UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ESCUELA TÉCNICA SUPERIOR INGENIERÍA INDUSTRIAL VALENCIA

MASTER THESIS

Industrial engineering in energy

Technical and economic feasibility study of photovoltaic systems Integrated on building facades of the Universitat Politècnica de València (UPV)

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Academic year: 2021-22

ABSTRACT

This paper considers the technical and economic feasibility of a 90° BAPV (building applied photovoltaic) facade installation placed on all the considered feasible building walls located on the UPV campus. In order to investigate this feasibility, the calculation programs PV*SOL and SAM were used. Building 7 and 8 of UPV were recreated in these programs in order to investigate the impact of shadow on the energy production. This was necessary because, recreating the whole campus in these program's would have taken a large amount of time. To measure the surface of the feasible facades the 3D-polygon option in Google Earth Pro was used. With these measured surfaces it was possible to calculate the total energy production of the whole campus in SAM which amounted to a total of 7.13GWh/year. By comparing that with a consumption of 38GWh/year, this renewable energy production makes up 18.75% of the total energy need for the campus. Considering a CO_2 emission reduction of 152g/kWh of photovoltaic energy production and a total production of 7.13GWh/year, 1,000 ton of CO_2 will not be released into the atmosphere. With a cost of 1,000€/kWp for the whole installation, a total price of 9.65M€ has been estimated. Using a price of 100€/MWh for electricity bought to the grid, a simple payback time of 8.9 years and a discounted payback period of 12.4 years is obtained.

Keywords: PV on Facades, Renewable energy system, selfconsumption, decarbonization.

RESUMEN

Este trabajo considera la viabilidad técnica y económica de un sistema fotovoltaico sobre fachadas a 90° en cada edificio del campus de vera de la UPV. El cálculo de la producción de los Edificos se realizó mediante los programas PV * SOL y SAM. En estos programas se recrearon los edificios 7 y 8 de la UPV para investigar el impacto de la sombra en la producción de energía. Esto era necesario porque recrear todo el campus en estos programas habría llevado una gran cantidad de tiempo. Para medir el tamaño de la superficie de las fachadas factibles se utilizó la opción 3D-polygon en Google Earth Pro. Como resultados se optubo que el potencial de producción total de energía es de 7,13GWh/año. Al compararlo con un consumo de 38GWh/año del campus de vera de la UPV, la producción de energía renovable supone el 18,75%. Considerando una reducción de emisiones de 152gCO_2/kWh por producir a partir de la energía fotovoltaica se dejan de emitir 1.000 toneladas de CO_2 a la atmósfera. El coste de la inversión sería de 9,65M€. Finalmente, se utiliza una estimación de precio de 100€/MWh para la electricidad compradaa la red obteniendo un paybakc de 8,9 años.

Palabras clave: Fotovoltainca en fachadas, energias renovables, autoconsumo, descarbonización

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ABBREVIATION	EXPLANATION
UPV	Universitat Politècnica de València
PV	Photovoltaic
BAPV	Building applied photo voltaic
BIPV	Building integrated photovoltaic
SAM	System Advisor Model
ROI	Rate of interest
ROR	Rate of return
RES	Renewable energy sources
CO_2	Carbon dioxide
O&M	Operation and maintenance
IPCC	Intergovernmental Panel on Climate Change
DHI	direct horizontal irradiance
DNI	Direct normal irradiance
POA	plane-of-array irradiance
DSM	demand-side management
AJB	Array junction box

MANUSCRIPT

Chapter 1. Introduction

Nowadays more and more businesses and private households are making use of RES (Renewable energy sources), not only because it is good for the environment but also because it is a good investment and provides a progressive image for a company. There are not so many downsides besides the investment costs that the installation requires combined with the maintenance cost. The upsides of PV (photovoltaic) panels outweigh the downsides, especially now the sun tax in Spain is removed and that's why UPV is willing to investigate the feasibility of photovoltaic panels for the school. They have done research for placing them by the conventional method, this being on a roof placed at an angle of around 30° with an orientation to the south. This method is commonly used due to the fact that it gives the best electrical efficiency. But what if the roof(s) do not offer enough space for a PV installation that is supposed to cover a decent part of the consumption and when the ground space is considered too expensive. Then other solutions like BAPV (building applied photovoltaic) or BIPV (building integrated photovoltaic) facades can be investigated. Because BIPV gets implemented when the structure is being build or when the building is being totally renovated, this method won't be considered in this study. BAPV on the other hand can be preformed on the already existing structure by the use of racks. This method applied to all of the feasible building walls of UPV will be investigated in this paper.

1.1 Objective

This research aims to determine the economic and technical feasibility of installing facade PV systems on the UPV (Universitat Politècnica de València). This paper gives the UPV a proper idea of what the outcome would be if they would realize the project. To conclude if the project is feasible, there will be some results of great importance. The most important results will be the total possible amount of electric energy that can be produced, the total cost of the project, and the payback of the installation. With these results, it is possible to conclude whether BAPV (building applied photovoltaic) panels at UPV walls is favorable or not.

1.2 Project Justification

The reason that UPV wants to research BAPV facades is because rooftop installations have already extensively been researched. as a result, this study will make it possible to compare the results from a conventional 30° PV installation, with a facade PV installation. The main results that should be compared will be the difference in payback time, amount of electricity production and the investment cost. It is also important to compare the parameter inputs from these projects because these can cause a big difference in the calculated payback time.

1.3 System types

A separation can be made between BAPV and BIPV [1]. BAPV stands for building applied photo voltaic which means that the solar panels are being attached on an already finished structure with a rack mount. Most of the installations to this day are BAPV installations because placing solar panels is relatively new compared to the lifetime of a building. However, there is an uprise in the use of BIPV, especially in new building projects. The panels in this case are integrated in the parts used to build the structure. These parts being walls, roof tiles and even windows. The upside of this type is that these building parts have to be bought anyway, which makes it cost efficient. But because it is a rather new product the energy yield is on the low side and price is rather high. None the less it is more and more feasible due to the increase in use.

A BAPV facade can be classified into two main groups, curtain wall and horizontal sunshade type. The curtain wall type is attached vertically on the wall with some free space in between to ensure natural airflow to cool down the panels. This type of installation has the highest efficiency per available square meter and gives the building an aesthetic look shown at Figure 1. This is the type of installation that will be researched further on in this study.

Figure 1: BAPV facade illustration

The horizontal sunshade types shown in Figure 2 helps to reduce the daylight entrance, reduces heat from the solar rays to warm up the building and improves the systems overall efficiency if used above or in front of windows. By using this type of installation to cover all of the walls, shadow is formed on the panels below which reduces efficiency, to counter this effect a distance has to be kept between the underlaying panels in which case the generated energy for the already limited amount of space, is reduced. It is recommended to orientate this type of installation on the southwest of the building [2].

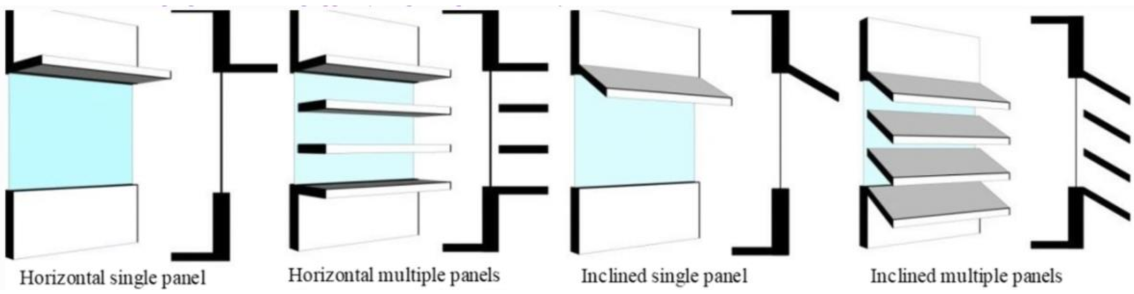

Figure 2: BAPV shading device types [2]

BIPV on the other hand can be classified into two main groups. A BIPV system and a BIPVT system. Both systems are used to provide cooling for the panels to have a good efficiency and life span. A BIPV system has an opening in the bottom and at the top of the facade/panel, this provides a natural airflow at the back of the facade panels. This natural airflow is generated due to the fact that the panels generate heat and therefore the air warms up between the panels and the facade wall. The heated air has a lower density and will rise up while the cold air will flow in at the bottom due to the fact that the air pressure wants to balance out with the surroundings. A schematic of this type of installation is presented at Figure 3.

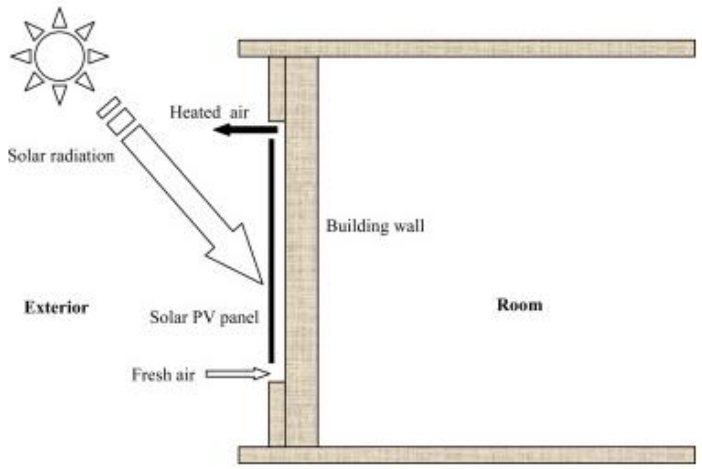

Figure 3: BIPV schematic [3]

BIPVT on the other hand is a more advanced cooling system which can provide heat for the building in the winter months. This system requires a ventilator due to the fact that the hot air will not be inclined to rise up because the air is lead to a room that is already warm. A simplified schematic of this installation can be seen at Figure 4 below.

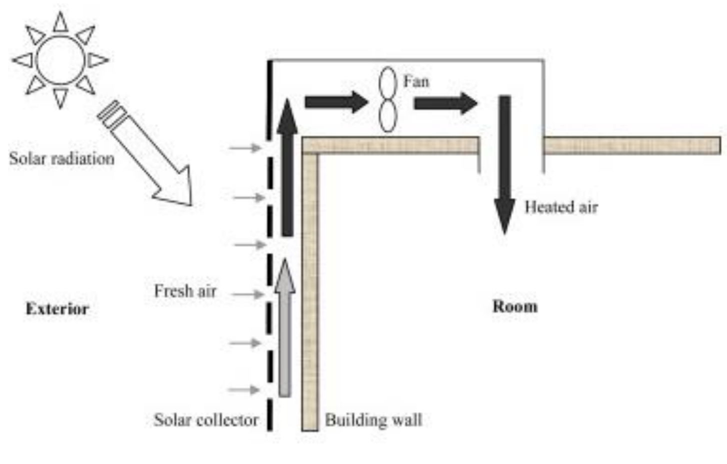

Figure 4: BIPVT schematic [3]

1.4 The advantages of BAPV facades compared with a 30° installation

Before going deeper into the project calculations, the important differences between a facade placement and a more common 30° tilt installation [4] will be considered. This will provide a better understanding of which type of installation is more favorable in which situation. Most of the advantage and disadvantages tend to be variable according to the installation's location, available space, consumption curve and the desired amount of electricity production. At this moment 80% of the PV systems are rooftop mounted [5] but there is an increased tendency towards photo voltaic facade placement.

1.4.1 Pollution on panel

Solar panels have a protection coating that provides resilience against extreme weather conditions, scratches and also keeps dust from piling up. This smooth protection layer will cause the dirt, dust and other impurities to slide off the moment it rains. But the lower the tilt angle the higher the probability that there will remain some impurities on the panels. Placing the panels vertically will, however reduce the chance of remaining impurities. Especially in areas where there is a lot of snow this could play a big factor. When the panels are covered with snow the panels will not produce any electricity. Placing the panels vertically in environments where this is a common problem could prove favorable.

1.4.2 Production potential

Walls have, on average more production potential than roofs, thanks to the bigger available surface. This is especially the case on taller buildings [6]. The taller the building the bigger the wall surface is compared to the roof surface. Buildings with four floors have on average four times more facade surface then there is available surface on the roof [7]. When the entire available wall area would be used for a PV installation, it would on average produce up to triple the amount of energy that a roof surface could provide. The radiation per square meter on the other hand is on average higher on the roof compared to that from the walls. This disparity increases as the temperature of the climate increases (closer to the equator) and decreases as the climate gets colder (closer to the poles). This is visible on Figure 5 which displays the average annual BIPV/BAPV potential depending on the location. The roof has a higher kWh/m² peak, especially in warmer areas due to the sun having a higher tilt. Spain is considered being rather close to the equator compared with other European countries and herby shows a high contrast between the roof radiation and the wall radiations. But if the wall radiation of Spain is compared with the radiations of other European countries, Spain is considered more feasible. This makes the facade installation in Spain still more viable than in colder climates, considering the energy policy and energy price are equal.

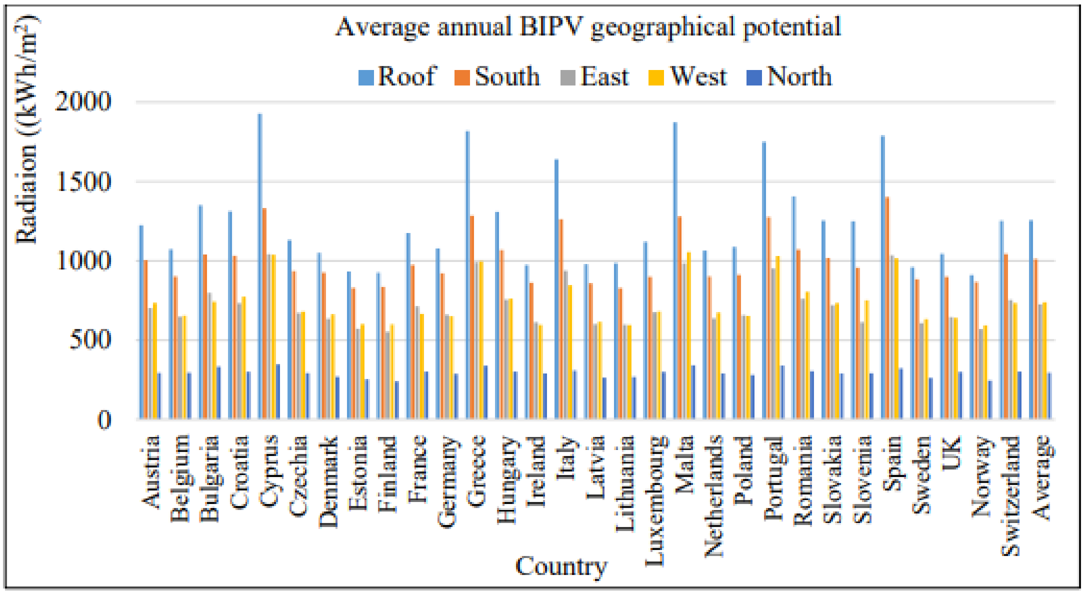

Figure 5: Geographical BPV potential [6]

1.4.3 Day-production curve

Placing a panel aimed to the south with a low tilt will cause a high production when the sun is at its highest. The average kilowatt hour production of this type of installation will be higher compared to a facade installation. The downside of this method is that the production will be high at midday but strongly decreased during the rest of the day which is visible at Figure 6. This figure displays the comparison of a conventional south orientated PV installation with an inclination of 30°, a facade installation and the actual consumption of the school at 16 September. If a lot of facilities use this type of installation, there is a big chance the production and consumption on the electrical grid will be in unbalance. Unbalance in the grid causes problems such as black-outs and must be prevented at all costs. Placing the panels with different orientations and a higher tilt, will give a flatter production curve during the day. This is already being rewarded by the grid operators by using monitoring meters that compare the production and consumption curve of the electrical installation. This means that producing electric energy on the moment that the energy demand is low, is less rewarding then producing on moments when there is need for a lot of energy.

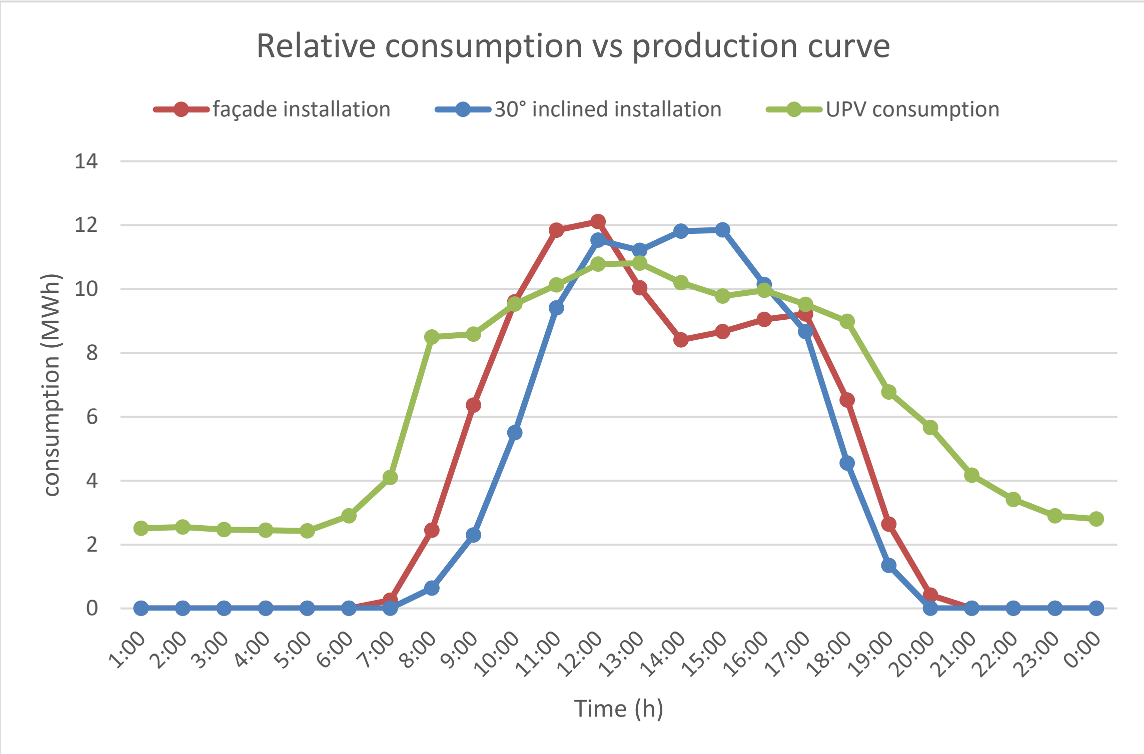

Figure 6: relative day production and consumption curve at 16 September

1.4.4 Year-production curve

While a conventional 30° tilt installation produces more energy in the summer months, the production curve of a vertical installation aimed to all four orientations, will remain rather constant throughout the month. This effect is created by the lower tilt the sun has in the winter months compared to the tilt in the summer months. This causes more direct lighting to fall on the vertical panels in the winter which gives a high production even though the irradiation is lower compared to the summer. This effect can be seen on Figure 19 where the blue curve represents the horizontal irradiance and the other curves the vertical irradiance from the four orientations. The sum of these four orientation curves give a more or less flat curve which is seen advantageous because in the end the total actual electricity production has to match the total electricity that is consumed. This consumption curve has his peak in the winter. Therefore a facade installation with a flatter annual curve is considered advantageous compared to a 30° tilt installation with his peak production in the summer.

1.4.5 Corporate image

A corporate identity or corporate image is the way in which the company, school, city,… represents itself to the public. The goal is to obtain a good image for the company in order to attract investors, employees,… or students in order to maintain or create a good and successful environment for the enterprise, in this case the university. The image depends on the delivered services and is favorable in function of the satisfaction of the customer. It also depends on the future plans of the enterprise. At last the image depends on the appearance of the company. All these factors are difficult to obtain and consume time, energy and sometimes a lot of money. By placing solar panels in an original way like BAPV facades creates a green and progressive image that even returns its investment cost.

1.4.6 Decarbonization

The use of fossil fuels for generating electricity or power for machinery contributes to environmental degradation and adversely effects climate change. This negative impact on the climate is caused by the release of carbon dioxide due to the combustion of fossil fuels. This carbon dioxide gas forms a layer in the atmosphere that lets the short wave solar rays pass, but holds back the long wave infra red rays that are reflected by the earths surface by absorbing/reflecting them. This effect generates warmth because of instead, being reflected back into space, it is captured inside of the earths atmosphere. This phenomenon is called the greenhouse effect due to the same effect that is created in these glass structures used to create a warm environment for the plants, where the glass reflects the long wave rays back into the internal housing which generates a higher temperature.

Detailed studies by IPCC (Intergovernmental Panel on Climate Change) states that in order to avoid climate change greater then 2°C by 2050 it is necessary to not surpass the mark of 450 ppm in atmospheric carbon-concentration. This goal is rather challenging because we already surpassed the 400ppm mark which can be seen at Figure 7. To prevent the ppm from a continuing rise, a shift has to be made from fossil fuels to renewable energy. The current fastest growing source of renewable energy is solar energy [8] with an average grow rate of 50% since 2005 [9]. In order to calculate the amount of avoided

CO_2 emission, the total emission of the panel itself has to be taken into account. This includes O&M (operation and maintenance) as well as the fabrication process of the panel. The value of these two factors is considered 46gCO_2/kWh by IPCC [9]. As second factor the amount of avoided CO_2 emission by not consuming electrical energy from the grid has to be considered. This factor depends on the types of resources used for creating the electrical energy and is considered 198gCO_2/kWh averagely for Spain while Europe has a average of 267gCO_2/kWh, both in the year 2019 [10]. By subtracting those two values it can be concluded that 152gCO_2 is avoided for each kWh of electrical energy produced by solar panels in Spain.

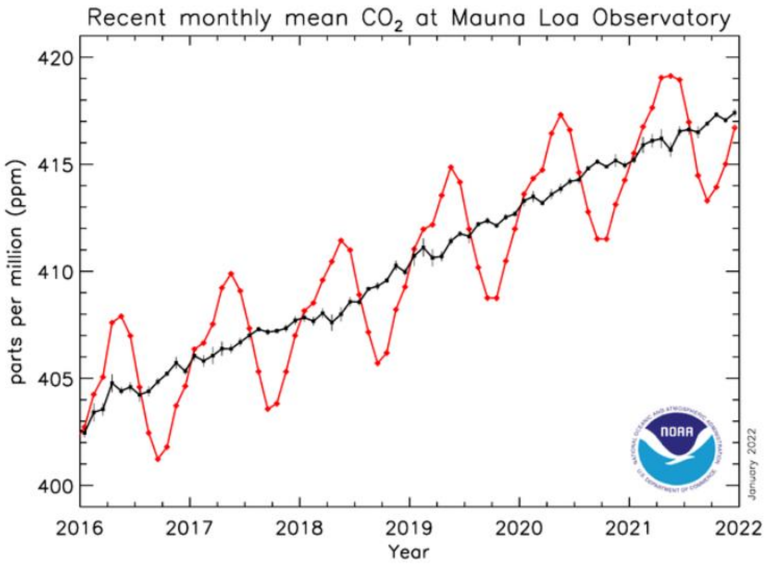

Figure 7: CO_2 presence in the air in ppm [11]

1.4.7 Optimal space usage

Panels are most commonly placed on roofs. The reason for this is that ground space is limited and can cost a lot of money, especially in cities. For Valencia a price of 1,896 €/m² is considered [12]. This price makes it verry unfavorable to place panels on the ground. Although it should be taken into account that it is possible to resell these lands in the future for possibly a higher price. Placing the panels on the roof is non the less a better option in city environment, because most of the time the roof has no other function besides completing the closed building structure, providing space for A/C equipment, chimneys and in some cases windows. Placing solar panels on the roof ensures an efficient way of using all the available space provided by your facility. Walls offer the same possibilities and will on average provide more available space for solar panels.

