁰ TILT TRUE SOUTH GIVES THE TOTAL HIGHEST ANNUAL ELECTRICITY WITH AND WITHOUT JULY INCLUDED.

	30,-20	40,-20	50,-20	60,-20	30,-10	40,-10	50,-10	60,-10	30,00	40,00	50,00	60,00	30,10	40,10	50,10	60,10	30,20	40,20	50,20	60,20
January	7	7	7	6	7	7	7	7	7	7	7	7	7	7	7	6	7	7	7	6
February	42	46	49	51	43	48	51	53	43	48	51	53	42	47	51	53	41	46	49	51
March	89	94	97	97	91	97	100	101	92	98	101	102	91	97	101	101	90	95	98	99
April	133	137	137	134	135	139	139	136	136	140	140	137	135	139	140	137	133	137	138	135
May	147	145	140	133	147	145	140	132	147	144	139	131	146	144	138	130	145	143	138	130
June	133	129	123	115	132	128	122	113	132	127	121	112	131	127	120	112	130	126	120	111
July	148	146	141	133	147	145	139	130	146	142	137	128	144	140	134	125	142	138	132	123
August	116	116	114	109	118	118	116	110	119	119	117	112	120	120	118	113	119	120	118	113
September	80	83	84	82	81	85	86	85	82	85	87	86	82	85	86	85	81	84	85	83
October	45	48	51	52	46	50	53	54	46	50	53	55	46	50	53	54	45	49	51	52
November	15	16	18	18	15	17	18	19	15	17	19	19	15	17	18	19	15	17	18	19
December	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Total	957	971	963	932	965	980	972	942	967	982	974	943	962	977	968	938	951	964	955	924
Total-July	809	825	822	800	818	836	833	812	821	839	838	816	818	836	834	812	810	826	823	801

Appendix. C: Simulation of different tilt angles

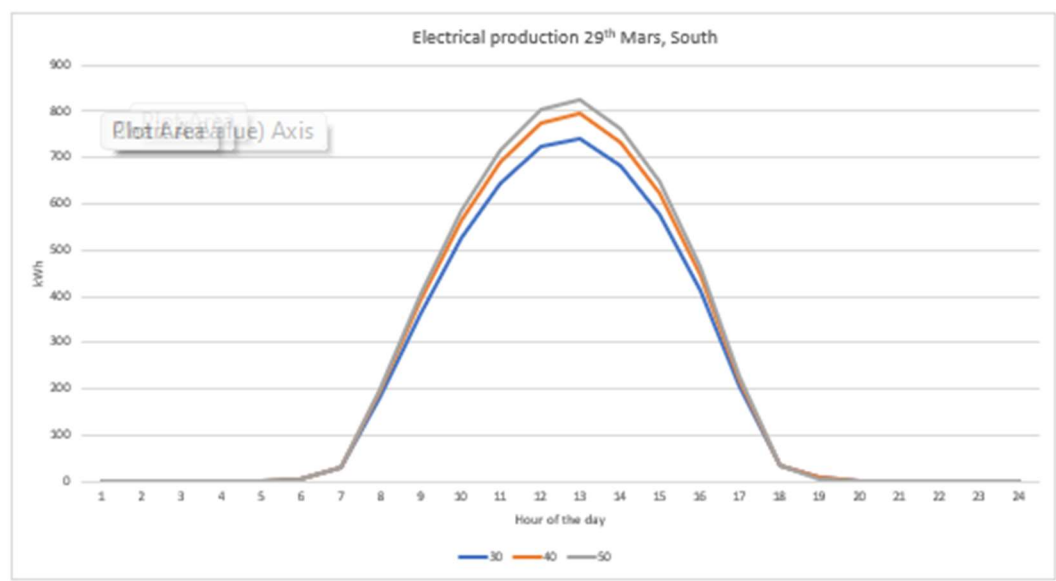


FIG. 6: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 28TH OF MARS TRUE SOUTH WITH TILT ANGLES 30°, 40°, 50°.