1.5 The disadvantages of BAPV facades

1.5.1 Energy production

Placing a facade-PV installation in an area close to the equator will drastically reduce the production compared to a conventional tilt installation. This is because the suns average position close to the equator is higher compared to an area close to the poles. This causes the solar rays to strike the panel more directly from above instead of sideways and here by decreases the vertical panel efficiency compared to a normal tilt installation. A facade installation that lays close to the equator like Arizona has 40% reduced production compared to a optimal setup [13]. While a location closer to the poles like Alaska will only have a 25 percentage drop [13]. Because Spain has a pretty high average sun position the potential production of a facade installation will be in quite a quantity lower then an optimal solar orientation which can be seen at Figure 5.

1.5.2 Placement price

The placement of a facade installation should be theoretically less costly because there are less mounting materials required compared to a rack setup used on flat roofs. The reality is that the placement of a vertical installation is less common which means that the market for this type of installation is smaller. This causes less competition between the companies which means higher prices. The risk for the employees is higher as well and the regulation is more strict which also means a higher cost. These three factors cause most likely a higher price compared to a more common 30-40° roof installation at this moment [14].

1.5.3 Damage or theft risk

If the solar panels are installed close to the bottom of a wall the risk for the panels to be compromised is high. This can be prevented by placing protections around them but this would reduce the efficiency and increase the installation cost. Which would increase the payback time. Camera surveillance might scare the possible perpetrators away and makes it more easy to find the culprit. After all the likeliness of this to happen depends on the location of the installation.

1.5.4 Feasible walls

Its only possible to place BAPV facades if the walls of the building are freestanding and there for not linked to another building. Even if you have freestanding available walls it is only recommended to place panels on the facade if there are not much objects like, buildings, tree's, walls,… nearby that could form shadow on the panels for a large period of time. Shadow formed on a panel does not only effect the production of that one panel but lowers the current true the whole panel string in which case the MPP (max power point) is effected. By using bypass diodes this panel will be in case of shadow fall or other malfunctions bypassed, which in this case will not reduce the current of the whole string but will only reduce the voltage that the one panel normally adds to the circuit and the voltage that will stand over the bypass diode which is shown in Figure 8. These bypass diodes will also prevent power dissipation by the panel not subjected to solar irradiation and will due to this avoid hotspots being created in the panel that could damage the panel. Even by using bypass diodes, shadow will have a big impact on the production, because shadow will most of the time fall on more panels at once which will reduce the power generated by the string a lot.

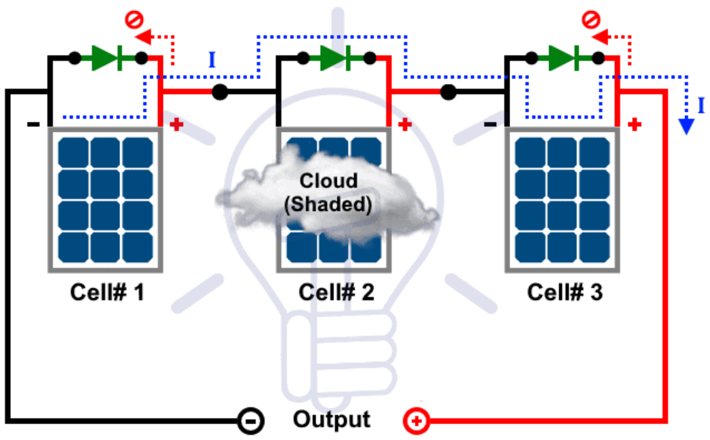

Figure 8: effect of shadow on a panel [15]

Chapter 2. Methodology

The first step made, is calculating the amount of energy that a vertical PV panel can produce depending on the facade azimuth on the campus. Because almost all the buildings on the campus are aimed in the same direction, only four different azimuth orientations were calculated. This part has first been carried out by simulating building 8 and 7 in a virtual PV calculation program to see the amount of electricity production with two different types of shade exposure. Where building 8 is favorable with some trees in the south, building 7 has a lot of nearby surrounding buildings. For the next step, the total usable surface from all the other buildings at the UPV campus was calculated using google earth. The building walls with too much shade or too many obstacles like windows were avoided. At last, the shadow impact from building 7 and 8 is used to calculate the possible amount of electrical energy production for the whole UPV campus.

2.1 Used tools

The programs used in this project to calculate the electrical and economic feasibility of PV facades are PV*SOL premium and SAM. Other programs, like PVsyst or PVWatts are used for the same purpose. The error margins of these programs are rather small, as shown in Table 1. These extensive programs allow to include many different inputs for the calculation and provide a 3D visualization option. This option makes it possible for the programs to calculate the amount of shadow to which the panels will be exposed and the hereby decreased energy production of the PV system. In addition, the program Google Earth is used to calculate the total available space the UPV campus provides for PV facade panels. This program made it easy and reasonably accurate to calculate the available wall surface in a small amount of time.

Tool	*Error Range*
SAM	-5.0% to 4.1%
PVSyst	-1.7% to 5.5%
*PV*SOL*	-5.5% to 1.4%
PVWatts	-16.2% to 8.9%

Table 1: Annual error range of four PV modeling tools [16]

2.1.1 SAM (System Advisor Model)

"The System Advisor Model (SAM) is a free techno-economic software model that facilitates decision-making for people in the renewable energy industry". The program has a lot of input options and also gives a lot of output results. But all these options makes the program rather difficult for a novice to start with.

The reason that SAM has been used for this project is due to the amount of possible options this program provides. One of these options makes it possible to simulate the panels at a 90° tilt while other programs don't provide this option due to its uncommon nature. The 3D option of the program on the other hand is rather basic while PV*SOL offers a lot of 3D functions.

Creating a desired simulation on SAM consists of going through different tabs in the program. Every tab has his own subject (such as module, system design, system cost,…) that provides the option to change the input parameters.

Once all the input parameters of the program are set according to the installation the results can be calculated. The outputs of the SAM program are generated by pressing the "simulate" button at the left bottom of the screen.

After the program calculations are done some basic results are displayed such as the total produced annual energy in kWh, payback period and investment cost. But there are a lot more results calculated by the program that can be found in the new emerged result tabs at the top of the program screen. These results include hourly data, single values, annual data and way more.

2.1.2 PV*SOL Premium

“PV*SOL premium is a dynamic simulation program with 3D visualization and detailed shading analysis for the calculation of photovoltaic systems”. This program has less input possibilities and is more visualizing which makes it a beginners friendly program. It also has a more elaborated 3D option which makes the design more corresponding with the reality.

The program recreates the ground scene of the project by using google earth, Bing Satellite or OSM. This ground scene includes the floor map of the compound with the right orientation of the visible buildings. Now you can let the building rise, given the right height and roof structure which can be a flat or pitched roof. For the next step you have to indicate the location where the panels should be placed, the slope of the panels as well as the type of the panel. And then with the exception of a few more parameters the program will calculate the possible amount of panels that can be attached to the walls. At last it is possible to include some other items like trees or walls that could cause shade for the panels. An example of a created project for this document is shown at Figure 9 below.

Figure 9: Possible result from a PV*SOL project

2.1.3 Google Earth

Google Earth is a free application that makes it possible to visit almost every place on earth by the use of satellite and aerial pictures. This virtual environment can be used to measure objects. This creates the possibility of quickly measuring the facades of the buildings located on the UPV campus, as shown in Figure 11. The function used for measuring the facades is called 3D polygon, which can be seen in Figure 10. This function displays the perimeter in meters and the surface in square meters of the demarcated area. These surfaces were calculated for the feasible-looking buildings on the campus that didn't show too many signs of excess shadow by obstacles in the area. All these feasible surfaces were measured in which the data were categorized by building and orientation, which is displayed at Table 12 later in this document.

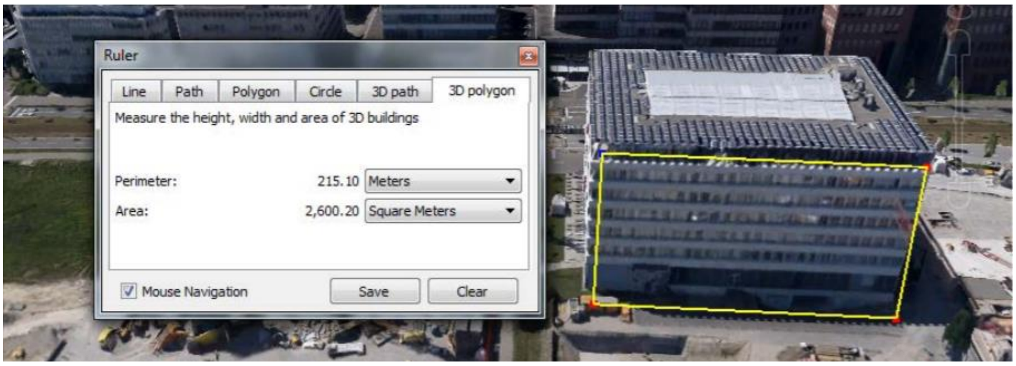

Figure 10: Visualization of the 3D polygon function on Google Earth

Figure 11: Visualization of the measured UPV campus with the 3D polygon function

2.2 Simulation inputs

To give reliable outputs like the payback period, total production, and many more, the program requires all sorts of relevant inputs. In this chapter, the most important inputs will be described.

2.2.1 Weather data

The installation's location is essential, because every location has different weather conditions. These conditions are implemented in the software by downloading weather data files. These files normally include local, hourly information about the temperature, direct nominal beam, defuse horizontal and global horizontal irradiation per square meter as well as hourly wind speeds. It can include snow, but because it rarely snows in Valencia, this factor is not considered.

For PV*Sol the weather data is used from MeteoNorm that provides site-dependent climate data. And for SAM the data is taken from Climate.OneBuilding. with coordinates "39.485 ; -0.4747", located in Valencia.

It is possible in SAM to choose from 5 Weather File Irradiance Data options. They are named as followed: DNI and DHI, DNI and GHI, GHI and DHI, POA from reference cell and POA from pyranometer. These options allow SAM to use the given weather data for the calculations in the way that is preferred. In order for SAM to be able to calculate feasible results, two columns of the solar irradiance component or a single column for the POA (plane of array) data has to be included in the weather files. DNI and DHI is considered the default option in which SAM calculates the incident irradiance using the DNI and DHI data from the weather file, this is also the option used in this project.

Another important setting is the calculation method used for virtual recreating the diffuse sky irradiance. This is the lighting originating from the sky dome outside of the sun's circle. Diffuse lighting is less important in a conventional installation because most of the energy is generated by direct irradiation. With facade panels diffuse lighting plays a bigger factor. SAM allows to chose from three different calculation methods named Isotropic, HDKR and Perez to convert the DHI (direct horizontal irradiance) into diffuse sky irradiance. In this document the Perez method has been used due to SAM's help file being the best option for most analyses. It accounts for horizon lightening, circumsolar and isotropic diffuse radiation using a more complex computational method than the Reindl and Hay and Davies methods. [17]”

2.2.2 Available space for the installation

The available space expressed in m² will determine the amount of panels that can be placed. In our case the orientation of the facade space is also of great importance because every orientation has a different irradiation pattern, therefore with every surface measurement the azimuth of the measurement is implemented as well. For example the north will produce less energy compared to the other orientations due to the fact that there is less solar irradiation. In this project the surface measurements are taken by using Google Earth. Every building is virtually inspected and measured which can be seen on Figure 22 which is discussed later on in this document.

2.2.3 Orientation and slope

The orientation and slope of the solar panels have a high impact on the production of the electric energy. The more direct lighting the solar panel receives the better, that is why the most common orientation is south with a slope of around 30°. In the case of placing panels with this type of tilt on the wall, it has to be taken in account that the panel, located above will cause shadow on this lower hanging panel. Placing the panels with a vertical tilt angle of 90° will not create shadow on the panels below, but reduces the amount of direct solar radiation that falls on the panels and with this the efficiency of the energy generation. In this case the vertical solution was used which gives a higher amount of electricity generation with the same amount of wall space due to the fact that it is not necessary to leave space in between the panels. The building orientations on the whole campus are mostly similar and goes like this: north:20°; east:110°;south: 200°; west: 290°, Tilt: 90°

2.2.4 Energy consumption

The energy consumption of the future prosumer is also an important aspect of the calculation. For an installation that is not focused on selling the produced energy it is recommended to have a lower production compared to the consumption. This is recommended because the price of the sold electricity is a lot higher than the price of the bought energy. This makes the ROR (rate of return) of an electrical installation that is producing more than consuming, a lot higher. In our case the production will never exceed the consumption even when hourly data are considered because the consumption is very high (38GWh/year), compared to the available space for solar panels. None the less the consumption data is included in SAM and PV*SOL. In Figure 12 the monthly consumption curve of the UPV campus is displayed and shows a rather flat curve with a peak at July. A flat consumption curve fits well with the flat production curve of a facade installation which is visible at Figure 19 where the sum of the 4 lower curves represent the total production of a four side PV facade installation. If all the summer months would have a rise in consumption a conventional 30° slope installation would also have been a good match. Which can also be seen at Figure 19 where the top curve represents the irradiation on a flat surface in Valencia.

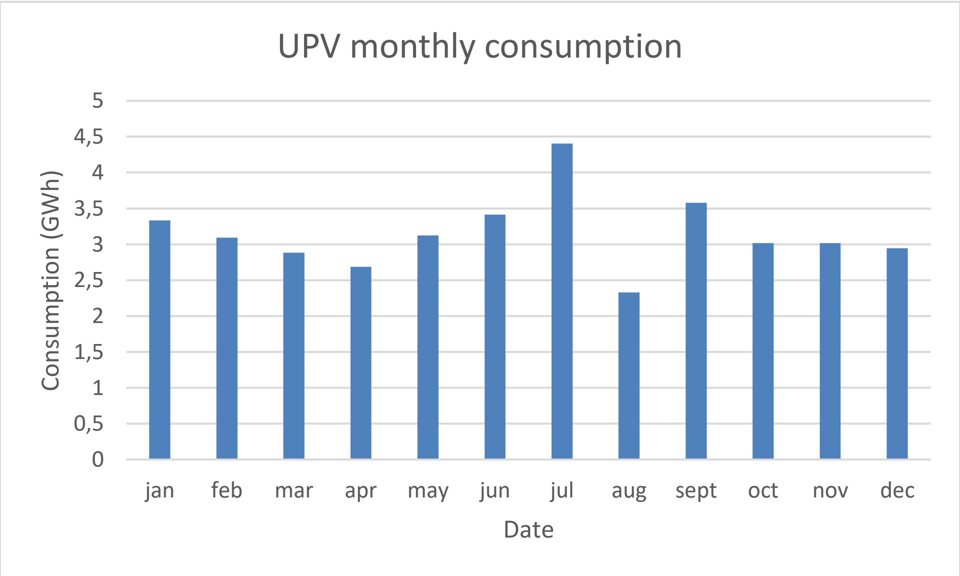

Figure 12: monthly consumption from the UPV campus

2.2.5 *Hourly energy price*

In annual terms the electricity price has shot up to 336.82%, since November 10 2020, when the average price was € 45.62 per MWh [18]. Multiplying the percentage by the average price gives an average of 153.65 euros for the year of 2021 shown in Figure 13. Given the price has increased from 61% in 2000 to an average of 100% in 2020, a 2% energy price increase rate has been taken [19]. This is rather low due to the expensive switchover from fossil fuels to renewable energy which will continue to happen the following years. Non the less the future prices are unpredictable and there for it is safer to presume a low inflation.

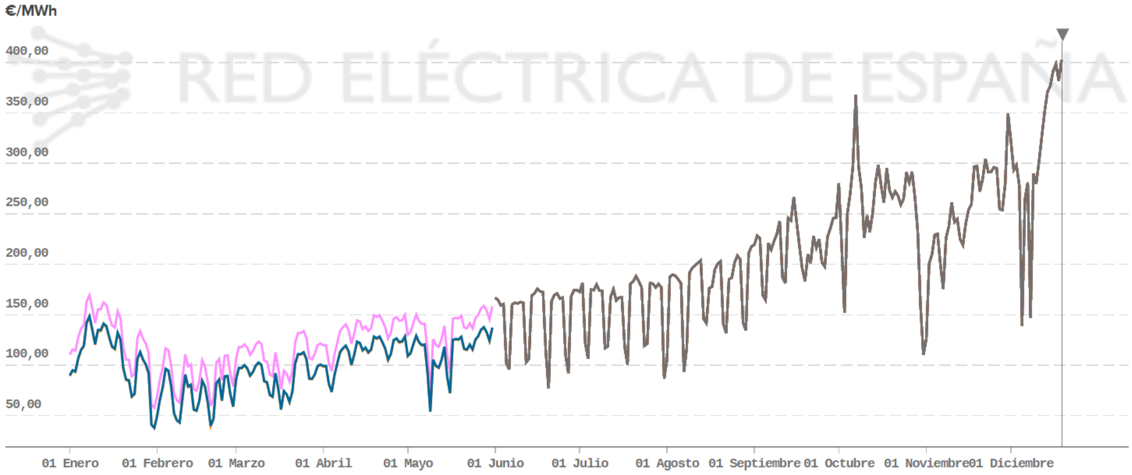

Figure 13: Monthly energy price variations in Spain [31]

One of the reasons of the high increase in electricity price (shown in Figure 12), is the increase of CO_2 and Gas rights due to a lower contribution of renewable energy mainly being the absence of wind. The price of these CO_2 emission rights have increased from 33 € at the beginning of the year to 56 € per ton in august 2021. The absence of wind doesn't only increase the CO_2 emission cost but has also impact on the wind energy production. Another factor is the increased Gas price which costs 47€/MWh seen that gas is used to produce electricity.

The energy price is not a fixed price per kWh but variable in function of time. This is because the campus uses the 6.1 tariff due to a consumption higher then 15kW. This causes the invoice shown at Appendix 13 to have 6 different tariffs. The reason of these 6 tariffs is the need for energy balance in the grid. The grid operator wants to reward people that are using electricity on the moments the electricity production is high and punish them when the available electricity is low. In the future adaptable consumption also known as demand-side management (DSM) will be even more common due to the difficulty of adapting the energy production of renewable energy sources to the consumption. In the past only the production was adjusted to achieve energy balance. This was rather easy because there were base load power stations that provided a constant production and peak load installations that turned on when a high amount of energy from the grid was required. Renewable energy on the other hand is harder to regulate because you’re stuck with the given weather that influences the production. Except from lowering the efficiency of the installation which is not recommended, wind and solar generation can not be controlled and that’s why the consumption will have to be controlled instead.

UPV has six different tariffs depending on time, month and day which is displayed for weekdays on Figure 14. The displayed numbers stand for the different tariffs that are displayed in Table 3. These tariffs are calculated out of quotations from 2020 which can be found at Appendix 14. Out of the quotation it is possible to get the Ai and Bi which makes it possible to calculate the TQi and the total cost with electrical taxes (ElTax) and VAT. Where OMIP stands for the actual energy price (€/MWh).

The formulas for the calculation can be found at Appendix 15 and goes as followed:

$$TQi = \frac{Ai + Bi * OMIP}{100}$$

$$Total\ price = TQi * (1 + ElTax) * (1 + VAT)$$

For the calculations shown in Table 2 the OMIP of 42.05 is used, which can be seen in the results of Table 3. To calculate the results for the OMIP of 100 €/MWh and 150€/MWh this same procedure was used in which the results are showed in Table 2.

Tariff	*Ai (c€/kWh)*	*Bi*	*TQi (€/kWh)*	*Total price*
P1	3.6897	1.088	0.08265	0.1051
P2	2.6556	1.094	0.07256	0.0923
P3	1.6449	1.082	0.06195	0.0788
P4	1.0706	1.083	0.05625	0.0715
P5	0.8979	1.080	0.05439	0.0692
P6	0.7023	1.095	0.05307	0.0675

Table 2: electricity price calculation for each tariff class

The prices not only depend on the time but depend as well on the actual energy price. These prices as previously mentioned went up by four times while the average month price on November 2021 amounts to193.43€/MWh compared with 45.45€/MWh for march 2020 [20]. That's why some of the following calculations will be done for three different prices. Presuming the prices will drop again we calculated the payback time for the following OMIP being 42.05 €/MWh which was the estimated price for the year 2021. 100€/MWh will be used as the future estimation price due to the switch to renewable energy and a 150€/MWh price will be used in order to see the possible outcome of the energy prices remaining high.

	42.05 €/MWh	*100 €/MWh*	*150€/MWh*
P1	0.1051	0.1853	0.2545
P2	0.0923	0.1729	0.2425
P3	0.0788	0.1585	0.2273
P4	0.0715	0.1513	0.2202
P5	0.0692	0.1488	0.2174
P6	0.0675	0.1482	0.2178

Table 3: Electricity price table with different energy tariffs

The calculated "P" tariffs are used variable of the time, day and month [21]. In the weekends the "P6" tariff is considered and during the weekdays the table displayed on Figure 14 is used. This table shows that during the night from 12PM to 8AM the tariff "P6" is considered. From 8 AM until 11 PM depending on the month a different tariff is used. The cheapest month for electricity consumption will be August with a "P6" tariff for the whole day. These tariffs are implemented in order to stimulate consuming electricity on the moments the consumption is low and vice versa.

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	6	6	6	6	6	6	6	6	2	2	1	1	1	2	2	2	2	2	1	1	1	2	2	2
Feb	6	6	6	6	6	6	6	6	2	2	1	1	1	2	2	2	2	2	1	1	1	2	2	2
Mar	6	6	6	6	6	6	6	6	4	4	4	4	4	4	4	4	3	3	3	3	3	3	4	4
Apr	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
May	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Jun	6	6	6	6	6	6	6	6	2	2	2	1	1	1	1	1	1	1	1	1	2	2	2	2
Jul	6	6	6	6	6	6	6	6	2	2	2	1	1	1	1	1	1	1	1	1	2	2	2	2
Aug	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Sep	6	6	6	6	6	6	6	6	4	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4
Oct	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Nov	6	6	6	6	6	6	6	6	4	4	4	4	4	4	4	4	3	3	3	3	3	3	4	4
Dec	6	6	6	6	6	6	6	6	2	2	1	1	1	2	2	2	2	2	1	1	1	2	2	2

Figure 14: tariff class per hour and month

2.2.6 Panel lifetime

The BAPV lifetime is the amount of time the panel can work with an acceptable declination of efficiency. This maximum declination is usually set on 80% and when falling below this setpoint, the lifetime of the panel is considered over [14]. The BIPV lifetime is currently estimated around 30 years, while new studies show it could be 50 years [5]. For the following calculations a lifetime of 30 years is considered. The used panel (Trina Solar TSM -500DE18M(II)) states a declination to 84.8% over a time period of 25 years which can be seen in the data sheets at Appendix 17.