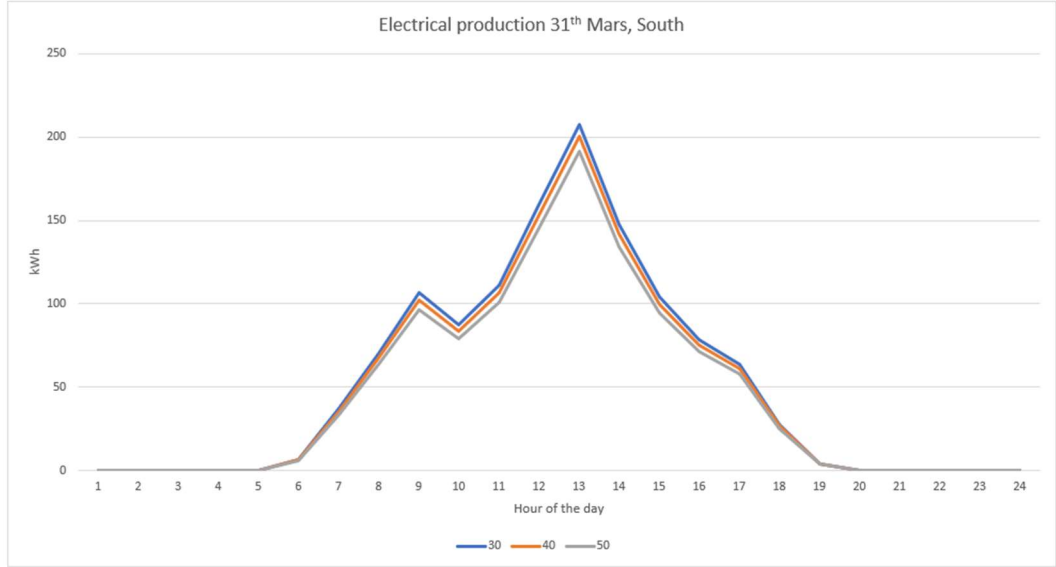


FIG. 19: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 31TH OF MARS TRUE SOUTH WITH TILT ANGLES 30°, 40°, 50°.

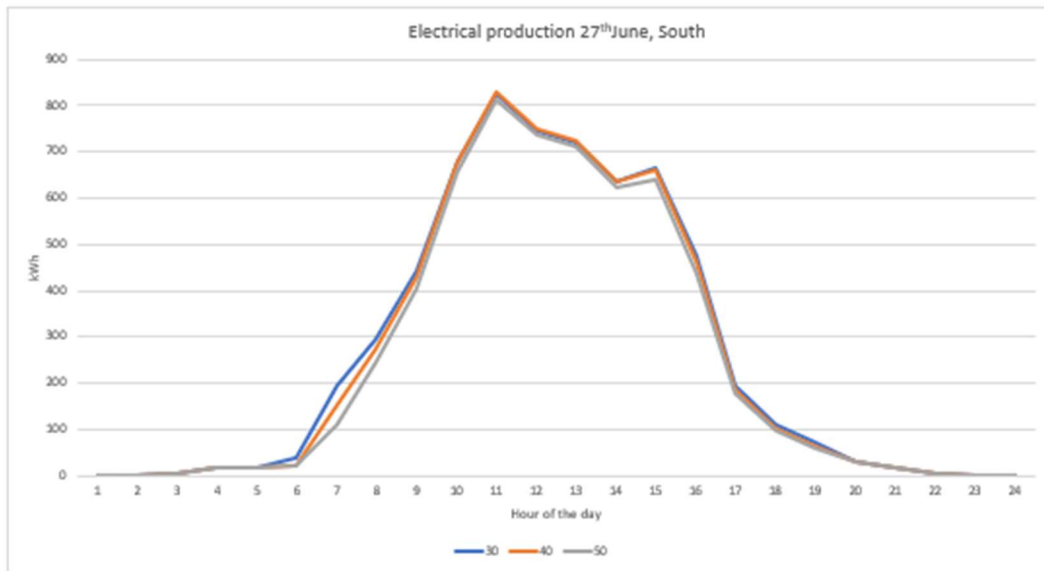


FIG. 7: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 27TH OF JUNE TRUE SOUTH WITH TILT ANGLES 30° , 40° , 50° .

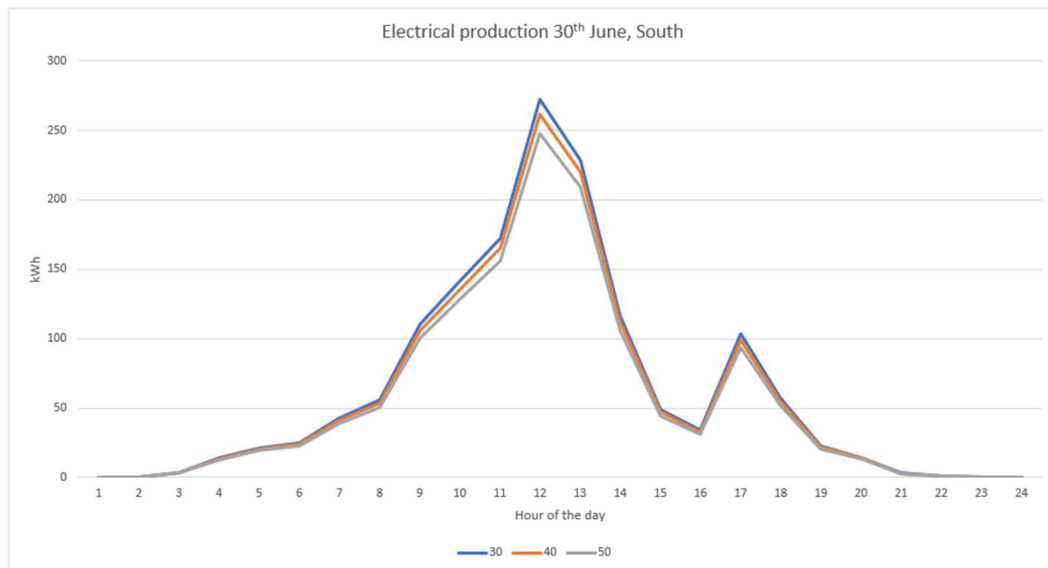


FIG. 21: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 30TH OF JUNE TRUE SOUTH WITH TILT ANGLES 30° , 40° , 50° .