2.2.7 Installation cost

The cost of the installation depends on a lot of different factors. One of these factors is the size of the installation. The bigger the size the lower the average profits that is necessary for the project to be lucrative. The next factor is the difficulty of the placement of the installation. A PV roof installation is easier to carry out due to its common type of installing and is less expensive than an uncommon facade installation. A third factor is the quality of the panels. In some cases high production panels are recommended because of the lack of space while other projects might go for a BIPV low efficient installation which provides an aesthetic look. Another factor is the profit margin of the company. There for it is important to compare different quotes from different companies in order to achieve the best possible price and payback time.

The total price of a solar installation is most commonly expressed in €/kWp. Which is in other words the amount in euros paid per thousand watt peak for the whole installation. For large scale installations this price on average is considered around 600-800€/kWp [22], while household installations have a price around 1,000-1,500 €/kWp. The total price of the installation is on average formed by 35% for the solar panels, 30% for the working hours and inspection, 20% for the inverter, 10% for the mounting materials and 5% for the cables and other small parts [13].

Due to the fact that a PV facade installation is uncommon and there for more expensive, the price used for this project is set on a 1,000€/kWp. This price is confirmed by other studies that conclude an average price of 450€/m² for facades and 350€/m² for roofs [23]. In our case we use panels of 2.39m² which gives, multiplied by 450€/m² a total price of 1,050€/kWp. Take in mind that the price is an estimation and is very dependent of the company and will most likely keep on dropping in the future, considering better production techniques and most likely a higher demand.

2.2.8 Grants

Grants can reduce the total investment cost and are given to stimulate, in our case, renewable energy. These grants are most commonly not fixed and must be seen as a bonus because you can't be sure that you will receive them. Most of the grants these days goes as followed: Different governments have a fixed budged that they offer as grants. The investor can participate and give all the information of his future installation. If his installation is considered more feasible compared to the other participants the installation will stand higher on the list and more likely will receive financial support.

Grants are a complex matter and change regularly, it is therefore important to have good professional contacts that are able to inform about the possibilities. The registration period is also limited every year and it should be taken into account that you must apply for the grant before the start of the project.

It was possible to participate for a grant in Valencia in the year 2021 with a budget of 7.5 million and a registration period from 15/05/2021 to 21/06/2021 with a maximum support of 65% of the total project cost [24].

These grants are not used in the calculations due to the possibility of not receiving any support.

2.2.9 Used parameters

The most important specifications, used in the calculation programs for the simulations for the two campus buildings that impact the energy production are shown in Table 4 below. The more detailed panel specifications used in SAM are shown in Figure 15.

Spec type:	**Value**
BAPV lifetime:	30 years
Annual degradation rate:	0.5%
Installation cost:	1000€/kWp
Location:	Valencia coordinates (39.485; -0.4747)
Weather data source:	Climate.OneBuilding.Org
Module efficiency:	21.38% (Trina Solar TSM 500DE18M(II)).
Module tilt:	90°
Sky diffuse model :	Perez
Inverter efficiency:	98% (SMA sunny tripower core 1 STP 50-40)
Total DC power loss:	2.973%
Operation and maintenance cost:	1.5% of initial installation cost
Transformer load losses:	1%.
AC Wiring losses:	1%.
Electricity load:	taken from the UPV 2019 consumption (see Figure 12)

Table 4: Used parameters for the calculation programs

The most important specifications used that impact the cost price and payback time of the installation are shown in Table 5. These parameters were used to simulate building 8 on the UPV campus. Most of these parameters are self-explanatory but the 1.5% operation and maintenance cost includes the annual maintenance and the replacement of the inverters after around 15 years of use.

Spec type	**Value**
Modules:	2,490
Inverters:	13
module:	179.1 €
inverter:	4,128.5 €
Balance of system equipment:	30€/m²
Installation labor:	25€/m²
Installer margin and overhead:	25€/m²
Contingency:	8%
Permitting and environmental studies:	4%
Engineering and developer overhead:	10%
Grid interconnection:	6%
Inflation rate:	1.5%
Real discount rate:	4%
Electricity tariff :	100€/MWh with grow rate of 2% (Table 3)
Operation and maintenance cost:	1.5% of initial installation cost

Table 5: Used price parameters for the calculation programs

Figure 15, below shows the system design parameters used in SAM to simulate building 8. By first recreating this building in the 3D platform in PV*SOL it was possible to see the amount of panels that each different orientated wall can support. The north and south wall of this building have a smaller dimension compared to the east and the west side which explains the lower amount of panels in these two orientations. The orientations of the walls are not perfectly aligned to the wind orientations but have a shift of 20° which is visible at the used parameters for the azimuth. The number of inverters are picked according to the highest possible efficiency for the system. As last important parameter, the angle of 90° is used for the panels tilt.

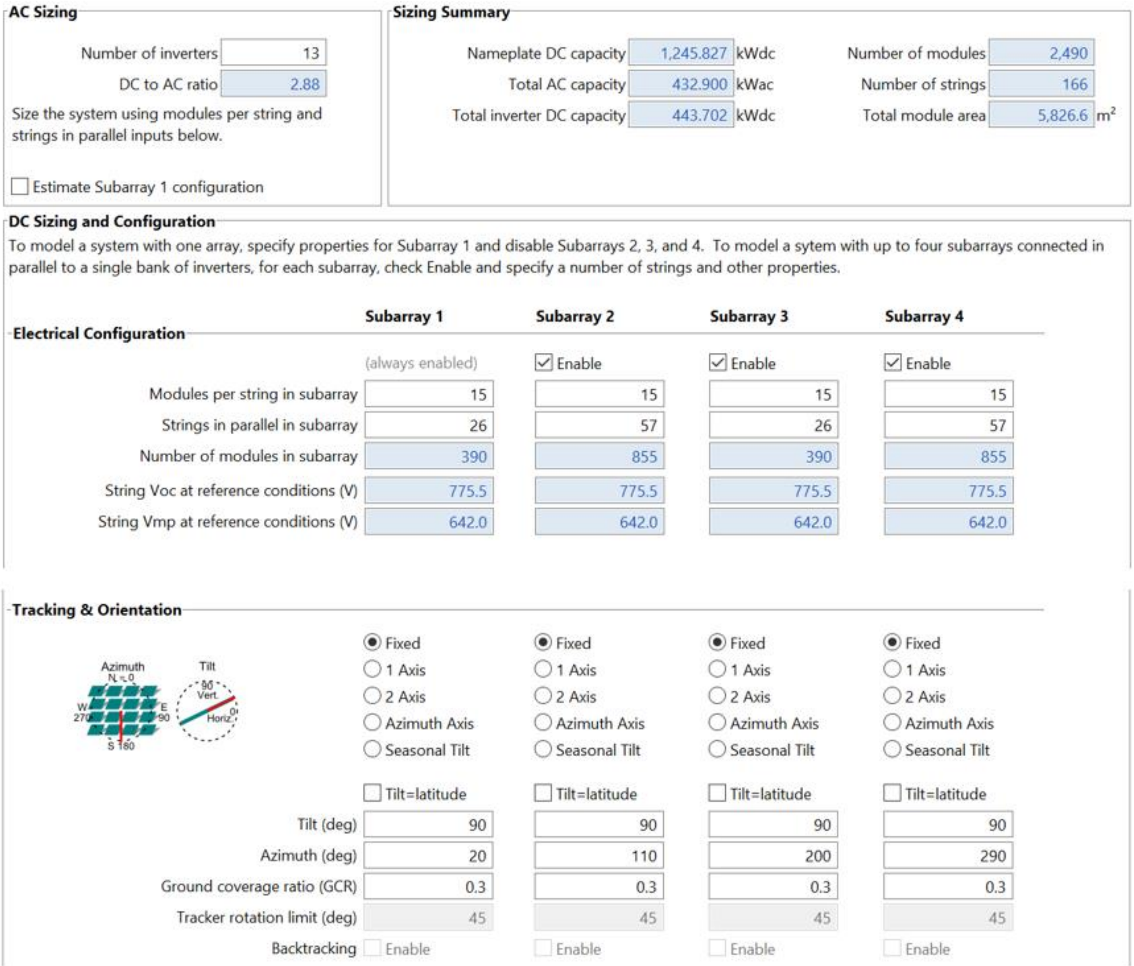

Figure 15: System design input parameters on SAM

Chapter 3. UPV PV system components

This chapter takes a closer look at the used components. These components are more or less the same as a normal inclined roof installation but the rails and brackets have to be able to support the 90° inclined panels.

Solar panel

The type of panel used in this project is the mono crystalline type. This panel is chosen for the calculations in order to have the highest power density for the limited available surface. It has a relatively low price, high efficiency and is rather big which reduces the working hours. This panel is also resistant to salt which is positive considered that Valencia is located at the seashore of the Mediterranean sea. The used panel is named Trina Solar TSM-500DE18M(ii) with the following specs.

Spec type	**value**
STC power rating:	500W
PTC power rating:	468.3W
STC power per unit of area:	210.4W/m2 (19.5W/ft2)
Peak efficiency:	21.04%
Imp:	11.69A
Ump:	42.8V
Isc:	12.28A
Voc:	51.7V
NOCT:	41°C
Series Fuse Rating:	20A
Maximum System Voltage:	1,500V
Length:	2,176mm (85,7in)
Width:	1,092mm (43in)
Depth:	35mm (1,4in)
Weight:	26.3kg (58lb)

Table 6: photovoltaic panel specifications

Inverter (Power conditioning unit) – The inverter transforms the generated DC voltage from the panels to a 230/400V AC voltage that is used for grid applications. The inverter is equipped with six maximum power point tracker in order to get a decent amount of energy out of the connected panels. If the panels need an even higher individual efficiency, microinverters or power optimizers are recommended. These electronic devices track the maximum power point for every single module instead of for the whole series as an inverter does. The reason we don't take advantage of these electronics is the price, for every module a device has to be connected and these devices are rather expensive. In Table 7 some of the important specifications are displayed, if there is interest in even more specs it is recommended to see the data sheets attached at the end of this document named Appendix 16.

Spec type	Value
Manufacturer:	SMA
Model:	Sunny Tripower core 1 STP 50-40
Rated Power Output:	50000W
Max/European efficiency:	98%
Max. Input Voltage:	1000V
Max. Input Current:	120A
Min. DC voltage / start voltage:	150V / 188V
Number of DC String Inputs (Inlets):	2
Number of MPP Trackers:	6
Max. Input Voltage per MPPT:	1000V
Max. Input Current per MPPT:	20
Max. output current:	72.5A
Nominal AC Voltage:	230V / 400V WYE
AC Current Distortion [THD]:	3%
Sleep (Night) Consumption:	<5W
Noise emission:	60dB(A)
Ambient Temperature Range:	-25°C…+60°C
AC grid range:	50Hz, 60Hz/ -6Hz…+5Hz

Table 7: inverter specifications

Junction box – This is a box mostly connected on the back of the panel which serves as the output interface of the panel. It also serves as protection for the panels in the case it is subjected to shadow or other factors that impact the energy production. The box has diodes that keep the power flow in one direction and prevents backwards power feed into the panels when the panels have a lack of sun. These diodes will also prevents current reduction for the series circuit. When the panel is subjected to shadow, it will be bypassed which will create a voltage drop instead which will have less impact on the power generation compared with a current reduction for the whole series. The junction box has to be completely waterproof in order to withstand the outdoor conditions and here for must carry a IP 67 label.

MC4 / MC5 connectors – In order to easily and safely connect the PV-panels with each other, MC4/MC5 connectors are used. MC stands for Multi-Contact and the 4 or 5 for the diameter contact pin in millimeters. These connectors can be easily connected by just pushing the male into the female connector. In order to disconnect these connectors a tool is required to prevent any accidentally disconnections. These connectors are universal and used for almost every brand of panel.

Manual/automatic disconnect switch - This piece of equipment allows to disconnect the generated power from the PV installation with the grid. The automatic disconnection will be executed when the voltage of the grid is getting high, possibly due to too much power injection from other PV installations. If the grid has no voltage at all, the inverter will also disconnect in order to prevent electrocution for the grid workers.

Monitoring system – The monitoring system is essential to assure the optimal working condition of the installation is maintained. The system collects data from the PV system and transmits it to a control center where all the gathered data from all the PV-installations is being monitored. If a lowering in efficiency is detected or the values do not correspond to the virtual calculations an intervention has to be carried out to assure optimal investment payback.

Circuit breaker – A circuit breaker protects the system from overcurrent to avoid system damage. When this device gets triggered it interrupts the currents pathway. This will prevent the current to cause fire or isolation damage. Unlike a fuse, which can only operate once, a circuit breaker can be reset (eighter manually or automatically) and can resume its normal operation.

Solar module racking – The PV modules will be mounted on a fixed metallic structure which do not rust and can carry the load of the panel hanging at a 90° angle. It also has to be able to withstand the highest wind velocity that can occur at the installed location.

Array junction box – AJB is referred as combiner box, and collects parallel DC power from the PV strings. The DC power is then eighter directly or through a main junction box connected to the inverter. It provides protection for the electrical connections from the weather as well as preventing people from accidental electrocution. It also has the ability to obstructs sudden surges due to lightening strokes in which case it grounds the surges immediately. It is also used to easily disconnect the desired DC string.

DC distribution box – The direct current distribution box is used to collect the DC output from the panels and feed it to the inverter. In this way the inverter is protected from failures from the DC side. This box also provides flexibility for the operator to connect and disconnect solar strings from the system. It also minimizes the system installation time and maximizes the inverters safety.

AC distribution box – The alternating current distribution box is an important part of the PV system, providing protection for the inverter from the load side. The sophisticate electronics inside of the inverter are rather vulnerable and due to this require some extra protection. If the inverter is damaged it is rather expensive to replace and will require some time, in which the system will be down. This box also provides flexibility for the operator to disconnect the inverter from the system in order to carry out maintenance or other adjustments to the system.

Chapter 4. Results

In this chapter the results from the PV*SOL and SAM calculations will be examined and interpreted. In order to see the impact of shadow on the PV facades, buildings 7 and 8 were virtually simulated. Building 8 is simulated because it's the most suitable building on the campus, with lots of space to install the PV panels without many obstacles like windows. There is also much space between the surrounding buildings, especially in the east and west side of the building, which provide the most significant surface for the panels. Building 7, on the other hand, is considered less suitable and is being calculated in order to see what the impact on the PV production is when there are a lot of surrounding buildings close proximity. Local results from these buildings were obtained by using weather data files from Valencia. The impact of the shadow from the two calculated buildings were used to simulate the electrical and economic feasibility for the whole UPV campus covered with PV facades.

The most important results will be the total amount of potential solar energy production, the installation's total cost and the payback time.

4.1 Building 8B,E,H PV facade feasibility

Building complex 8 is one of the most suitable buildings at UPV for PV-facade mounting. The name “building 8” is used for simplicity, but it is considered building 8B, E, and H. This building is well suited because all of the surrounding walls can be used without the need to avoid windows or other obstacles. Another advantage this building has is the amount of available surface, and, last but not least, the building is not heavily subjected to shadow by surrounding structures and trees, as can be seen in Figure 16 and Figure 17 below.

Figure 16: Building 8 west facade

Only the south side of building 8 has some trees that can produce shadows on the south wall. In the summer these trees will not create much shadow because the sun will have a high altitude during noontime. In the winter the trees lose most of their leaves and still have a large enough distance to not produce to much shadow on the wall surface. This is visible at Figure 17 that is taken in the end of autumn in the beginning of December.

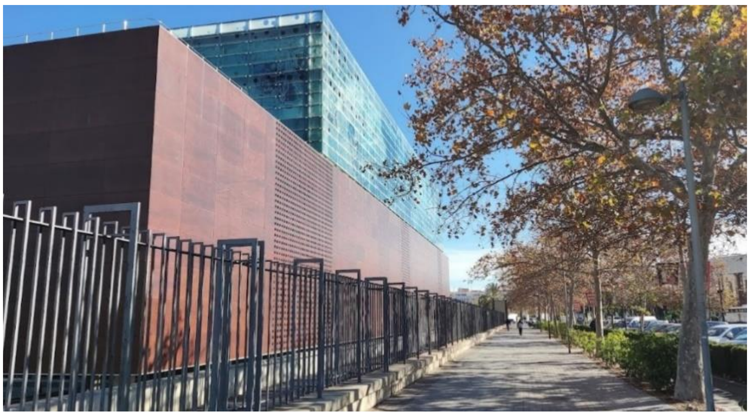

Figure 17: South façade of nuilding 8 at the end of the autumn

This building is virtually recreated with PV*SOL as can be seen on Figure 18. This made it possible to calculate the amount of vertical solar panels (from the type Trina Solar TSM-500DE18M(ii)) that can be installed on the walls, with dimensions of 1.098m (width) and 2.176m (depth).

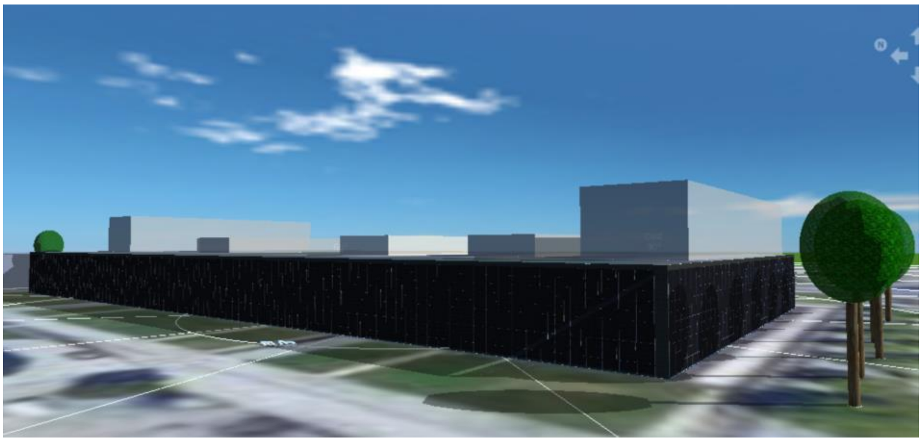

Figure 18: PV*SOL building 8 visualization

After knowing how much panels can be placed on every separate wall, it was possible to calculate results from building 8 with SAM as well. The system design parameters for the building used in SAM are shown in Figure 15.

4.1.1 Technical aspect

The amount of energy that a panel produces depends on the aimed orientation. In this case the panel has tilt of 90° with an azimuth to the south, west, north and east as can be seen on Figure 19 below which is calculated with PV*SOL Premium. The blue curve represents the production over the year of a panel that has a 0 degree tilt (flat surface). The orange curve displays the south orientations production and can be explained as followed: in the winter months the sun has a lower tilt in the middle of the day and hereby shines more directly on the vertical panels, whilst in the summer the sun will have a higher tilt at midday and shines a lot less directly onto the panels. This means the panels do not receive much direct lighting but are rather producing their energy from diffuse lighting. The grey curve represents the north panels, they have a verry low energy production compared to the east and west sides. This is because the sun will almost never directly shine onto the panels.

While the east and west should have almost the same production, it is slightly different. This is because the orientation of the building as previously mentioned is not exactly aimed to the east and west but is aimed as followed:

north:20°; east:110°;south: 200°; west: 290°

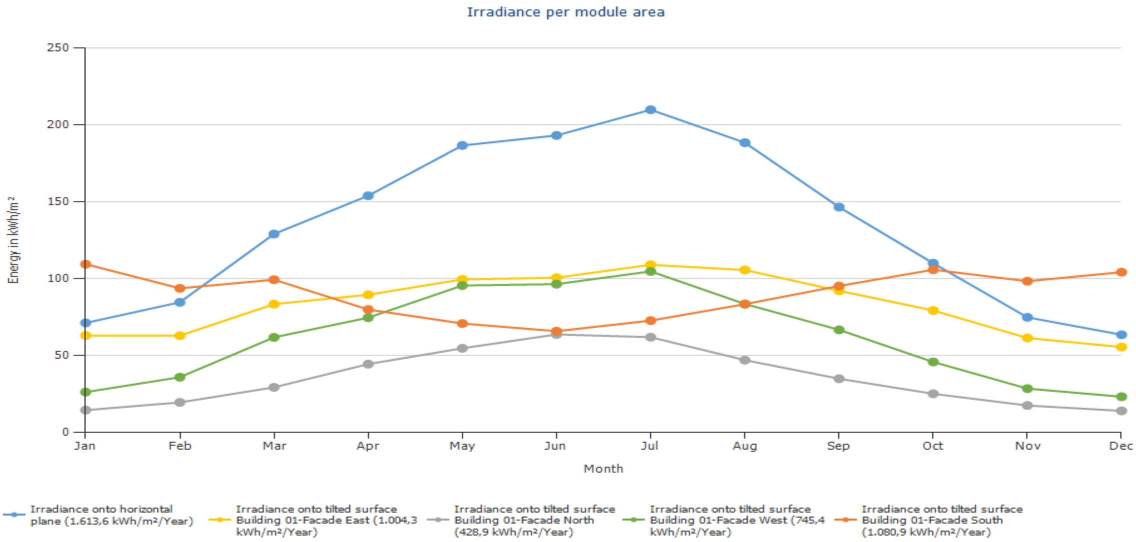

Figure 19: production curve of the four facade orientations for building 8 calculated with PV*sol

Covering all the facades of building 8 (which has a total surface of 6,770m²) full with Trina Solar TSM-500DE18M(ii) panels that needs an available surface of 2.39m² gives us a total of 2,490 panels, considering not all the available surface can be used due to avoid overlapping of the building walls and leaving some space in between the panels for convection. These 2,490 panels produce a 954.33MWh/Year calculated with PV*sol and calculated with SAM 958.23MWh/year. Considering an emission of 152gCO_2/kWh that is prevented by using solar panels instead of the grid, as previously explained in the chapter “Decarbonization”. An amount of 145.160 ton CO_2 is being prevented from polluting the air. If we compare the production with the consumption of the school which is around 38GWh per year, the amount of produced electricity is 2.5% of the total school consumption. These technical numbers are also summarized in Table 8.

Compared to a conventional installation with an angle of 15° aimed to the south, 1.81 GWh each year calculated with PV*sol would be produced. This is double compared with the facade installation. The downside of this conventional installation is the need for a lot of ground or roof space in order to be able to place the panels and such free space is rather expensive and hard to find in the city.

Project data	value
Panel tilt:	90°
Facade Orientations:	20°, 110°, 200°, 290°
Total available surface:	6,025m²
Used panel surface:	2.41m²
Amount of panels:	2,490
Production:	954.33MWh/year
Power density:	158.39kWh/m²/year
Emission prevention:	145.160 ton CO_2
Consumption production ratio:	2.5%

Table 8: Technical project data building 8

4.1.2 Economic feasibility

As previously mentioned, the total cost for large-scale, conventional PV-installations is around 800€/kWp [25]. This total price for the installation is on average formed by 35% for the solar panels, 30% for the working hours and inspection, 20% for the inverter, 10% for the mounting materials and 5% for the cables and other small parts [13].

For a facade installation, the price of the panels, other small parts and inverters stay the same. The price for the working hours and used working equipment will likely increase due to the more difficult work environment. A scaffold has to be build or the use of an aerial platform is required in order to be able to mount the racks and panels onto the wall surface. The price of the mounting materials should be lower due to the fact that there is less material required compared to rack setups for flat roofs. This gives an estimated price of 1,000€/kWp for large scale installations which is backed by other research [26][22][25][27][28][13][23] which states that large scale conventional installations have a considered price of 600-800€/kWp. Take in mind that the price will strongly depend on the enterprise because a facade installation is an exclusive way of installing the panels.

Using the price of 1,000€/kWp with the use of 2,490 panels of 500Wp gives a total price of 1,245,000 euro. This price is in approximation obtained on SAM given the following input parameters in the system cost tab previously shown in Table 5.

The basic calculation of the ROI (return on investment) goes as followed, there is a consumption price per kWh of electricity to pay. The panels will reduce an amount of feed in electricity from the grid and this will reduce the total invoice price for the electricity. If you divide the reduction of the invoice (€ 146,300 for the first year) with the total cost price of the installation (€ 1,245,000) and multiply it by 100 you have the ROI which is shown in equation (1). This annual invoice reduction is in other words the profit of the installation and when the sum of this yearly profit is equal to the total investment cost the break even point of the installation is reached. Considering that this is a basic version of the formula that does not include the degradation of the panels and other factors included in SAM and PV*SOL.

$$\boldsymbol{ROI} = \frac{\boldsymbol{Net\ return\ on\ investement}}{\boldsymbol{cost\ of\ investment}} * \mathbf{100}\% \qquad (1)$$

As can be seen on Figure 20, the simple payback time for the 100€/MWh analysis is around 8.8 years with a ROI of 11.5%. This is considered a good investment whereby Forbes says everything above a ROI of 7% (for stocks) is seen as a good value [29].

This means after 8.8 years, the remaining life span of the solar panels (which is estimated for about 25-30 years) will be profit. At the end of the lifecycle (considered 30 years), 3.15 times the investment cost will be received which is a value of 3,960,697. Or in other words 2.15 times the investment cost is earned as profit. While considering a discounted payback period which includes the time value of money, a timestamp of 12.3 years has been obtained. All this economic information is summarized in Table 9.

Project data	value
Installation price per kWp:	1,000€/kWp
Total installation price:	1,245,500 €
Energy tariff:	100€/MWh
ROI:	11.5%
Payback time SAM:	8.4 years
Payback time PV*sol:	8.8 years
Discounted payback period:	12.3 years

Table 9: Economic project data building 8

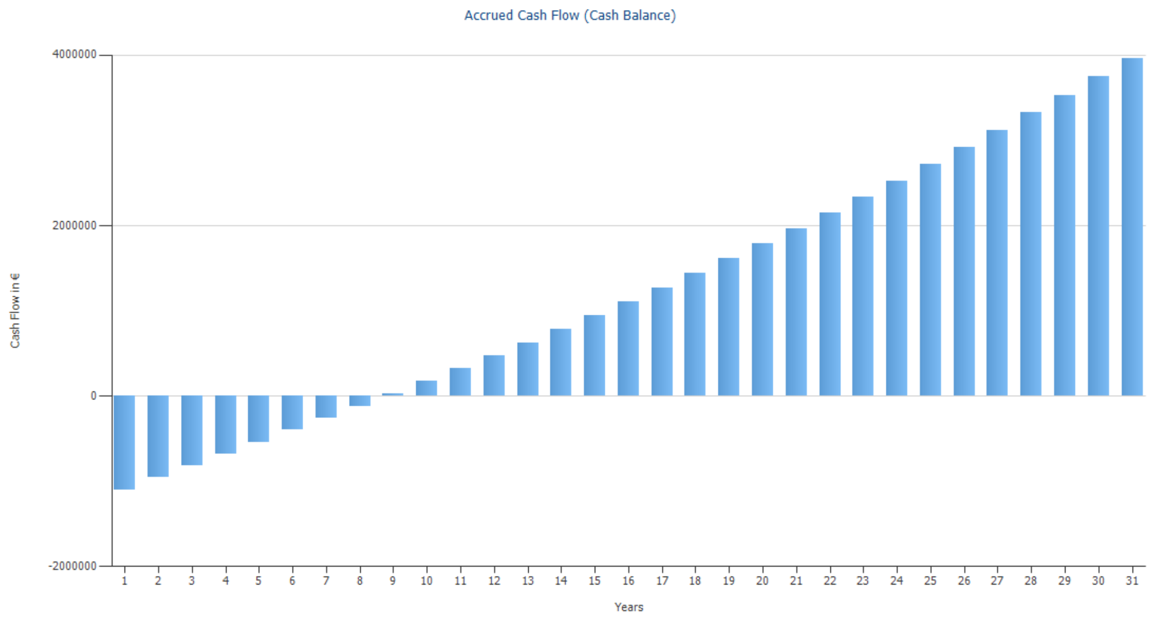

Figure 20: Accrued cash flow for building 8 facade installation from PV*SOL

4.2 Building 7 PV facade feasibility

The calculation of Building 7 is introduced to see the difference between an almost perfect building for BAPV (building 8) and a building with a more shady environment due to surrounding buildings and structures, which can be seen in Figure 21 below. The name “building 7” is used for simplicity, but it is actually considered building 7G,7F,7D,7A,7I and 7J.

The non-optimal buildings are included to ensure a high total energy production. None the less the facades with too much shade will be avoided to achieve a reasonable payback time and a high ROI.

Figure 21 Building 7 virtually generated with PV*Sol

4.2.1 Technical aspect

Building 7 has a total feasible surface of 8,142.9m², which provides space for 3,379 panels of the Trina solar tsm-500de18m(ii) type. These panels produce a total of 1.2GWh/year calculated with PV*Sol which is 3.33% of the total consumption of the UPV campus. If a 152gCO_2/kWh of CO_2 prevention is considered by the use of PV panels instead of electricity from the grid, a total amount of 191.19 ton CO_2 is prevented being spread into the air. This data is also summarized in Table 10.

By dividing the available surface by the total amount of produced energy it is possible to receive the production per square meter for a year (kWh/m²/year). For this project, a number of 154.47kWh/m²/year is obtained. Compared with a 158.39kWh/m²/year for building 8. This is expected because of the increased shadow factor building 7 is exposed to due to the surrounding buildings. The difference would even be higher if there weren't so many panels on building 7, aimed to the south. In this study 42% of the panels are aimed to the south side of building 7 while at project 8 it is only 15.7%.

Project data	value
Panel tilt:	90°
Facade Orientations:	20°, 110°, 200°, 290°
Total available surface:	8,142.9m²
Used panel surface:	2.41m²
Amount of panels:	3,379
Production:	1.2GWh/year
Power density:	154.47kWh/m²/year
Emission prevention:	191.19 ton CO_2
Consumption production ratio:	3.33%

Table 10: Technical project data building 7

4.2.2 Economic feasibility

The economic difference between building 8 and building 7 is rather low. The surrounding buildings have a large distance gap, which causes the shadow to not have that big of an impact on the energy production of the panels. This makes the payback time quite similar of that from building 8, which is estimated for 9.5 years where the discounted payback period is 12.7 years. The investment cost from building 7 is greater due to the fact that it is a larger installation and is estimated around 1,689,500 euros. This price is calculated with the 1,000€/kWp price previously explained in this document although this project might cost a bit more due to the higher difficulty of installing the panels this being, more distributed smaller facades. The ROI for this installation can be calculated by the equation (1) shown previously but is calculated by PV*SOL instead and amounts to 10.7%. This data is also summarized in Table 11.

The reason of this rather fast payback time is due to the fact that the electric energy price in Spain had an increase the past year, where the lack of wind, increased price of CO_2 certificates and the increase in gas price played a major role. the electricity price on 17 December 2021 was 443% higher than the same day, the year before, with a average price of 309.2€/MWh. This makes the profit of producing, self generated electricity rather favorable compared with buying it from the grid. None the less a price of 100€/MWh was used for this project considering the prices will decrease again. The future however predicts an increasing price, due to the switch from fossil energy to renewable energy which is not cheap. The reason that renewables are not cheap is the need for energy buffers. When there is not a lot of renewable energy production the energy will have to come from those buffers and for renewable energy peak days with clear skies and a lots of wind the buffers must be able to capture the excessive energy. But for now the prices will most likely drop back to a more reasonable price.

Project data	**value**
Installation price per kWp:	1,000€/kWp
Total installation price:	1,689,500 €
Energy tariff:	100€/MWh
ROI:	10.7%
Payback time PV*sol:	9.5 years
Discounted payback period:	12.7 years

Table 11: economic project data building 7

4.3 UPV campus PV facade feasibility

In this chapter we will look into the potential of the facades located on the UPV campus for BAPV. By knowing the azimuth, the feasible area, and the space required to place a panel it is possible to calculate the number of panels that could be placed on these surfaces. when the number of panels is known, it is possible with SAM to calculate the desired results.

4.3.1 Total feasible surface

In order to discover the feasible surface for most of the UPV buildings, the google earths 3D-polygon option has been used. This method is shown on Figure 22 below. This option made it possible to calculate in a short period of time the total feasible surface for every building located on the UPV campus. Of course this is not as accurate as measuring it with decent equipment, but for these big amounts of surfaces a slight difference wont make that big of an impact and most of the errors will most likely balance themselves out.

Figure 22: UPV total feasible area calculation with Google earth 3D polygon

Because not every surface is as promising for BAPV there were a few criteria that had to be fulfilled. If there are objects in close proximity that can produce shadows on the considered surface, than this surface will be avoided. Especially if this surface is aimed to the north, because this azimuth is already considered less feasible. Objects in this case are most of the time trees or other buildings. The fact that some objects are nearby but will only be exceptionally in the trajectory of the sun's solar rays has also been taken into account.

A list has been made from all the surfaces that are considered feasible for BAPV on the UPV campus. This list is visualized in Table 12. The total surface depending on the azimuth, will be used to calculate the total amount of energy production in the SAM program.

The first column in Table 12 displays the building on which the measurement has been taken. The other four columns give the amount of surface in m² depending on the orientation. The empty boxes are the walls that are avoided due to the reasons given above. The last row represents the sum of all the different azimuth surfaces.

By looking at the results it is clear that building 8 and 7 look very feasible considering the available space for vertical solar panels on the walls. Both of these buildings don't offer too much north space which is considered positive, knowing these area's provide a lower efficiency and profit. Building 3M on the other hand has a lot of total available facade space but in which 30% of the facades are orientated to the north. This means that, by covering building 3M fully with BAPV facades the payback time would be a lot higher compared with building 8 and 7.

Considering that the buildings of subdivision 7 have a total available area of 8,142.9m² and building 8 a total surface of 6,025m², these buildings cover a percentage of 31% of the total feasible area for BAPV facades of the campus considering a total of 47,853.9 m² of feasible facade space on the campus. All of the other buildings together cover a large amount of available space as well, but take in mind that the cost of covering several small facades is presumed higher than covering one large facade.

Building	*North (m²)*	*East (m²)*	*South (m²)*	*West (m²)*
1C	321	-	337	-
1E	-	357	386	296
1F	406	104	450	123
1G	-	178	-	-
1H	316	-	-	-
2A	-	-	173	402
2F	-	-	287	465
3A	125	574	98	515
3B	-	-	131	-
3C	-	83	258	-
3F	-	-	86	-
3H	-	-	105	-
3K	135	-	-	-
3M	1,636	1,193	301	2,191
3P	889	138	903	341
4A	-	-	95	-
4D	-	151	593	291
4G	242	178	316	-
4K	-	270	-	402
4L	114	110	320	474
4N	-	209	-	165
4P	-	209	-	165
4Q	137	-	134	165
5E	136	156	514	-
5F	-	175	108	-
5H	-	216	-	-
5J	174	189	-	-
5N	436	201	485	-
6C	183	-	227	169
6F	121	149	169	119
6G	1040	-	1,046	447
7A	202.4	255.5	255	359.1
7C	-	606	110	540
7D	457.9	262.7	431	-
7F	426.6	277.3	431.4	-
7G	231.4	274.7	178,3	339,8
7I	877.3	489.3	2,128.1	265.1
8A,D,C	-	558	199	537
8B,E,G	1,065	2,319	1,068	2,318
8F	447	351	344	216
8P	654	218	728	194
9C	634	260	206	191
9B	445	-	-	-
Total surface:	11,851.6	10,711.5	13,600.8	11,690

Table 12: Feasible BAPV wall surfaces on the UPV campus

4.3.2 Technical aspect

Due to the calculation of the total feasible surface for BAPV and the simulation of the two buildings it is possible to calculate the total possible energy production for the whole UPV campus. First we need to calculate the amount of produced kWh/m²/year. This is done by dividing the total amount of production from every azimuth by the used surface. If this result is multiplied by the total amount of available space from every azimuth of the whole campus you receive the total amount of energy provided from all the facades aimed to that azimuth. If you take the sum of these results you receive the total amount of energy produced by BAPV from all the orientations on the campus. These results can be seen on Table 13 below.

	North	*East*	*South*	*West*	*Total*
Surface building 8 (m²)	912	2,000	912	2,000	912
Production building 8 (MWh/year)	76.0	341.3	161.5	305.3	-
Calculation of (kWh/m²/year)	83,3	170,6	177,1	152,6	-
Total feasible surface of the entire campus (m²)	11,851.6	10,711.5	13,600.8	11,690	-
Total Energy production on campus (GWh/year)	0.99	1.83	2.41	1.78	7.00

Table 13: Results from the total energy production calculation

As can be seen in Table 13 the north has the lowest kWh/m²/year what makes sense due to the fact that the sun rarely shines directly on the north side of the building. There is a difference in production between the east and the west side, this can be explained due to the fact that the building is not perfectly aimed to the north and east but instead has a 20° shift. The total production, if the whole campus would be used for BAPV is 7GWh/year which is compared to the 38GWh/year consumption, 18% self-sufficiency.

Considering a production of 7GWh/year from the panels and a reduction of 152g carbon dioxide emission per kWh, explained previously in the Decarbonization chapter, a total amount of 1,000 ton CO_2 emission each year is being avoided. This is the equivalent of 217 cars being used during one year, assuming an average distance of 18,507km is being covered while using 22 gallons per km where one gallon of gasoline generates 8,887 grams of CO_2 in which one gallon is the equivalent of 3.785 litters [30].

	North	*East*	*South*	*West*	*Total*
Surface building 7 (m²)	2,195.6	1,559.5	3,423.8	964	8,142.9
Calculation of (kWh/m²/year)	83.3	170.6	177.1	152.6	-
Calculation of the Production building 7 (MWh/year)	183.04	266.15	606.41	147.18	1,202.7
*PV*Sol calculated production building 7 (MWh/year)*	-	-	-	-	1,257

Table 14: Results from the energy production calculation check

In order to confirm the results of Table 13, a control check has been done by using building 7 as comparison. The kWh/m²/year has been calculated in Table 13 and is there after used in Table 14 above. By multiplying the surface of building 7 with the kWh/m²/year, previously calculated, we receive the production by each facade depending on the orientation. By taking the sum of these results, we get the total amount of production that all four facades provide. If we compare these results by the calculation performed by PV*Sol, we can see that the difference between the two results is neglectable.

It is not only possible to scale the results from building 8 and 7 to the whole campus but it is also possible to calculate the results with SAM and to use the impact of the shadow on the results of building 8 and 7 as reference. This is being done, because simulating the shadow of the entire campus is not possible on neither SAM and PV*SOL. This calculation results in a yearly energy production of 7.13GWh, which comes close to the previously scaled 7GWh. An energy yield of 722kWh/kW has been obtained and a power density of 154.36kWh/m²/year. These results are also displayed in Table 15.

Project data	value
Panel tilt:	90°
Facade Orientations:	20°, 110°, 200°, 290°
Total available surface:	47,853m²
Used panel surface:	2.41m²
Amount of panels:	19,728
Production:	7.13GWh/year
Power density:	154.36kWh/m²/year
Emission prevention:	1,000 ton CO_2
Consumption production ratio:	18.75%

Table 15: Technical project data for the entire campus

4.3.3 Economic aspect

The total price of the system can be calculated by the use of the total amount of available wall surface for BAPV, that comes down to a value of 47,853.9 m². We know the dimensions of a panel which is 1.1 m by 2.19 m. This gives a panel surface of 2.41m². It is known that our panel of the type Trina Solar TSM -500DE18M(II) has 500 Wp, using the price of 1,000 €/kWp, meaning one panel has a installation cost of 500€. If we use these numbers in the following formula we get the total cost of the whole installation.

$$total\ cost = \frac{price\ per\ kWp * kWp\ of\ a\ panel * total\ available\ surface}{surface\ required\ for\ a\ panel}$$

$$= \frac{1000\ €/kWp * 0.500kWp * 46{,}853.9\ \mathrm{m}^2}{2.41m^2} = 9{,}656{,}066€ \qquad (2)$$

The result of this formula can be compared with the results of building 8, taken from the PV*SOL calculations represented in equation 3 which has a total surface of 6,770m² with a total cost price of 1,250,000 €.

$$6{,}025m^2 * X = 1{,}250{,}000\ € \quad (3)$$

$$46{,}156m^2 * X = 9{,}656{,}066\ € \quad (4)$$

X in this case represents the price per surface (€/m²). If we calculate X out of formula (3) of building 8, it gives us the following equation (5).

$$X = \frac{1,250,000\ €}{6,025 m^2} = 207.47€/m^2 \quad (5)$$

If we multiply this X (price per square meter) with the total available surface we can conclude both solution strategies give about the same result.

$$46,156 m^2 * 207.47 = 9,575,933€ \quad (6)$$

This is only a minor error in a project this size, the price of € 9,656,066 will be used in further calculations. The campus is also simulated in SAM with an amount of shadow between that of building 8 and 7. This calculation results in a price of 9,850,846 € with normal payback time of 8.8 years and a discounted payback period of 12.3 years. This data is also summarized in Table 17.

Take in mind that the installation price is an estimation. The exact price can only be known the moment you ask different firms to give a quotation because the prices are verry variable and discounts for larger orders depends on the contacted company. This normal payback time of 8.8 years consists out of the annual earnings from the installation and installation cost. The discounted payback period includes the nominal discount rate which accounts for the time value of money. In other words, it also includes the earnings that would be made if the money was invested in assets instead of the installation. If we include the real discount rate of 4% and the inflation rate of 1.5% we get a nominal discount rate of 5.56% calculated with SAM. With an investment cost of 9,656,066 € and annual savings shown in Table 16 a discounted payback period of 12.4 years has been obtained.

year	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Earnings (€)	1,045,984	1,042,181	1,026,109	1,018,387	1,017,150	1,020,965	1,028,737
annual cash flow (€)	1,045,984	987,288	920,863	865,794	819,195	778,957	743,546
acquired cash flow (€)	- 8,610,081	- 7,622,792	- 6,701,929	- 5,836,135	- 5,016,939	- 4,237,981	- 3,494,434
year	8	9	10	11	12	13	14
Earnings (€)	1,039,642	1,053,031	1,068,431	1,085,469	1,103,869	1,123,412	1,143,941
annual cash flow (€)	711,849	683,040	656,526	631,864	608,729	586,876	566,124
acquired cash flow (€)	- 2,782,584	- 2,099,544	- 1,443,017	-811,153	-202,424	384,452	950,576

Table 16: Cash flow with scaled profits from PV*SOL results

Project data	value
installation price per kWp:	1,000€/kWp
total installation price:	9,656,066 €
Energy tariff:	100€/MWh
ROI:	11.3%
Payback time SAM:	8.9 years
discounted payback period:	12.4 years

Table 17: economic data entire campus

4.4 Normal BAPV tilt installation

The main reason of this chapter is to compare the BAPV facade with an ordinary roof or ground installation. This is necessary in order to see the bigger picture and to conclude if a facade installation is worth placing. In the next chapter there will be an enclosure that compares all the possible solutions.

The location of this terrain is at the other side of the road from the UPV campus. It is used mainly by students as a parking with unhardened terrain. The idea is to create carports to protect the cars and generate energy at the same time.

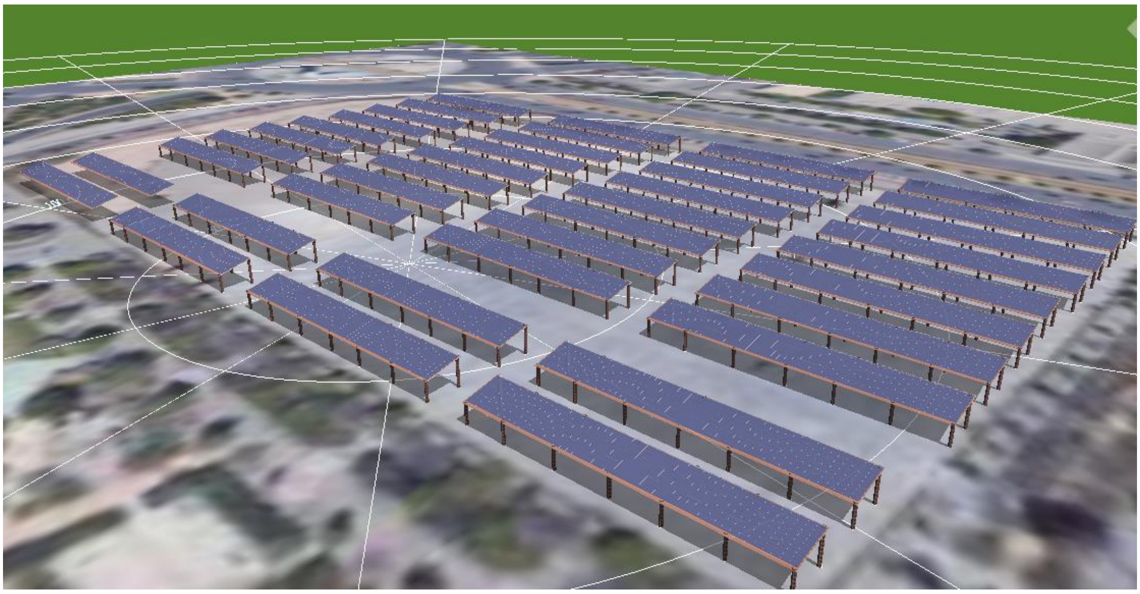

Figure 23: Parking roof solution simulated with PV*Sol

4.4.1 Technical aspect

This project example has space for 4,400 of the same panels used for the previous projects. These panels would produce 3,191,675 kWh each year calculated with PV*SOL which is the equivalent of 8.4% of the total consumption of the UPV campus. But with some space optimalisation there could be at least 6,000 panels. These roofs have an angle of 15° in order to maintain a reasonable carport construction. This area alone has the equivalent of half of the total calculated electricity production the whole campus covered with BAPV facades would provide which is previously calculated for 6.86GWh/year. This data is also summarized in Table 18.

Project data	value
panel tilt:	15°
facade Orientations:	200°
Total available surface:	10,604m²
Amount of panels:	4,400
Production:	3.19GWh/year
power density:	300.1kWh/m²/year
Consumption production ratio:	8.4%

Table 18: Technical data 15° tilt installation

4.4.2 Economic feasibility

For this PV-installation a price of 800€/kWp has taken into account which is the price of a conventional installation. This gives a total price of 1,760,000€ for the solar installation. For the amount of 40 carports with dimensions 50m length to 6.5m depth a total price of 500,000 € is considered. This gives a total cost price of 2,260,000 euro with a simple payback time of 4.9 years and a discounted payback period of 5.7 years. This info is also summarized in Table 19.