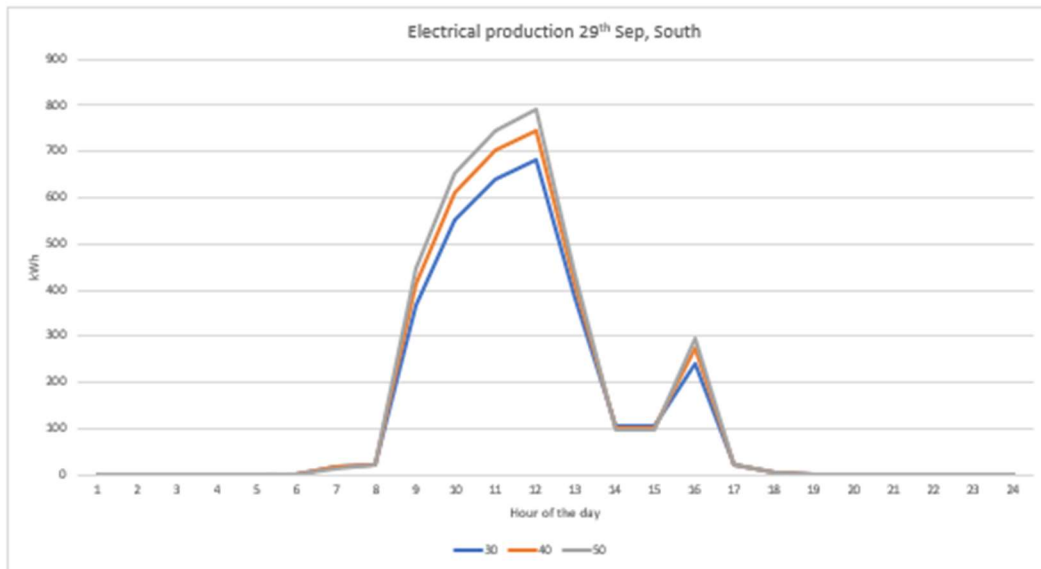


FIG. 22: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 29TH OF SEPTEMBER TRUE SOUTH WITH TILT ANGLES 30° , 40° , 50° .

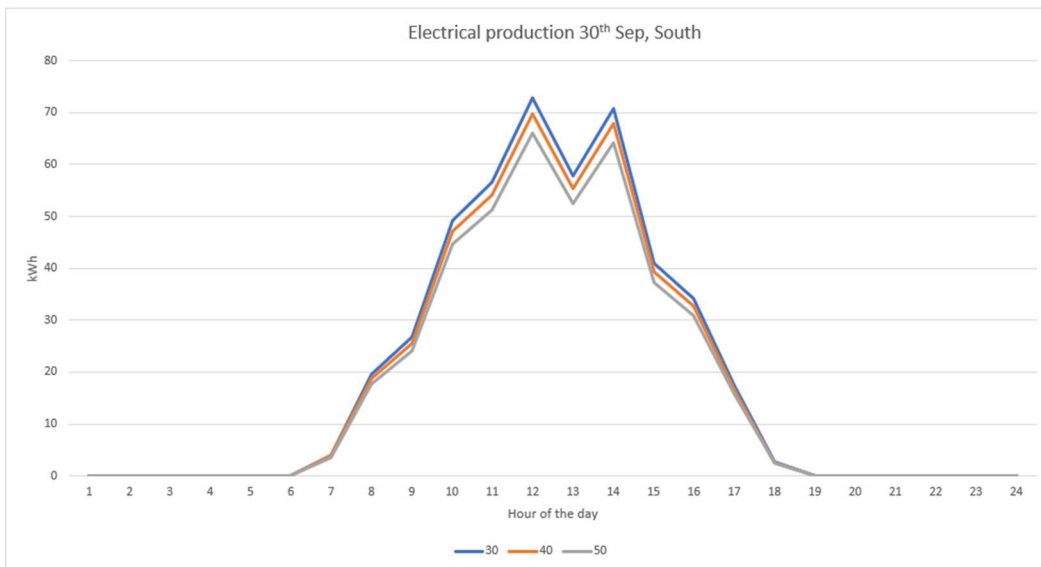


FIG. 23: SIMULATED ELECTRICAL PRODUCTION (1kWp) FOR 30TH OF SEPTEMBER TRUE SOUTH WITH TILT ANGLES 30° , 40° , 50° .