This project looks a lot more feasible then the facade project, but the price of the building grounds should be considered as well. These are rather expensive in city environment and taken the ground prices into account the project wouldn't be feasible. Never the less the ground prices will be paid back the moment it is sold again with a big chance of having an increased value.

Take in mind that this was just an imaginary project in order to see the difference in results between a conventional and a facade installation. These grounds will likely be used for building purposes. They could non the less consider building panels on the roof of the possible future facility, with not too much HVAC equipment in order to increase the available area to install photo voltaic panels.

Project data	value
installation price per kWp:	1,000€/kWp
total installation price:	2,260,000 €
Energy tariff:	100€/MWh
ROI:	21.12%
Payback time PV*sol:	4.9 years
discounted payback period:	5.7 years

Table 19: economic data 15° tilt installation

4.5 Project comparisons

In this chapter there will be a comparison of all the calculated projects. This will give a clear view of the situation, the most important results are displayed in Table 20. These values are taken from the PV*SOL projects and SAM for the whole campus.

It is clear from looking at the payback period that a conventional installation is the best investment. The next best option is a facade installation with a low percentage of shadow which is represented by building 8. The reason that the payback time from the total UPV campus is higher than that of building 8 is due to the increased shadow.

The surface distribution of the different orientations also has an impact on these payback times. The total surface of the campus is more or less equally distributed in every orientation. While building 8 has a lower amount of surface aimed to the south (which has a higher efficiency). To put it in percentage 24.7% of the total campus surface has a north orientation while building 8 only has 15.7% which can be seen at Table 12. This should lower the payback time but due to the less shady environment the payback time is still lower then building 7. This takes us to the next chapter where we compare orientations and the amount of impact they have on the energy production.

	Installation Price (€/kWp)	*Total available surface (m²)*	*Total installation price (€)*	*Production per square meter (kWh/year/m²)*	*Total Production (kWh/year)*	*Payback Time (years)*	*Energy yield (kWh/kW)*
Building 7: facade walls	1,000	8,142.9	1,689,500	154.47	1,257,844	9.5	710
Building 8: facade walls	1,000	6,025.2	1,250,000	158.39	954,333	8.8	768
Total UPV coverage	1,000	46,156	9,656,066	154.36	7,125,000	8.9	722
installation with 15° inclination	1,027	10,604.3	2,260,000	300.97	3,191,675	4.9	1,449

Table 20: project comparison

4.6 Orientation comparison

The results used in this chapter are the results from the SAM calculations performed on building 8. The given surface is in this case not the total surface of the building 8 facade but the used surface. The installation price is calculated with the system cost parameters shown in chapter 4.1.2 and 2.2.9. With the increased price of the electricity the payback times looks good but take in mind that this price in the future is variable and difficult to predict. None the less the price for this comparison is set on 100 €/MWh while average tariffs from October to December were above 200 €/MWh [31]. The price previous year was on average 42.5€/MWh.

The results on Table 21 show that the north facade, looking at the production per square meter, is the least efficient. With a payback time of 15.8 years and a energy yield of 405kWh/kW, it would still be feasible if the eye was set on creating a good image, but for an investment this payback time is rather questionable. The payback time of the situation where only the north is left out (7.6 years), is almost a whole year lower compared with the all orientations method (8.4 years). The east and south show a big difference in production per square meter although it is expected to be more or less equal. The reason for this is the fact that the building is not exactly aimed to the four wind orientations but has a positive azimuth shift of 20°. If the building was aimed exactly at these four orientations it is calculated that the east would have a production of 341 MWh and the west a production of 342 MWh, which is considered more or less the same. The efficiency of the south facade is the highest with a 1,103kWh/kW which gives a rather favorable payback period of 6.1 years.

Building 8	*Total surface (m²)*	*Total installation price (€)*	*Production per square meter (kWh/year/m²)*	*Total Production (MWh/year)*	*Payback Time (years)*	*Energy yield (kWh/kW)*
All orientations	6,025.2	1,251,622	159.04	958.2	8.4	768
North left out	4,914	1,045,077	178.76	878.4	7.6	836
North facade	912.6	195,944	86.66	79.0	15.8	405
East facade	2000.7	443,343	193.73	387.6	7.3	798
South facade	912.6	206,545	235.86	215.2	6.1	1,103
West facade	2000.7	443,343	143.98	288.0	9.8	673

Table 21: Orientation comparison

4.7 Price shift consequence

The payback time of an installation dependents on all sorts of variables. The definition of the payback time is the time it takes in order to payback the initial investment. This means that the larger the investment cost per m² or in other words, the price of the installation per m², the longer the payback time will be. This takes us to the next variable which is the income received from the investment, in this case the solar panel installation. This income depends on a few factors, one of them being the maintenance cost, which includes annual checkups on the production of the installation due to malfunctions, malfunctioning solar panel replacement, cleaning of the panels and replacing the inverters after around 15 years. This maintenance is included in the payback time at a price of 1.5% per year of the initial investment cost for the installation.

The second factor that determines the income is the amount of electrical energy being produced, The larger the energy production of the installation the less electrical energy that has to be bought from the grid, which is seen as the profit of the installation.

The last factor that is shown in Figure 24, is the energy price demanded from the electrical energy provider. This price depends on the actual energy price which increased a lot in the year of 2021. It is rather difficult to estimate the future prices because, the way our energy is produced is shifting from fossil fuel to renewable energy. The expectation is that the electricity price will increase due to the need of verry large energy buffers or backup fossil electric plants for the periods that there is almost no renewable energy production (cloudy days with no wind). These backup systems have to be maintained and manned, which is expensive. This will likely cause the fixed prices for being linked to the grid to increase, in order for the operator to have the economical needs to prevent black-outs. If this is the case, the variable price from the electricity itself might decrease due to the low cost of generating energy with renewable sources.

In Figure 24 the results variable in function of the energy tariff are displayed. It is visible that this price has a big impact on the payback time of the installation because it is the most important factor that determines the profit of the investment.

Where the price of 42.5 €/MWh is considered feasible, with a normal payback time of 11.6 years. The other tariffs offer a way better payback time where 5.8 years for 150 €/MWh is considered a very good investment. The reason of these rather low payback times are the continuous drop in price of solar panels, the size of the installation and the almost 100% self consumption due to the large amount of consumption the campus has. These results can be explained where Carlos García Buitrón, CEO and founder of the Madrid-based green power retailer Ecovatios states that large industrial conventional self consumption installations can have a payback time of 5 years due to the regulatory changes while residential installations have a payback time of 10 years [29].

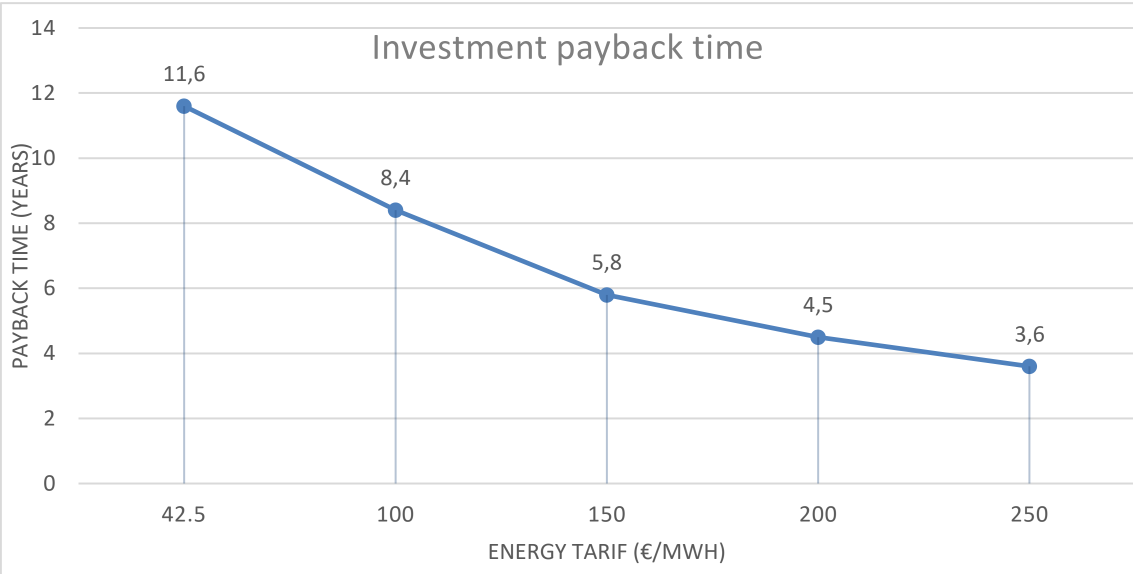

Figure 24: : Sensitivity study of the payback time for a facade installation in function of different electricity tariffs

Chapter 5. Conclusion

With the aid of several calculation programs (PV*SOL, SAM and Google Earth), it was possible to simulate the technical and economic results that the feasible BAPV facades on the campus de vera could provide. At first building 8 and 7 was virtually simulated in order to see the impact shadow has on the energy production. After that, all the building surfaces feasible for BAPV have been measured with Google Earth. This made it possible to calculate the technical and economic results for the whole campus with SAM. These results consider a total production of 7.13GWh/year. Considering this campus consumes 38GWh/year, 18.75% of the total consumption would be self-produced. By using a price of 1,000€/kWp, a total price of 9.65 million euros is obtained.

By using a grid tariff of 100€/MWh for the upcoming years and an investment price of 9.65 million euros for the whole installation, excluding incentives and subsidies in the calculation, a simple payback time of 8.9 years and a discounted payback period of 12.4 years was obtained. There are several reasons for this relatively low payback time for a facade installation: the recent increase in electricity cost, continuous reduction of the panel cost in the past years (while corona caused a slight increase), installation size, and the big self-consumption. The last significant factor is the recent regulatory changes in Spain which made it especially more favorable for industrial-scale projects. These changes reduced the payback time of conventional installations to a possible period of 5 years for non household installations. The impact of the electricity tariff is rather significant due to the big rise in the year 2021, in which average daily prices of 309.2€/MWh were typical. If an annual tariff of 250€/MWh were considered typical in the upcoming years, the payback time would decrease to a calculated 3.6 years for building 8, which is very feasible. Another positive feature of PV facades is the better match of the production curve with the consumption curve for the months and days. This match proves advantageous because providers offer less money for grid injection than the electricity grid consumption tariffs.

Using solar panels, the production of 7.13GWh/year would avoid 1,000 ton of CO_2 being released into the atmosphere considering an emission reduction of 152gCO_2/kWh of solar panel production. This is the equivalent of 217 cars being used during one year with an average driving distance of 18,507km. Although it is considered a reasonably good investment and good for nature, this project also provides other advantages. One of them is the effect on the university's image, in which this project is considered progressive and eco-friendly. Another benefit this project offers is the possible interaction with the students. For example, they can help manage the project in co-operation with the professors to reduce the investment cost and teach them project management and technical skills. Further practical feasibility studies can also be performed when the project is finished.

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Budget

BUDGET CALCULATION

The used price calculation for BAPV-facades in this research is 1,000 €/kWp. This price is used considered different sources [26][22][25][27][28][13][23]. This 1,000 €/kWp price gives a total cost price for the project of € 9,656,066 considering a usable space of 46,156m² for BAPV facades on the whole campus.

In Figure 25 the price of a conventional PV-installation is displayed. Given a BAPV facade installation is rather equal to build compared with a conventional installation, the investment price will not be much different. But considering the installation in this document is a lot bigger, the price will be reduced. This reduction is backed by a research on Spanish soil which states a price of 600 €/kWp for a surface of 12,000m² for the total installation[22]. None the less a price of 1,000 €/kWp is used due to the more difficult work environment a facade installation entails.

The used price of 1,000€/kWp is also justified with a small price table which includes big aspects of the installation which is shown at Table 22. This budget is kept simple and is only to demonstrate the possible costs. A real quotation will be given by the firms, if the school is willing to carry out this project. An attempt was made to obtain an invoice but because a student requested this information, no feedback was received.

These prices are estimations of what the installation could cost because the price is very dependable on the time period and company.

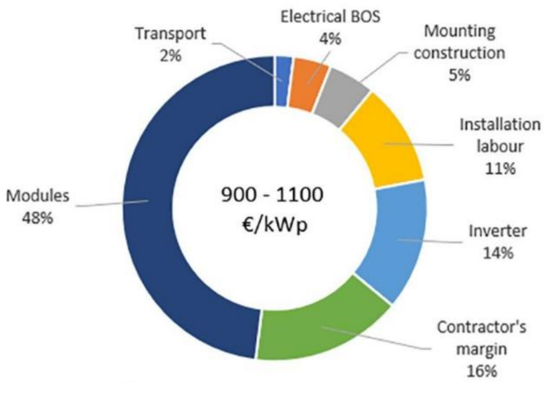


Figure 25:Average breakdown of total PV installation costs (10-50kWp) [28]

Table 22: Example of the total financial cost of the BAPV installation for the UPV campus

S.numb	description	Price	Quantity	Total cost (€)
1	Trina Solar TSM - 500DE18M(II)	204.6 €/PP (with 10% reduction)	19,728	4,036,348.8
2	SMA sunny tripower core 1 STP 50-40	4,126.34 €/pp	91	375,496.94
3	Cables	23.5€/kW	9,927.5	231,804.4
4	Fuses & connectors	35.24€/set	3,971	139,938.0
5	Protection switches	5.87€/PP	1,469.3	8,569.6
6	Energy monitoring meters	46.99€/PP	43	2,020.6
7	Monitoring system	2,349.36€/PP	1	2,349.4
8	Labor	25€/m²	47,853.9	1,196,347.5
9	Installer margin and overhead	25€/m²	47,853.9	1,196,347.5
10	Permitting and environmental studies	4%	(1to7)	191,861.0
11	Transport	5%	(1to7)	239,826.4
12	Grid interconnection	6%	(1to7)	287,791.6
13	Designer and engineering	1.5%	(1to7)	71,947.9
14	VAT	21%	(1to13)	1,675,936.3
15	Total cost			9,656,585.5

Whereby the designer and engineering costs includes the following variable costs:

description	units	€/unit	Total cost (€)
Data collection and processing (hours)	300	53.2	5,320
Calculation (hours)	120	53.2	3,724
Implantation study (Hours)	80	53.2	4,256
Preliminary study (Hours)	260	53.2	4,788
Computer	1	950	950
Printed documents	2,000	1,2	2,400
Total	340	53.2	43,782

Table 23: Variable designer and engineering costs

The sum of these variable costs amounts to a total of € 43,782.

The fixed amounts of designer and engineering costs are included in Table 24 which amounts to a total of € 23,283.

description	cost (€)
Preliminary study	9,320
Implementation study	6,698
Peripherals	7,265
Total	23,283

Table 24: fixed designer and engineering costs

In which the absolute total is the sum of both tables shown in Table 25, and amount to a total of € 67,065.

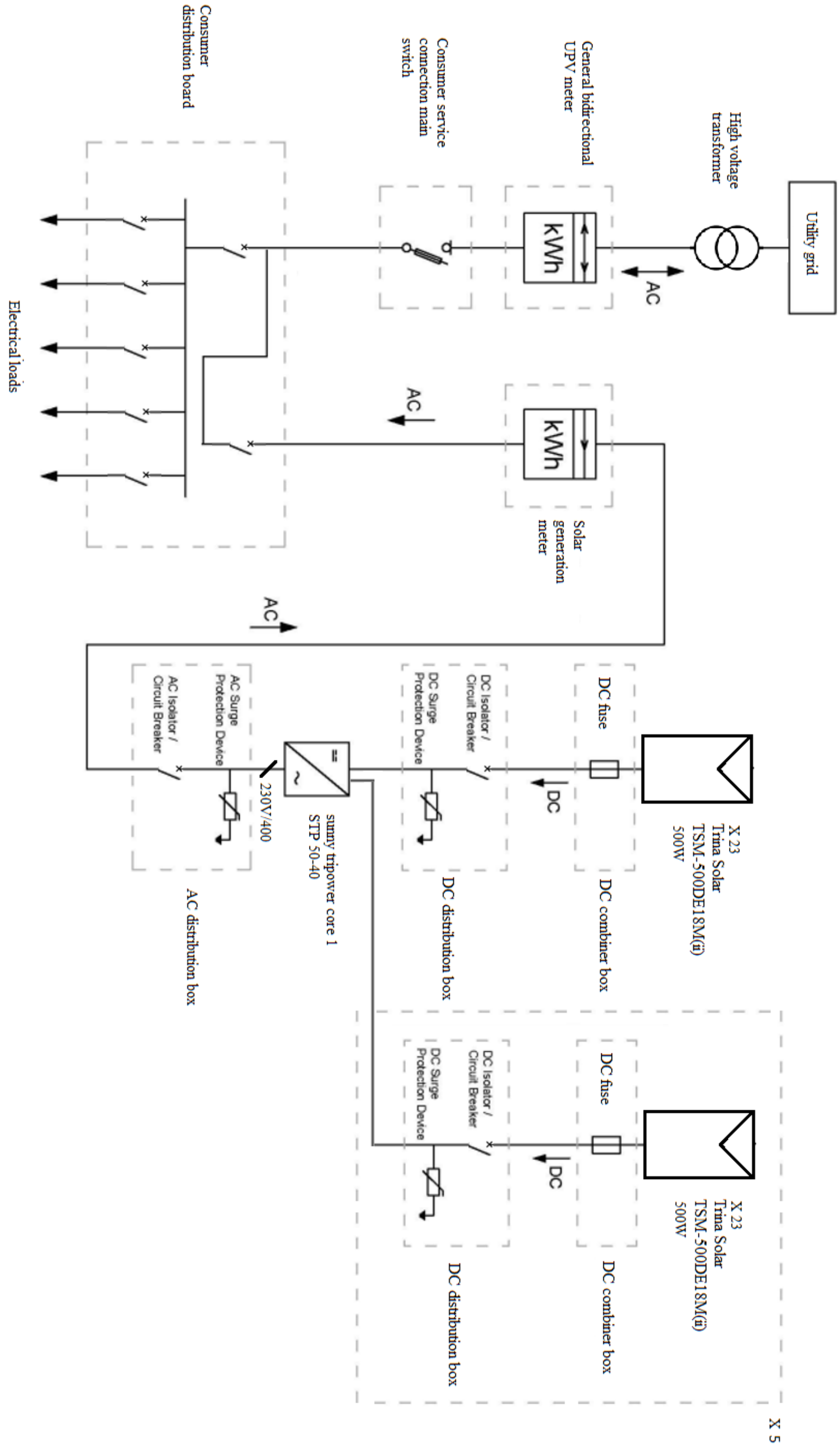
description	cost (€)
Variable total designer and engineering price	43,782
Fixed total designer and engineering price	23,283
Total	67,065

Table 25: sum of fixed and variable costs

Drawings

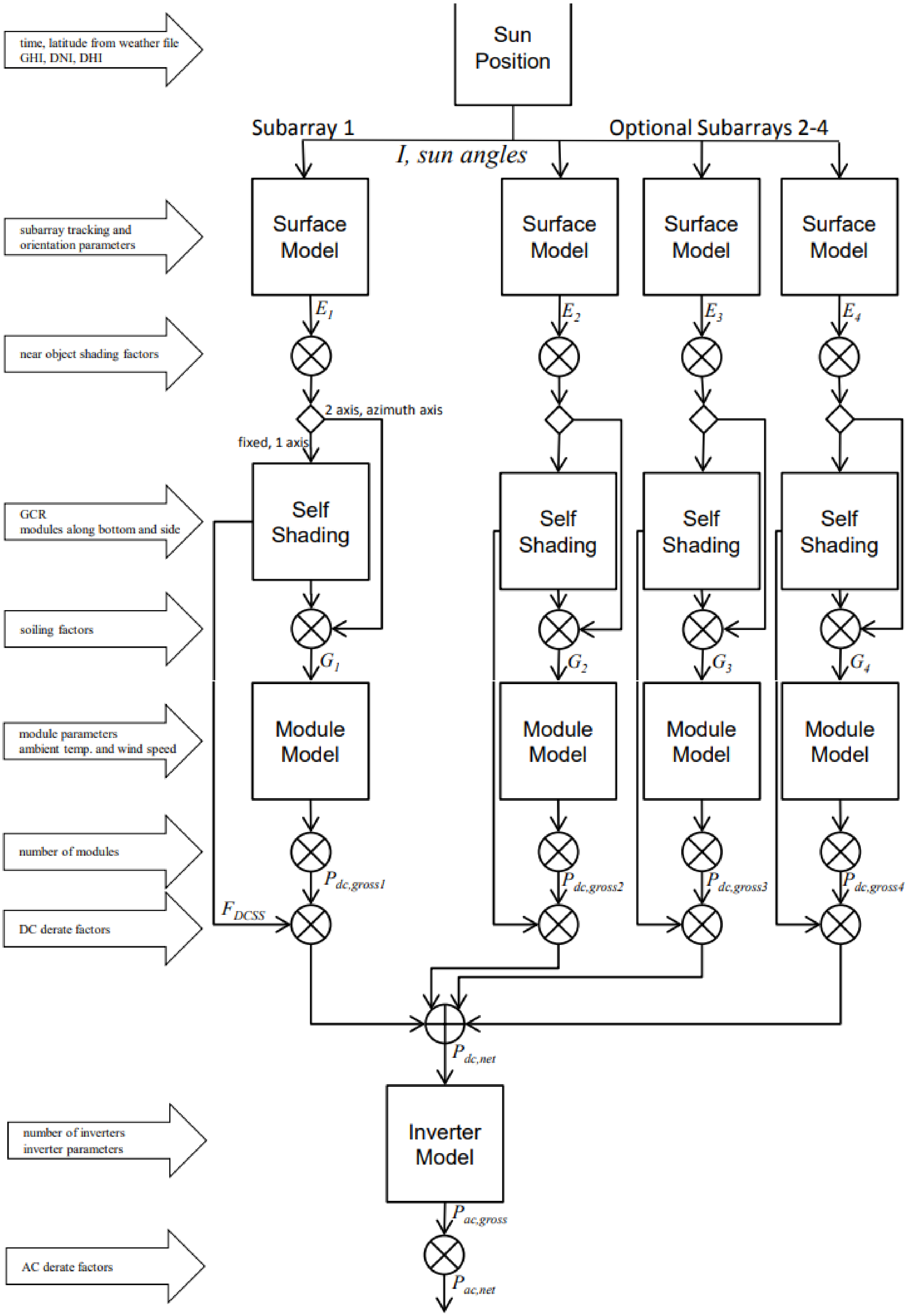
Plan 1: Ground plan of the UPV campus

Plan 2: schematic of a BIPV/BAPV installation [25]



This plan is an connection example for one inverter and does not represent the whole installation.

Plan 3: Working of internal calculations of SAM



Annex

Appendix A – Results total campus covered with BAPV facades

Appendix 1: SAM results for the entire UPV campus

System Advisor Model Report

Detailed Photovoltaic	9.9 DC MW Nameplate	39.48, -0.47
Commercial	$1.00/W Installed Cost	UTC +1

Performance Model

Modules	
Trina Solar TSM-500DE18M(II)	
Cell material	Mono-c-Si
Module area	2.34 m²
Module capacity	500.33 DC Watts
Quantity	19,725
Total capacity	9.87 DC MW
Total area	46,156 m²

Inverters	
SMA America: STP 33-US-41	
Unit capacity	33.300000 AC kW
Input voltage	330 - 800 VDC DC V
Quantity	91
Total capacity	3.03 AC MW
DC to AC Capacity Ratio	3.26
AC losses (%)	1.00

Four subarrays:	**1**	**2**	**3**	**4**
Strings	326	298	369	322
Modules per string	15	15	15	15
String Voc (DC V)	775.50	775.50	775.50	775.50
Tilt (deg from horizontal)	90.00	90.00	90.00	90.00
Azimuth (deg E of N)	20	110	200	290
Tracking	no	no	no	no
Backtracking	-	-	-	-
Self shading	no	no	no	no
Rotation limit (deg)	-	-	-	-
Shading	yes	yes	yes	yes
Snow	no	no	no	no
Soiling	yes	yes	yes	yes
DC losses (%)	2.97	2.97	2.97	2.97

Performance Adjustments	
Availability/Curtailment	none
Degradation	none
Hourly or custom losses	none

Annual Results (in Year 1)				
GHI kWh/m²/day	4.73	4.73	4.73	4.73
POA kWh/m²/day	36.00	87.00	73.00	63.00
Net to inverter	7,442,000 DC kWh			
Net to grid	7,125,000 AC kWh			
Capacity factor	8.2			
Performance ratio	0.74			

Financial Model

Project Costs	
Total installed cost	$9,850,846
Salvage value	$0

Analysis Parameters	
Project life	30 years
Inflation rate	1.5%
Real discount rate	4%

Project Debt Parameters	
Debt fraction	0%
Amount	$0
Term	0 years
Rate	0%

Tax and Insurance Rates	
Federal income tax	0 %/year
State income tax	0 %/year
Sales tax (% of indirect cost basis)	0%
Insurance (% of installed cost)	0 %/year
Property tax (% of assessed val.)	0 %/year

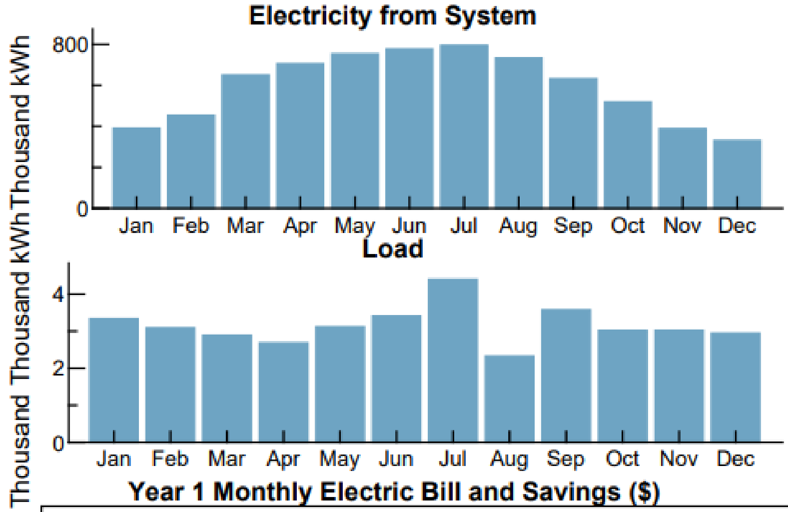
Incentives
None

Electricity Demand and Rate Summary
Annual peak demand 13,272 kW
Annual total demand 37,819,600 kWh
Generic Commercial
Monthly excess with kWh rollover
Annual rate escalation: 2%/year
Tiered TOU energy rates: 6 periods, 1 tier

Results	
Nominal LCOE	12.7 cents/kWh
Net present value	$10,467,800
Payback period	8.9 years

Detailed Photovoltaic	9.9 DC MW Nameplate	39.48, -0.47
Commercial	$1.00/W Installed Cost	UTC +1

Year 1 Monthly Generation and Load Summary



Year 1 Monthly Electric Bill and Savings ($)

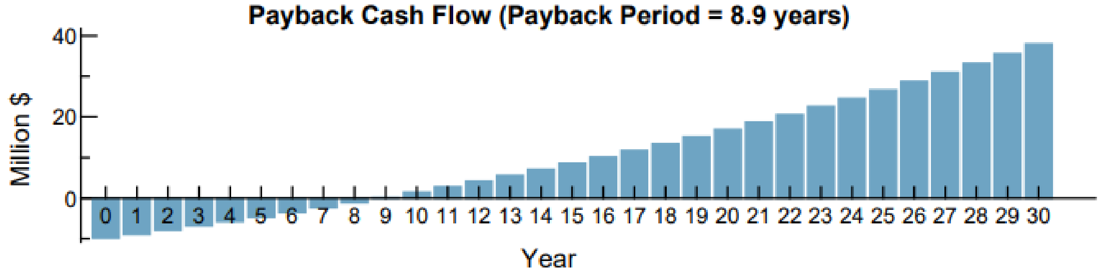
Month	Without System	With System	Savings
Jan	555,727	489,190	66,536
Feb	513,652	436,774	76,877
Mar	437,362	339,191	98,170
Apr	398,618	293,840	104,778
May	464,083	352,097	111,985
Jun	573,030	440,962	132,068
Jul	738,310	602,624	135,685
Aug	345,061	236,476	108,584
Sep	543,982	446,875	97,106
Oct	447,970	370,857	77,112
Nov	457,493	399,078	58,414
Dec	483,682	427,836	55,846
Annual	5,958,974	4,835,805	1,123,169

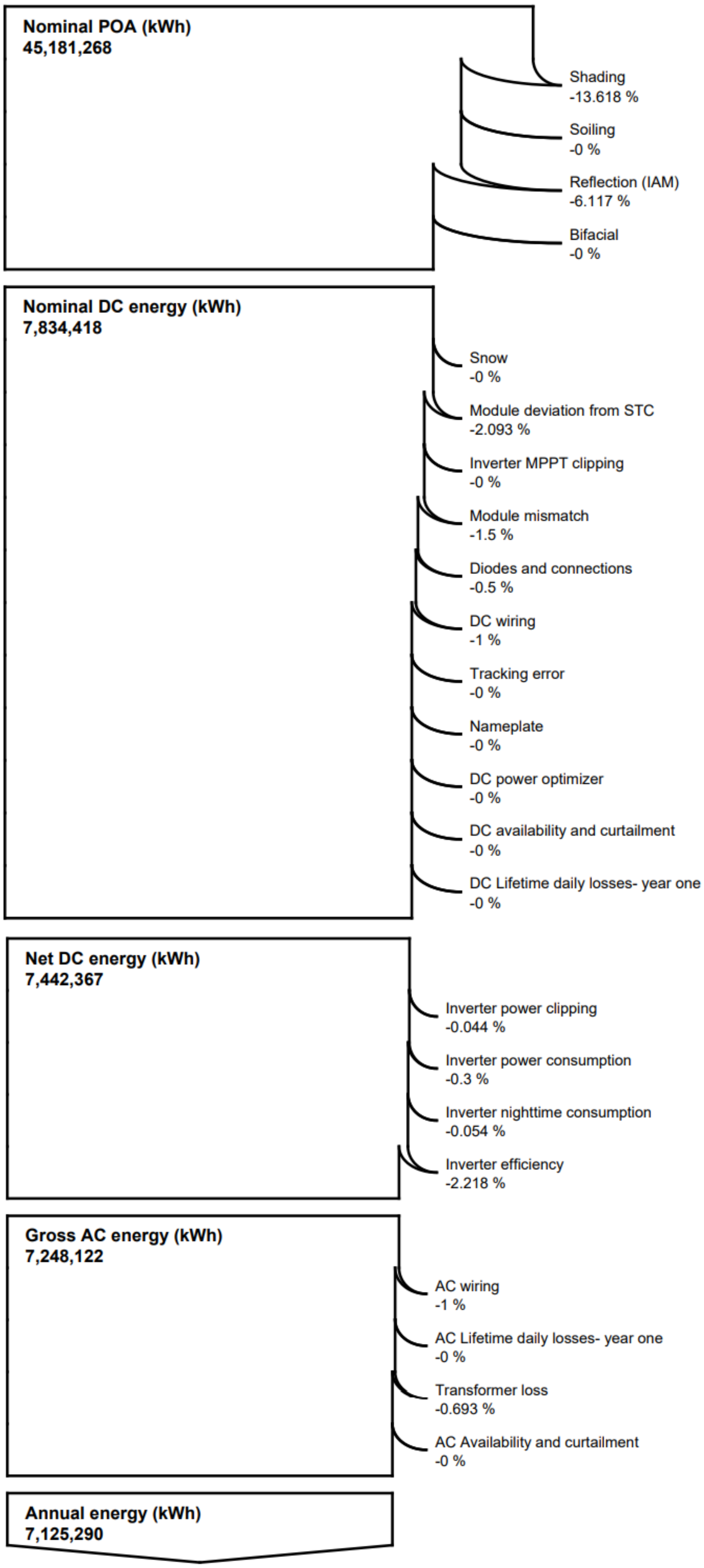
NPV Approximation using Annuities

Annuities, Capital Recovery Factor (CRF) = 0.0693		
Investment	$-682,200	Sum:
Expenses	$-174,300	$725,000
Savings	$0	NPV = Sum / CRF:
Energy value	$1,581,600	$10,467,000

Investment = Installed Cost - Debt Principal - IBI - CBI
Expenses = Operating Costs + Debt Payments
Savings = Tax Deductions + PBI
Energy value = Tax Adjusted Net Savings
Nominal discount rate = 5.56%

Payback Cash Flow (Payback Period = 8.9 years)

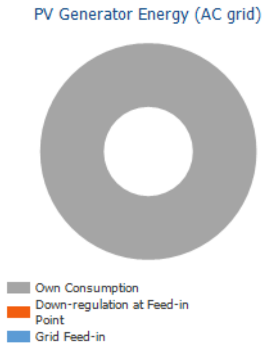



Nominal POA (kWh)
45,181,268
Shading
-13.618 %
Soiling
-0 %
Reflection (IAM)
-6.117 %
Bifacial
-0 %
Nominal DC energy (kWh)
7,834,418
Snow
-0 %
Module deviation from STC
-2.093 %
Inverter MPPT clipping
-0 %
Module mismatch
-1.5 %
Diodes and connections
-0.5 %
DC wiring
-1 %
Tracking error
-0 %
Nameplate
-0 %
DC power optimizer
-0 %
DC availability and curtailment
-0 %
DC Lifetime daily losses- year one
-0 %
Net DC energy (kWh)
7,442,367
Inverter power clipping
-0.044 %
Inverter power consumption
-0.3 %
Inverter nighttime consumption
-0.054 %
Inverter efficiency
-2.218 %
Gross AC energy (kWh)
7,248,122
AC wiring
-1 %
AC Lifetime daily losses- year one
-0 %
Transformer loss
-0.693 %
AC Availability and curtailment
-0 %
Annual energy (kWh)
7,125,290

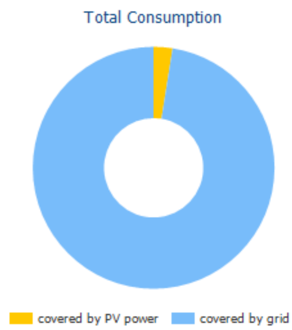
Appendix B – Results building 8B,E,H PV-facade installation

Appendix 2: Results PV*SOL Building 8B,E,H Facade installation

PV System		
PV Generator Output	1.250,00	kWp
Spec. Annual Yield	762,87	kWh/kWp
Performance Ratio (PR)	84,87	%
Yield Reduction due to Shading	8,0	%/Year
PV Generator Energy (AC grid)	954.333	kWh/Year
Own Consumption	954.332	kWh/Year
Down-regulation at Feed-in Point	0	kWh/Year
Grid Feed-in	0	kWh/Year
Own Power Consumption	100,0	%
CO_2 Emissions avoided	448.186	kg / year



Appliances		
Appliances	38.000.000	kWh/Year
Standby Consumption (Inverter)	746	kWh/Year
Total Consumption	38.000.746	kWh/Year
covered by PV power	954.332	kWh/Year
covered by grid	37.046.413	kWh/Year
Solar Fraction	2,5	%



Financial Analysis	
Internal Rate of Return (IRR)	10,70 %
Revenue or Savings	192834,1 €/Year
Accrued Cash Flow (Cash Balance)	3.078.906,97 €

Tech. Quality of the PV System	
PV Generator Energy (AC grid)	1.257.844 kWh/Year
Spec. Annual Yield	743,62 kWh/kWp
Performance Ratio (PR)	79,5 %

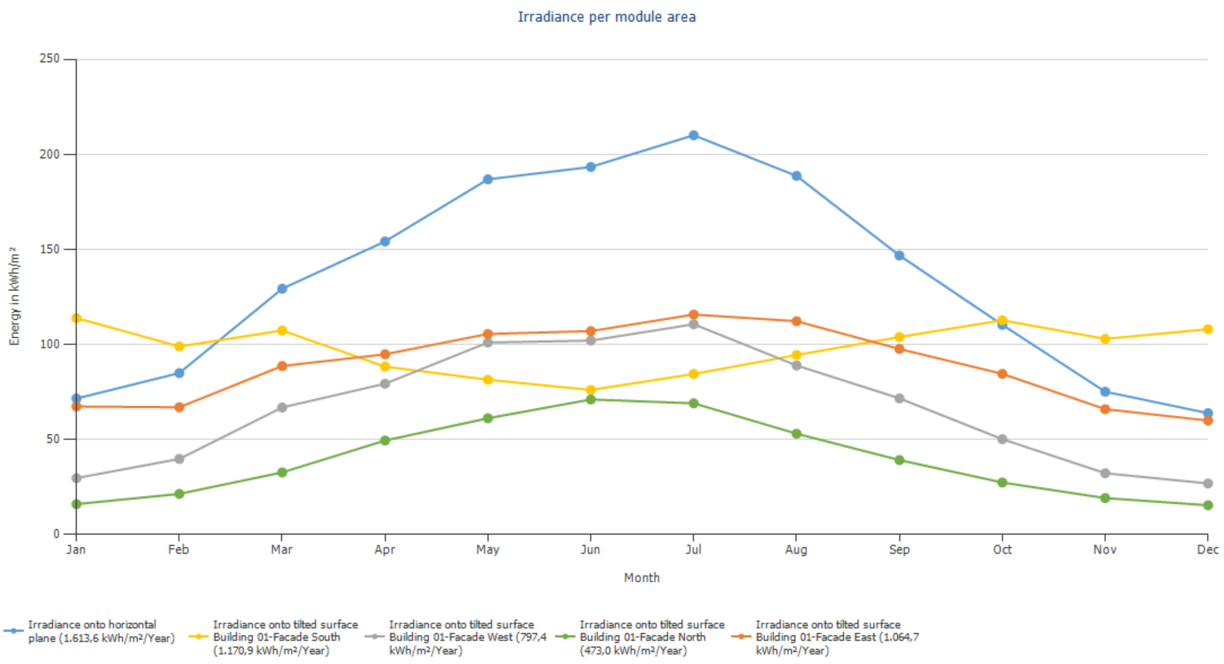
System integration			
Energy from Grid	36.743.651 kWh/Year	Grid Feed-in	0 kWh/Year

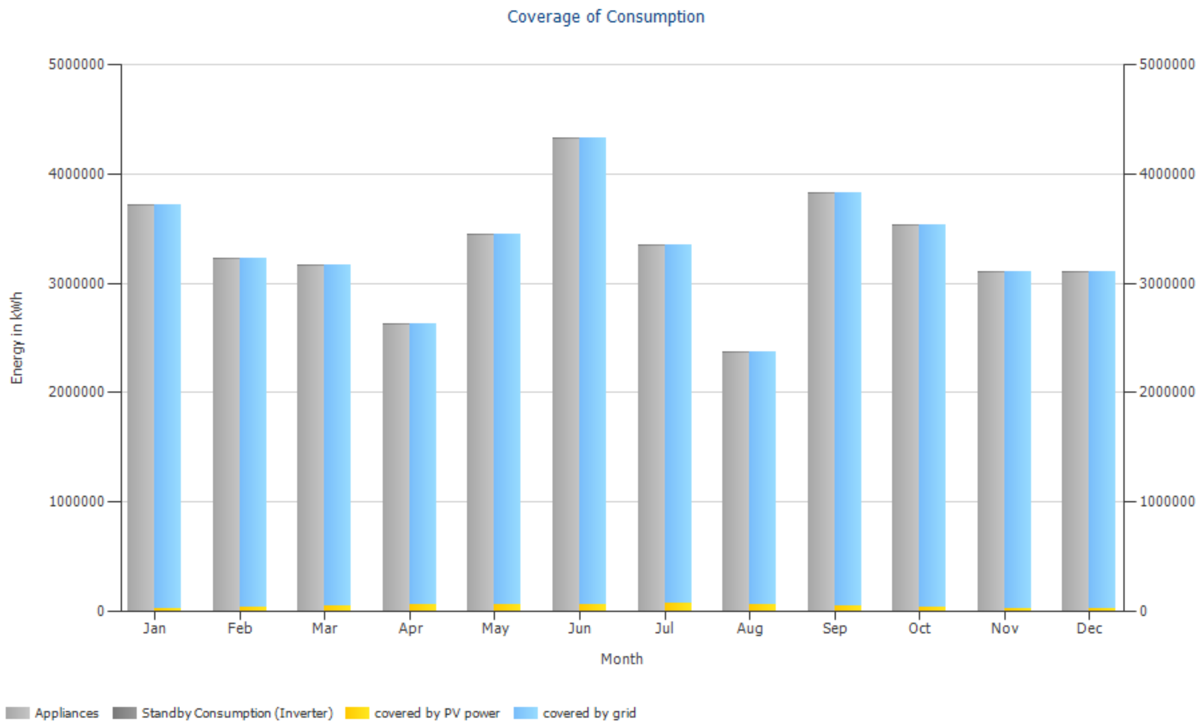
Building 01-Facade South		
PV Generator Output	195,00	kWp
PV Generator Surface	939,93	m²
Global Radiation at the Module	1170,90	kWh/m²
Global Radiation on Module without reflection	1172,78	kWh/m²
Performance Ratio (PR)	70,58	%
PV Generator Energy (AC grid)	161531,80	kWh/Year
Spec. Annual Yield	828,37	kWh/kWp

Building 01-Facade West		
PV Generator Output	430,00	kWp
PV Generator Surface	2.072,66	m²
Global Radiation at the Module	797,38	kWh/m²
Global Radiation on Module without reflection	798,52	kWh/m²
Performance Ratio (PR)	88,88	%
PV Generator Energy (AC grid)	305372,50	kWh/Year
Spec. Annual Yield	710,17	kWh/kWp

Building 01-Facade North		
PV Generator Output	195,00	kWp
PV Generator Surface	939,93	m²
Global Radiation at the Module	473,00	kWh/m²
Global Radiation on Module without reflection	473,81	kWh/m²
Performance Ratio (PR)	82,24	%
PV Generator Energy (AC grid)	76031,13	kWh/Year
Spec. Annual Yield	389,90	kWh/kWp

Building 01-Facade East		
PV Generator Output	430,00	kWp
PV Generator Surface	2.072,66	m²
Global Radiation at the Module	1064,67	kWh/m²
Global Radiation on Module without reflection	1065,96	kWh/m²
Performance Ratio (PR)	89,69	%
PV Generator Energy (AC grid)	411397,29	kWh/Year


Irradiance per module area
Energy in kWh/m²
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Irradiance onto horizontal plane (1.613,6 kWh/m²/Year)
Irradiance onto tilted surface Building 01-Facade South (1.170,9 kWh/m²/Year)
Irradiance onto tilted surface Building 01-Facade West (797,4 kWh/m²/Year)
Irradiance onto tilted surface Building 01-Facade North (473,0 kWh/m²/Year)
Irradiance onto tilted surface Building 01-Facade East (1.064,7 kWh/m²/Year)


Coverage of Consumption
Energy in kWh
5000000
4000000
3000000
2000000
1000000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Appliances
Standby Consumption (Inverter)
covered by PV power
covered by grid

Global radiation - horizontal	**1.613,61**	**kWh/m²**	
Deviation from standard spectrum	-16,14	kWh/m²	-1,00 %
Ground Reflection (Albedo)	159,75	kWh/m²	10,00 %
Orientation and inclination of the module surface	-852,03	kWh/m²	-48,49 %
Module-independent shading	-6,94	kWh/m²	-0,77 %
Reflection on the Module Interface	-1,26	kWh/m²	-0,14 %
Global Radiation at the Module	**896,99**	**kWh/m²**	
	896,99	kWh/m²	
	x 6025,185	m²	
	= 5.404.558,17	kWh	
Global PV Radiation	**5.404.558,17**	**kWh**	
Soiling	0,00	kWh	0,00 %
STC Conversion (Rated Efficiency of Module 20,76 %)	-4.282.570,46	kWh	-79,24 %
Rated PV Energy	**1.121.987,70**	**kWh**	
Module-specific Partial Shading	-69.712,58	kWh	-6,21 %
Low-light performance	-12.483,44	kWh	-1,19 %
Deviation from the nominal module temperature	-18.373,16	kWh	-1,77 %
Diodes	-1.844,73	kWh	-0,18 %
Mismatch (Manufacturer Information)	-10.195,74	kWh	-1,00 %
Mismatch (Configuration/Shading)	-7.904,26	kWh	-0,78 %
PV Energy (DC) without inverter down-regulation	**1.001.473,80**	**kWh**	
Failing to reach the DC start output	-341,06	kWh	-0,03 %
Down-regulation on account of the MPP Voltage Range	-184,83	kWh	-0,02 %
Down-regulation on account of the max. DC Current	0,00	kWh	0,00 %
Down-regulation on account of the max. DC Power	0,00	kWh	0,00 %
Down-regulation on account of the max. AC Power/cos phi	-12,71	kWh	0,00 %
MPP Matching	-145,49	kWh	-0,01 %
PV energy (DC)	**1.000.789,70**	**kWh**	

Energy at the Inverter Input	**1.000.789,70**	**kWh**	
Input voltage deviates from rated voltage	-655,58	kWh	-0,07 %
DC/AC Conversion	-26.325,22	kWh	-2,63 %
Standby Consumption (Inverter)	-745,67	kWh	-0,08 %
Total Cable Losses	-19.476,18	kWh	-2,00 %
PV energy (AC) minus standby use	**953.587,05**	**kWh**	
PV Generator Energy (AC grid)	**954.332,72**	**kWh**	

	Year 1	Year 2	Year 3	Year 4	Year 5
Investments	-€ 1.250.000,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 144.645,45	€ 142.619,68	€ 140.417,92	€ 139.359,85	€ 139.189,21
Annual Cash Flow	**-€ 1.105.354,55**	**€ 142.619,68**	**€ 140.417,92**	**€ 139.359,85**	**€ 139.189,21**
Accrued Cash Flow (Cash Balance)	-€ 1.105.354,55	-€ 962.734,87	-€ 822.316,96	-€ 682.957,11	-€ 543.767,90

	Year 6	Year 7	Year 8	Year 9	Year 10
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 139.710,31	€ 140.773,45	€ 142.264,80	€ 144.096,99	€ 146.204,07
Annual Cash Flow	**€ 139.710,31**	**€ 140.773,45**	**€ 142.264,80**	**€ 144.096,99**	**€ 146.204,07**
Accrued Cash Flow (Cash Balance)	-€ 404.057,60	-€ 263.284,15	-€ 121.019,35	€ 23.077,65	€ 169.281,72

	Year 11	Year 12	Year 13	Year 14	Year 15
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 148.535,21	€ 151.052,40	€ 153.726,57	€ 156.535,70	€ 159.463,36
Annual Cash Flow	**€ 148.535,21**	**€ 151.052,40**	**€ 153.726,57**	**€ 156.535,70**	**€ 159.463,36**
Accrued Cash Flow (Cash Balance)	€ 317.816,93	€ 468.869,33	€ 622.595,89	€ 779.131,59	€ 938.594,95

	Year 16	Year 17	Year 18	Year 19	Year 20
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 162.497,23	€ 165.628,42	€ 168.850,00	€ 172.157,49	€ 175.547,45
Annual Cash Flow	**€ 162.497,23**	**€ 165.628,42**	**€ 168.850,00**	**€ 172.157,49**	**€ 175.547,45**
Accrued Cash Flow (Cash Balance)	€ 1.101.092,18	€ 1.266.720,60	€ 1.435.570,60	€ 1.607.728,09	€ 1.783.275,54

	Year 21	Year 22	Year 23	Year 24	Year 25
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 179.017,67	€ 182.566,90	€ 186.194,51	€ 189.900,10	€ 193.684,17
Annual Cash Flow	**€ 179.017,67**	**€ 182.566,90**	**€ 186.194,51**	**€ 189.900,10**	**€ 193.684,17**
Accrued Cash Flow (Cash Balance)	€ 1.962.293,21	€ 2.144.860,11	€ 2.331.054,62	€ 2.520.954,72	€ 2.714.638,89

System Data		
Grid Feed-in in the first year (incl. module degradation)	0	kWh/Year
PV Generator Output	1250	kWp
Start of Operation of the System	7/10/2021	
Assessment Period	30	Years
Interest on Capital	0	%

Economic Parameters		
Internal Rate of Return (IRR)	11,49	%
Accrued Cash Flow (Cash Balance)	3.960.697,71	€
Amortization Period	8,8	Years
Electricity Production Costs	0,0423	€/kWh

Payment Overview		
Specific Investment Costs	1.000,00	€/kWp
Investment Costs	1.250.000,00	€
One-off Payments	0,00	€
Incoming Subsidies	0,00	€
Annual Costs	0,00	€/Year
Other Revenue or Savings	0,00	€/Year

Remuneration and Savings		
Total Payment from Utility in First Year	0,00	€/Year
First year savings	146.300,41	€/Year
UPV (Example)		
Energy Price Tariff period 1	0,1853	€/kWh
Saving Tariff period 1	28.589,31	€/Year
Energy Price Tariff period 2	0,1729	€/kWh
Saving Tariff period 2	17.467,53	€/Year
Energy Price Tariff period 3	0,1585	€/kWh
Saving Tariff period 3	8.118,39	€/Year
Energy Price Tariff period 4	0,1513	€/kWh
Saving Tariff period 4	15.335,17	€/Year
Energy Price Tariff period 5	0,1488	€/kWh
Saving Tariff period 5	26.480,03	€/Year
Energy Price Tariff period 6	0,1482	€/kWh
Saving Tariff period 6	54.499,11	€/Year
Inflation Rate for Energy Price	2	%/Year

Appendix 3: Results SAM Building 8B,E,H Facade installation for 42,5€/kWh

System Advisor Model Report

Detailed Photovoltaic	1.2 DC MW Nameplate	39.48, -0.47
Commercial	$1.00/W Installed Cost	UTC +1

Performance Model

Modules	
Trina Solar TSM-500DE18M(II)	
Cell material	Mono-c-Si
Module area	2.34 m²
Module capacity	500.33 DC Watts
Quantity	2,490
Total capacity	1.25 DC MW
Total area	5,826 m²

Inverters	
SMA America: STP 33-US-41	
Unit capacity	33.300000 AC kW
Input voltage	330 - 800 VDC DC V
Quantity	13
Total capacity	432.9 AC kW
DC to AC Capacity Ratio	2.88
AC losses (%)	1.00

Four subarrays:	**1**	**2**	**3**	**4**
Strings	26	57	26	57
Modules per string	15	15	15	15
String Voc (DC V)	775.50	775.50	775.50	775.50
Tilt (deg from horizontal)	90.00	90.00	90.00	90.00
Azimuth (deg E of N)	20	110	200	290
Tracking	no	no	no	no
Backtracking	-	-	-	-
Self shading	no	no	no	no
Rotation limit (deg)	-	-	-	-
Shading	yes	yes	yes	yes
Snow	no	no	no	no
Soiling	yes	yes	yes	yes
DC losses (%)	2.97	2.97	2.97	2.97

Performance Adjustments	
Availability/Curtailment	none
Degradation	none
Hourly or custom losses	none

Annual Results (in Year 1)				
GHI kWh/m²/day	4.73	4.73	4.73	4.73
POA kWh/m²/day	36.00	87.00	73.00	63.00
Net to inverter	1,000,000 DC kWh			
Net to grid	958,000 AC kWh			
Capacity factor	8.8			
Performance ratio	0.79			

Financial Model

Project Costs	
Total installed cost	$1,251,621
Salvage value	$0

Analysis Parameters	
Project life	30 years
Inflation rate	1.5%
Real discount rate	4%

Project Debt Parameters	
Debt fraction	0%
Amount	$0
Term	25 years
Rate	0%

Tax and Insurance Rates	
Federal income tax	0 %/year
State income tax	0 %/year
Sales tax (% of indirect cost basis)	0%
Insurance (% of installed cost)	0 %/year
Property tax (% of assessed val.)	0 %/year

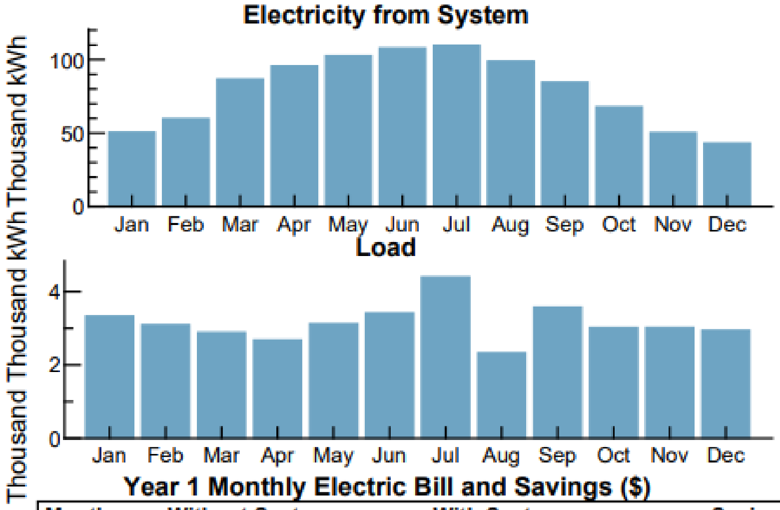
Incentives
None

Electricity Demand and Rate Summary
Annual peak demand 13,272 kW
Annual total demand 37,819,600 kWh
Generic Commercial
Monthly excess with kWh rollover
Annual rate escalation: 2%/year
Tiered TOU energy rates: 6 periods, 1 tier

Results	
Nominal LCOE	11.9 cents/kWh
Net present value	$656,200
Payback period	11.6 years

Detailed Photovoltaic	1.2 DC MW Nameplate	39.48, -0.47
Commercial	$1.00/W Installed Cost	UTC +1

Year 1 Monthly Generation and Load Summary



Year 1 Monthly Electric Bill and Savings ($)

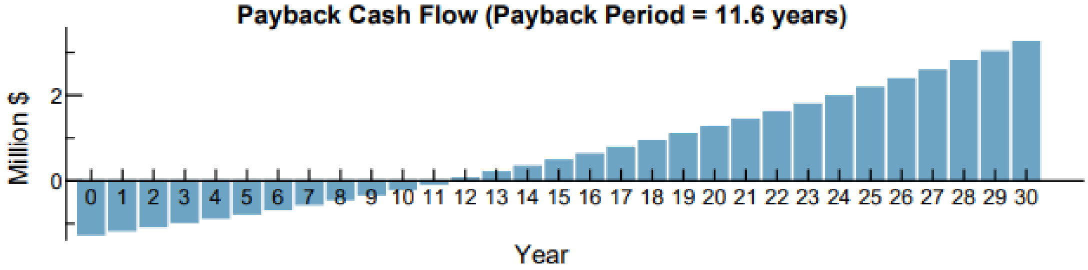
Month	Without System	With System	Savings
Jan	287,406	282,816	4,590
Feb	264,691	259,352	5,339
Mar	632,793	619,264	13,529
Apr	183,678	177,115	6,562
May	214,063	207,000	7,062
Jun	298,371	288,756	9,614
Jul	383,968	374,102	9,865
Aug	157,163	150,480	6,682
Sep	965,892	933,603	32,288
Oct	206,589	201,923	4,666
Nov	669,848	664,385	5,462
Dec	246,322	242,489	3,833
Annual	4,510,789	4,401,291	109,497

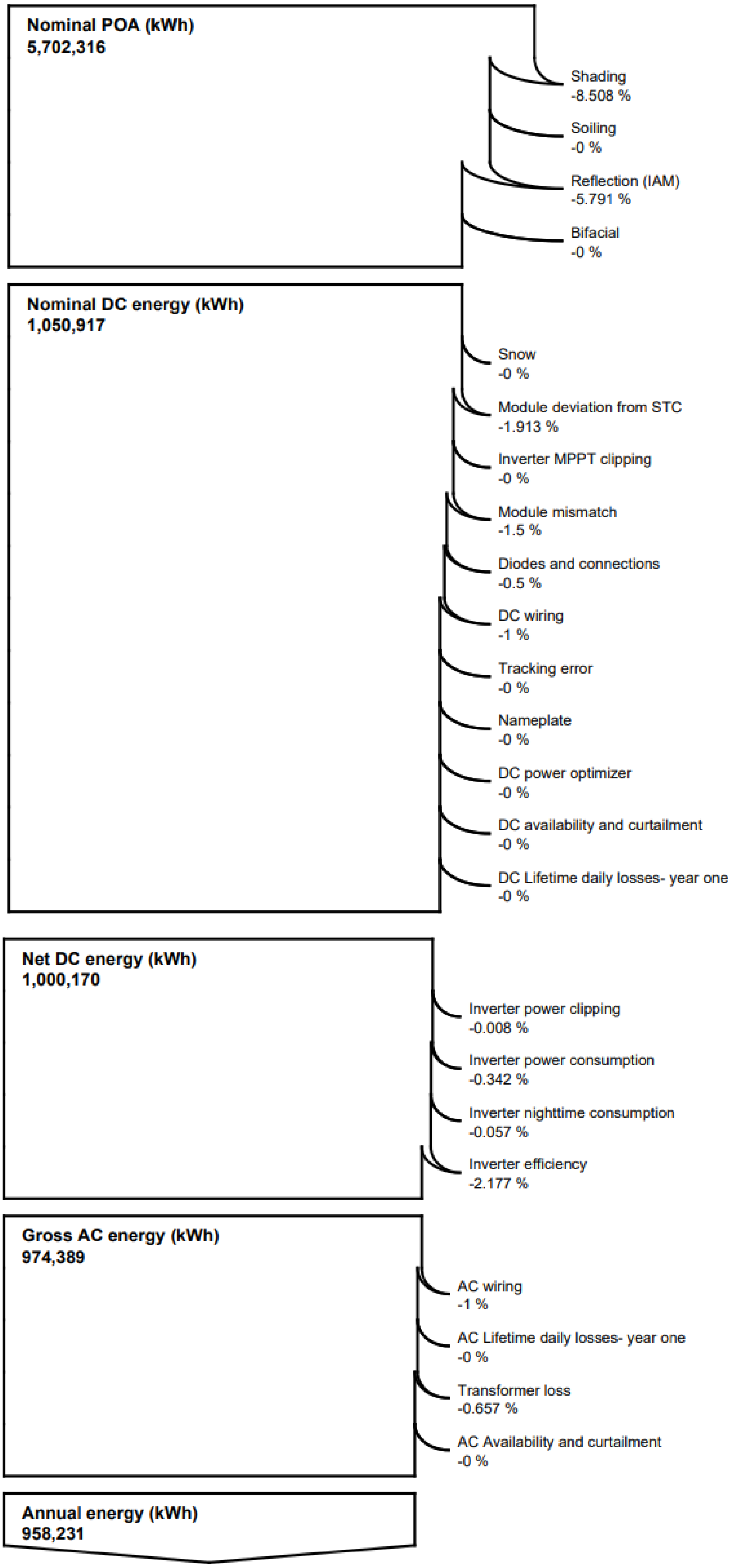
NPV Approximation using Annuities

Annuities, Capital Recovery Factor (CRF) = 0.0693		
Investment	$-86,600	Sum:
Expenses	$-21,900	$45,400
Savings	$0	NPV = Sum / CRF:
Energy value	$154,100	$656,000

Investment = Installed Cost - Debt Principal - IBI - CBI
Expenses = Operating Costs + Debt Payments
Savings = Tax Deductions + PBI
Energy value = Tax Adjusted Net Savings
Nominal discount rate = 5.56%

Payback Cash Flow (Payback Period = 11.6 years)




Nominal POA (kWh)
5,702,316
Shading
-8.508 %
Soiling
-0 %
Reflection (IAM)
-5.791 %
Bifacial
-0 %
Nominal DC energy (kWh)
1,050,917
Snow
-0 %
Module deviation from STC
-1.913 %
Inverter MPPT clipping
-0 %
Module mismatch
-1.5 %
Diodes and connections
-0.5 %
DC wiring
-1 %
Tracking error
-0 %
Nameplate
-0 %
DC power optimizer
-0 %
DC availability and curtailment
-0 %
DC Lifetime daily losses- year one
-0 %
Net DC energy (kWh)
1,000,170
Inverter power clipping
-0.008 %
Inverter power consumption
-0.342 %
Inverter nighttime consumption
-0.057 %
Inverter efficiency
-2.177 %
Gross AC energy (kWh)
974,389
AC wiring
-1 %
AC Lifetime daily losses- year one
-0 %
Transformer loss
-0.657 %
AC Availability and curtailment
-0 %
Annual energy (kWh)
958,231

Appendix 4: Results SAM Building 8B,E,H Facade installation for 100€/kWh

System Advisor Model Report

Detailed Photovoltaic	1.2 DC MW Nameplate	39.48, -0.47
Commercial	$1.00/W Installed Cost	UTC +1

Performance Model

Modules	
Trina Solar TSM-500DE18M(II)	
Cell material	Mono-c-Si
Module area	2.34 m²
Module capacity	500.33 DC Watts
Quantity	2,490
Total capacity	1.25 DC MW
Total area	5,826 m²

Inverters	
SMA America: STP 33-US-41	
Unit capacity	33.300000 AC kW
Input voltage	330 - 800 VDC DC V
Quantity	13
Total capacity	432.9 AC kW
DC to AC Capacity Ratio	2.88
AC losses (%)	1.00

Four subarrays:	**1**	**2**	**3**	**4**
Strings	26	57	26	57
Modules per string	15	15	15	15
String Voc (DC V)	775.50	775.50	775.50	775.50
Tilt (deg from horizontal)	90.00	90.00	90.00	90.00
Azimuth (deg E of N)	20	110	200	290
Tracking	no	no	no	no
Backtracking	-	-	-	-
Self shading	no	no	no	no
Rotation limit (deg)	-	-	-	-
Shading	yes	yes	yes	yes
Snow	no	no	no	no
Soiling	yes	yes	yes	yes
DC losses (%)	2.97	2.97	2.97	2.97

Performance Adjustments	
Availability/Curtailment	none
Degradation	none
Hourly or custom losses	none

Annual Results (in Year 1)				
GHI kWh/m²/day	4.73	4.73	4.73	4.73
POA kWh/m²/day	36.00	87.00	73.00	63.00
Net to inverter	998,000 DC kWh			
Net to grid	956,000 AC kWh			
Capacity factor	8.8			
Performance ratio	0.78			

Financial Model

Project Costs	
Total installed cost	$1,251,621
Salvage value	$0

Analysis Parameters	
Project life	30 years
Inflation rate	1.5%
Real discount rate	4%

Project Debt Parameters	
Debt fraction	0%
Amount	$0
Term	0 years
Rate	0%

Tax and Insurance Rates	
Federal income tax	0 %/year
State income tax	0 %/year
Sales tax (% of indirect cost basis)	0%
Insurance (% of installed cost)	0 %/year
Property tax (% of assessed val.)	0 %/year

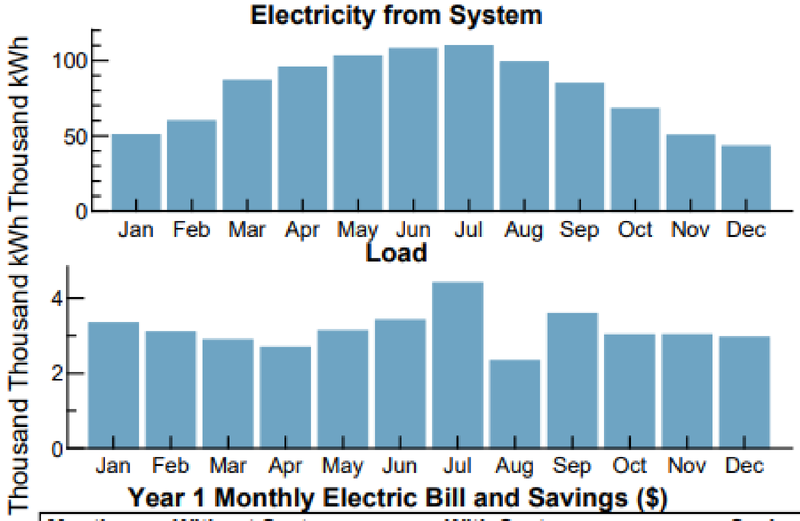
Incentives
None

Electricity Demand and Rate Summary
Annual peak demand 13,272 kW
Annual total demand 37,819,600 kWh
Generic Commercial
Monthly excess with kWh rollover
Annual rate escalation: 2%/year
Tiered TOU energy rates: 6 periods, 1 tier

Results	
Nominal LCOE	12 cents/kWh
Net present value	$1,495,200
Payback period	8.4 years

Detailed Photovoltaic	1.2 DC MW Nameplate	39.48, -0.47
Commercial	$1.00/W Installed Cost	UTC +1

Year 1 Monthly Generation and Load Summary



Year 1 Monthly Electric Bill and Savings ($)

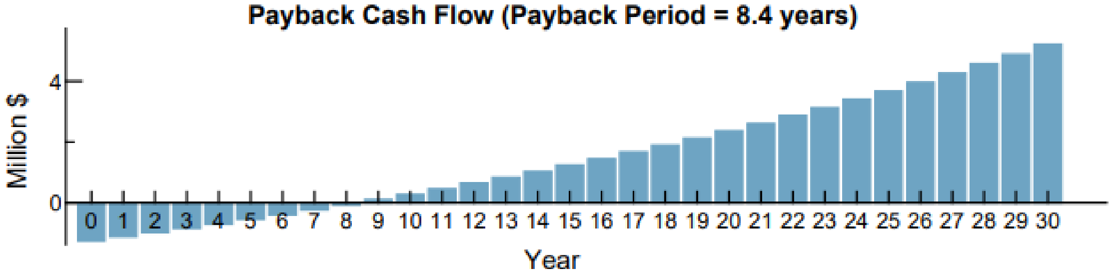
Month	Without System	With System	Savings
Jan	555,727	547,074	8,652
Feb	513,652	503,523	10,129
Mar	437,362	424,269	13,092
Apr	398,618	384,443	14,175
May	464,083	448,831	15,251
Jun	573,030	554,770	18,260
Jul	738,310	719,656	18,653
Aug	345,061	330,416	14,644
Sep	543,982	531,006	12,975
Oct	447,970	437,894	10,075
Nov	457,493	449,915	7,577
Dec	483,682	476,393	7,288
Annual	5,958,974	5,808,196	150,777

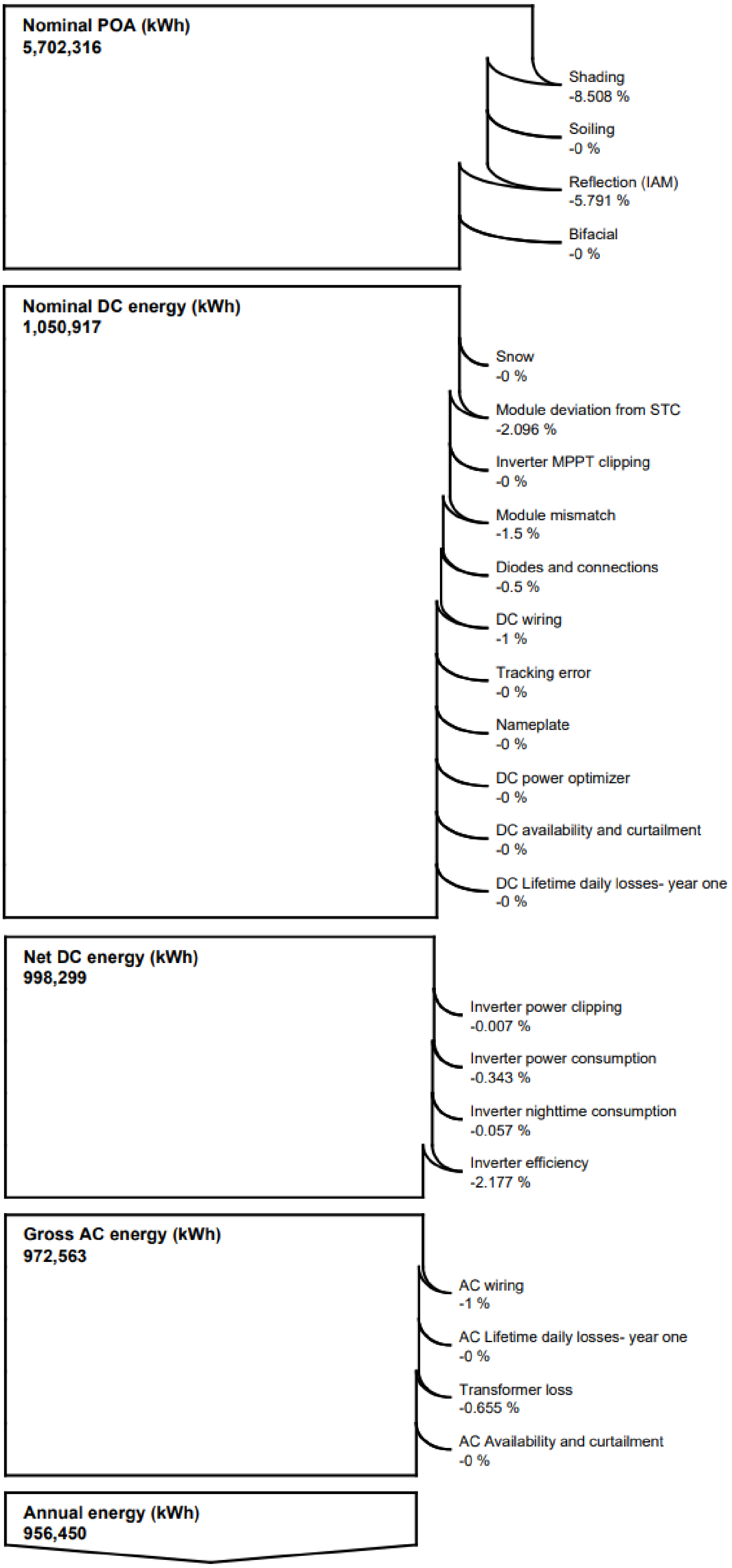
NPV Approximation using Annuities

Annuities, Capital Recovery Factor (CRF) = 0.0693		
Investment	$-86,600	Sum:
Expenses	$-21,900	$103,500
Savings	$0	NPV = Sum / CRF:
Energy value	$212,200	$1,495,000

Investment = Installed Cost - Debt Principal - IBI - CBI
Expenses = Operating Costs + Debt Payments
Savings = Tax Deductions + PBI
Energy value = Tax Adjusted Net Savings
Nominal discount rate = 5.56%

Payback Cash Flow (Payback Period = 8.4 years)




Nominal POA (kWh)
5,702,316
Shading
-8.508 %
Soiling
-0 %
Reflection (IAM)
-5.791 %
Bifacial
-0 %
Nominal DC energy (kWh)
1,050,917
Snow
-0 %
Module deviation from STC
-2.096 %
Inverter MPPT clipping
-0 %
Module mismatch
-1.5 %
Diodes and connections
-0.5 %
DC wiring
-1 %
Tracking error
-0 %
Nameplate
-0 %
DC power optimizer
-0 %
DC availability and curtailment
-0 %
DC Lifetime daily losses- year one
-0 %
Net DC energy (kWh)
998,299
Inverter power clipping
-0.007 %
Inverter power consumption
-0.343 %
Inverter nighttime consumption
-0.057 %
Inverter efficiency
-2.177 %
Gross AC energy (kWh)
972,563
AC wiring
-1 %
AC Lifetime daily losses- year one
-0 %
Transformer loss
-0.655 %
AC Availability and curtailment
-0 %
Annual energy (kWh)
956,450

Appendix 5: Results SAM Building 8B,E,H Facade installation for 150€/kWh

System Advisor Model Report

Detailed Photovoltaic	1.2 DC MW Nameplate	39.48, -0.47
Commercial	$1.00/W Installed Cost	UTC +1

Performance Model

Modules	
Trina Solar TSM-500DE18M(II)	
Cell material	Mono-c-Si
Module area	2.34 m²
Module capacity	500.33 DC Watts
Quantity	2,490
Total capacity	1.25 DC MW
Total area	5,826 m²

Inverters	
SMA America: STP 33-US-41	
Unit capacity	33.300000 AC kW
Input voltage	330 - 800 VDC DC V
Quantity	13
Total capacity	432.9 AC kW
DC to AC Capacity Ratio	2.88
AC losses (%)	1.00

Four subarrays:	1	2	3	4
Strings	26	57	26	57
Modules per string	15	15	15	15
String Voc (DC V)	775.50	775.50	775.50	775.50
Tilt (deg from horizontal)	90.00	90.00	90.00	90.00
Azimuth (deg E of N)	20	110	200	290
Tracking	no	no	no	no
Backtracking	-	-	-	-
Self shading	no	no	no	no
Rotation limit (deg)	-	-	-	-
Shading	yes	yes	yes	yes
Snow	no	no	no	no
Soiling	yes	yes	yes	yes
DC losses (%)	2.97	2.97	2.97	2.97

Performance Adjustments	
Availability/Curtailment	none
Degradation	none
Hourly or custom losses	none

Annual Results (in Year 1)				
GHI kWh/m²/day	4.73	4.73	4.73	4.73
POA kWh/m²/day	36.00	87.00	73.00	63.00
Net to inverter	1,000,000 DC kWh			
Net to grid	958,000 AC kWh			
Capacity factor	8.8			
Performance ratio	0.79			

Financial Model

Project Costs	
Total installed cost	$1,251,621
Salvage value	$0

Analysis Parameters	
Project life	30 years
Inflation rate	1.5%
Real discount rate	4%

Project Debt Parameters	
Debt fraction	0%
Amount	$0
Term	25 years
Rate	0%

Tax and Insurance Rates	
Federal income tax	0 %/year
State income tax	0 %/year
Sales tax (% of indirect cost basis)	0%
Insurance (% of installed cost)	0 %/year
Property tax (% of assessed val.)	0 %/year

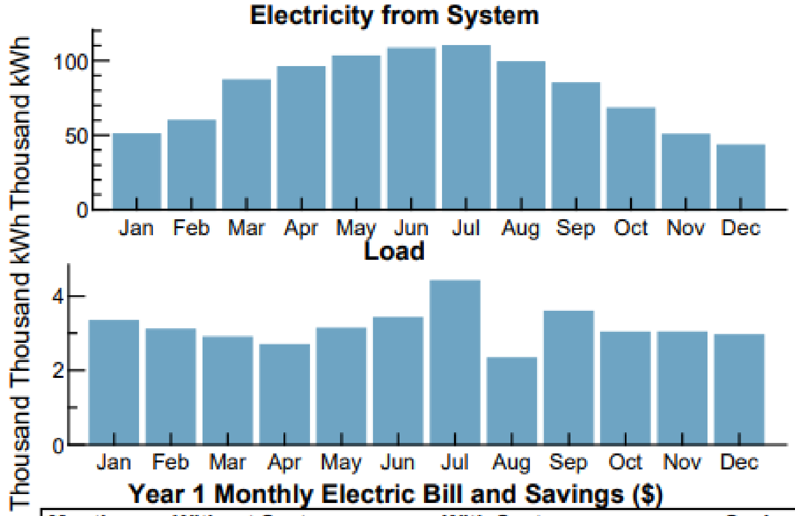
Incentives
None

Electricity Demand and Rate Summary
Annual peak demand 13,272 kW
Annual total demand 37,819,600 kWh
Generic Commercial
Monthly excess with kWh rollover
Annual rate escalation: 2%/year
Tiered TOU energy rates: 6 periods, 1 tier

Results	
Nominal LCOE	11.9 cents/kWh
Net present value	$2,849,100
Payback period	5.8 years

Detailed Photovoltaic	1.2 DC MW Nameplate	39.48, -0.47
Commercial	$1.00/W Installed Cost	UTC +1

Year 1 Monthly Generation and Load Summary



Year 1 Monthly Electric Bill and Savings ($)

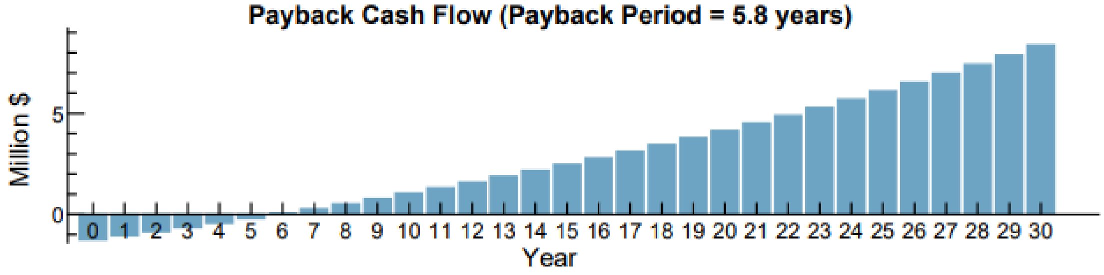
Month	Without System	With System	Savings
Jan	787,272	775,095	12,176
Feb	728,488	714,191	14,297
Mar	637,007	617,892	19,115
Apr	583,918	563,124	20,794
May	679,617	657,260	22,357
Jun	810,017	784,221	25,795
Jul	1,044,048	1,017,732	26,315
Aug	507,114	485,551	21,562
Sep	791,607	772,748	18,859
Oct	656,057	641,286	14,771
Nov	666,200	655,140	11,059
Dec	688,495	678,207	10,288
Annual	8,579,846	8,362,453	217,393

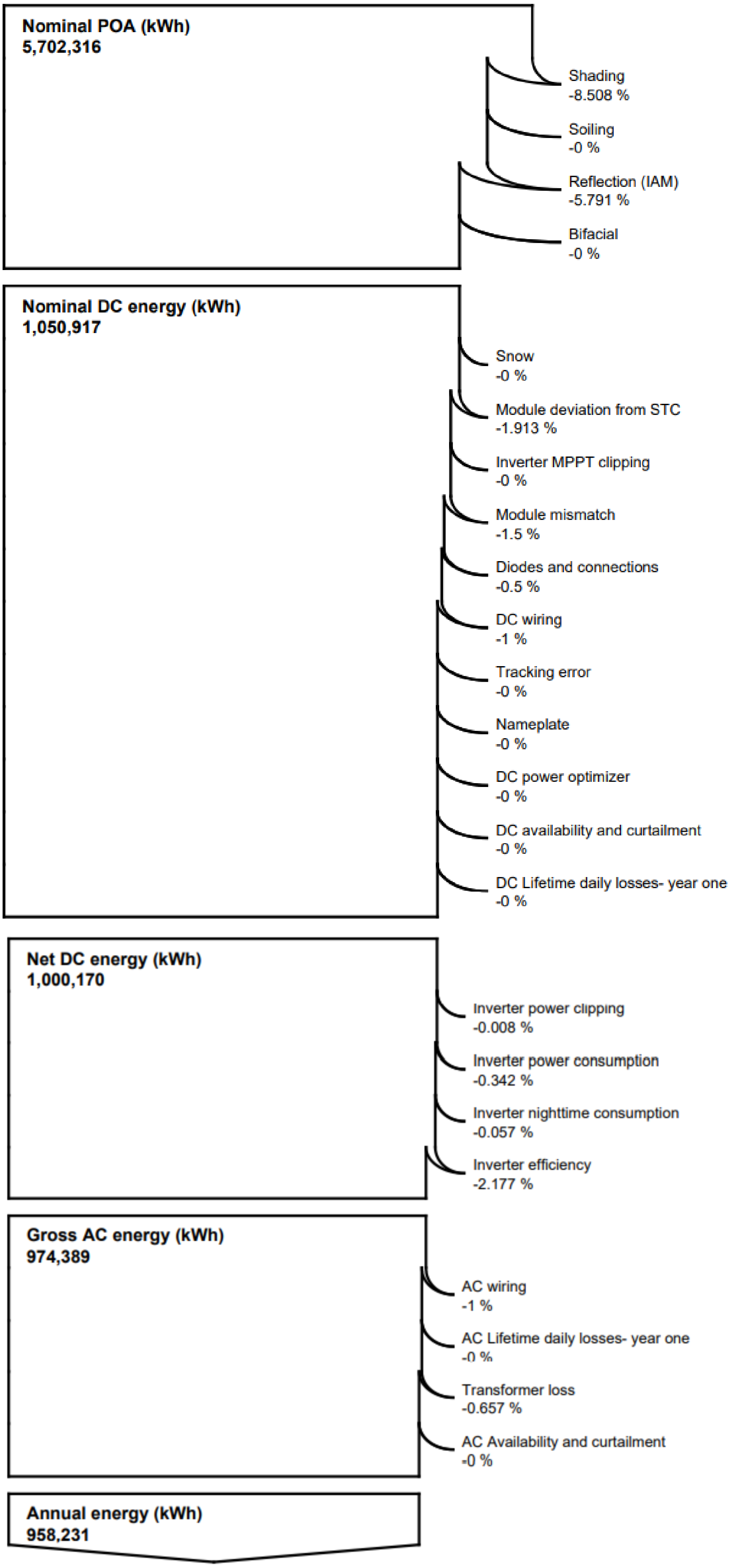
NPV Approximation using Annuities

Annuities, Capital Recovery Factor (CRF) = 0.0693		
Investment	$-86,600	Sum:
Expenses	$-21,900	$197,300
Savings	$0	NPV = Sum / CRF:
Energy value	$306,000	$2,849,000

Investment = Installed Cost - Debt Principal - IBI - CBI
Expenses = Operating Costs + Debt Payments
Savings = Tax Deductions + PBI
Energy value = Tax Adjusted Net Savings
Nominal discount rate = 5.56%

Payback Cash Flow (Payback Period = 5.8 years)

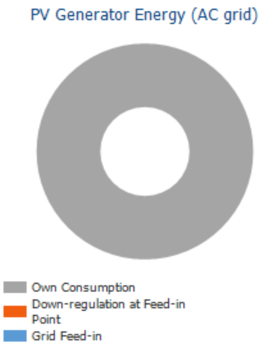



Nominal POA (kWh)
5,702,316
Shading
-8.508 %
Soiling
-0 %
Reflection (IAM)
-5.791 %
Bifacial
-0 %
Nominal DC energy (kWh)
1,050,917
Snow
-0 %
Module deviation from STC
-1.913 %
Inverter MPPT clipping
-0 %
Module mismatch
-1.5 %
Diodes and connections
-0.5 %
DC wiring
-1 %
Tracking error
-0 %
Nameplate
-0 %
DC power optimizer
-0 %
DC availability and curtailment
-0 %
DC Lifetime daily losses- year one
-0 %
Net DC energy (kWh)
1,000,170
Inverter power clipping
-0.008 %
Inverter power consumption
-0.342 %
Inverter nighttime consumption
-0.057 %
Inverter efficiency
-2.177 %
Gross AC energy (kWh)
974,389
AC wiring
-1 %
AC Lifetime daily losses- year one
-0 %
Transformer loss
-0.657 %
AC Availability and curtailment
-0 %
Annual energy (kWh)
958,231

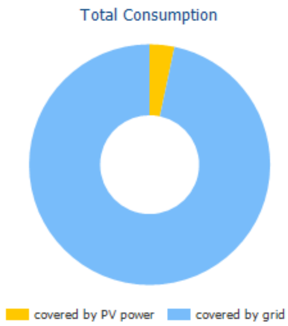
Appendix C – Results building 7A,D,F,G,I PV-facade installation

Appendix 6: Results PV*SOL Building 7A,D,F,G,I Facade installation

PV System		
PV Generator Output	1.689,50	kWp
Spec. Annual Yield	743,62	kWh/kWp
Performance Ratio (PR)	79,54	%
Yield Reduction due to Shading	13,9	%/Year
PV Generator Energy (AC grid)	1.257.844	kWh/Year
Own Consumption	1.257.843	kWh/Year
Down-regulation at Feed-in Point	0	kWh/Year
Grid Feed-in	0	kWh/Year
Own Power Consumption	100,0	%
CO_2 Emissions avoided	590.484	kg / year



Appliances		
Appliances	38.000.000	kWh/Year
Standby Consumption (Inverter)	1.495	kWh/Year
Total Consumption	38.001.495	kWh/Year
covered by PV power	1.257.843	kWh/Year
covered by grid	36.743.651	kWh/Year
Solar Fraction	3,3	%



Financial Analysis	
Internal Rate of Return (IRR)	10,70 %
Revenue or Savings	192834,1 €/Year
Accrued Cash Flow (Cash Balance)	3.078.906,97 €

Tech. Quality of the PV System	
PV Generator Energy (AC grid)	1.257.844 kWh/Year
Spec. Annual Yield	743,62 kWh/kWp
Performance Ratio (PR)	79,5 %

System integration			
Energy from Grid	36.743.651 kWh/Year	Grid Feed-in	0 kWh/Year

Global radiation - horizontal	**1.613,61**	**kWh/m²**	
Deviation from standard spectrum	-16,14	kWh/m²	-1,00 %
Ground Reflection (Albedo)	159,75	kWh/m²	10,00 %
Orientation and inclination of the module surface	-820,99	kWh/m²	-46,72 %
Module-independent shading	-1,89	kWh/m²	-0,20 %
Reflection on the Module Interface	-1,40	kWh/m²	-0,15 %
Global Radiation at the Module	**932,94**	**kWh/m²**	
	932,94	kWh/m²	
	x 8143,64	m²	
	= 7.597.510,59	kWh	
Global PV Radiation	**7.597.510,59**	**kWh**	
Soiling	0,00	kWh	0,00 %
STC Conversion (Rated Efficiency of Module 20,76 %)	-6.020.265,39	kWh	-79,24 %
Rated PV Energy	**1.577.245,21**	**kWh**	
Module-specific Partial Shading	-165.590,13	kWh	-10,50 %
Low-light performance	-15.360,31	kWh	-1,09 %
Deviation from the nominal module temperature	-27.223,83	kWh	-1,95 %
Diodes	-2.125,56	kWh	-0,16 %
Mismatch (Manufacturer Information)	-27.338,91	kWh	-2,00 %
Mismatch (Configuration/Shading)	-34.459,63	kWh	-2,57 %
PV Energy (DC) without inverter down-regulation	**1.305.146,83**	**kWh**	
Failing to reach the DC start output	-741,02	kWh	-0,06 %
Down-regulation on account of the MPP Voltage Range	-6.019,67	kWh	-0,46 %
Down-regulation on account of the max. DC Current	0,00	kWh	0,00 %
Down-regulation on account of the max. DC Power	0,00	kWh	0,00 %
Down-regulation on account of the max. AC Power/cos phi	-2,28	kWh	0,00 %
MPP Matching	-525,21	kWh	-0,04 %
PV energy (DC)	**1.297.858,66**	**kWh**	

Energy at the Inverter Input	**1.297.858,66**	**kWh**	
Input voltage deviates from rated voltage	-3.115,83	kWh	-0,24 %
DC/AC Conversion	-36.898,61	kWh	-2,85 %
Standby Consumption (Inverter)	-1.495,19	kWh	-0,12 %
Total Cable Losses	0,00	kWh	0,00 %
PV energy (AC) minus standby use	**1.256.349,03**	**kWh**	
PV Generator Energy (AC grid)	**1.257.844,22**	**kWh**	

System Data		
Grid Feed-in in the first year (incl. module degradation)	0	kWh/Year
PV Generator Output	1689,5	kWp
Start of Operation of the System	10/11/2021	
Assessment Period	25	Years
Interest on Capital	1	%
Economic Parameters		
Internal Rate of Return (IRR)	10,70	%
Accrued Cash Flow (Cash Balance)	3.078.906,97	€
Amortization Period	9,5	Years
Electricity Production Costs	0,059	€/kWh
Payment Overview		
Specific Investment Costs	1.000,00	€/kWp
Investment Costs	1.689.500,00	€
One-off Payments	0,00	€
Incoming Subsidies	0,00	€
Annual Costs	0,00	€/Year
Other Revenue or Savings	0,00	€/Year
Remuneration and Savings		
Total Payment from Utility in First Year	0,00	€/Year
First year savings	192.834,11	€/Year
UPV (Example)		
Energy Price Tariff period 1	0,1853	€/kWh
Saving Tariff period 1	37.220,15	€/Year
Energy Price Tariff period 2	0,1729	€/kWh
Saving Tariff period 2	23.932,85	€/Year
Energy Price Tariff period 3	0,1585	€/kWh
Saving Tariff period 3	11.091,17	€/Year
Energy Price Tariff period 4	0,1513	€/kWh

Saving Tariff period 4	22.037,85	€/Year
Energy Price Tariff period 5	0,1488	€/kWh
Saving Tariff period 5	33.882,61	€/Year
Energy Price Tariff period 6	0,1482	€/kWh
Saving Tariff period 6	70.206,25	€/Year
Inflation Rate for Energy Price	2	%/Year

	Year 1	Year 2	Year 3	Year 4	Year 5
Investments	-€ 1.689.500,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 186.803,46	€ 184.281,69	€ 179.642,76	€ 176.525,78	€ 174.565,46
Annual Cash Flow	**-€ 1.502.696,54**	**€ 184.281,69**	**€ 179.642,76**	**€ 176.525,78**	**€ 174.565,46**
Accrued Cash Flow (Cash Balance)	-€ 1.502.696,54	-€ 1.318.414,85	-€ 1.138.772,09	-€ 962.246,31	-€ 787.680,85

	Year 6	Year 7	Year 8	Year 9	Year 10
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 173.485,30	€ 173.075,58	€ 173.178,04	€ 173.672,15	€ 174.467,43
Annual Cash Flow	**€ 173.485,30**	**€ 173.075,58**	**€ 173.178,04**	**€ 173.672,15**	**€ 174.467,43**
Accrued Cash Flow (Cash Balance)	-€ 614.195,56	-€ 441.119,98	-€ 267.941,93	-€ 94.269,78	€ 80.197,65

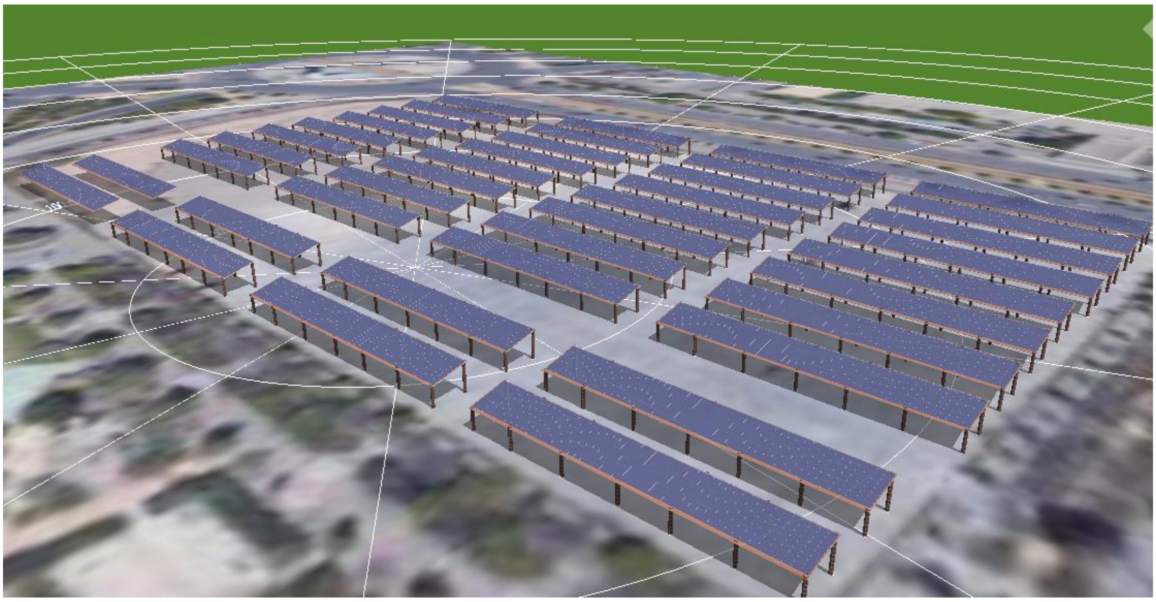
	Year 11	Year 12	Year 13	Year 14	Year 15
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 175.494,56	€ 176.701,83	€ 178.049,76	€ 179.508,42	€ 181.055,27
Annual Cash Flow	**€ 175.494,56**	**€ 176.701,83**	**€ 178.049,76**	**€ 179.508,42**	**€ 181.055,27**
Accrued Cash Flow (Cash Balance)	€ 255.692,21	€ 432.394,04	€ 610.443,80	€ 789.952,22	€ 971.007,49

	Year 16	Year 17	Year 18	Year 19	Year 20
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 182.673,28	€ 184.349,82	€ 186.074,84	€ 187.841,34	€ 189.643,72
Annual Cash Flow	**€ 182.673,28**	**€ 184.349,82**	**€ 186.074,84**	**€ 187.841,34**	**€ 189.643,72**
Accrued Cash Flow (Cash Balance)	€ 1.153.680,78	€ 1.338.030,59	€ 1.524.105,43	€ 1.711.946,77	€ 1.901.590,50

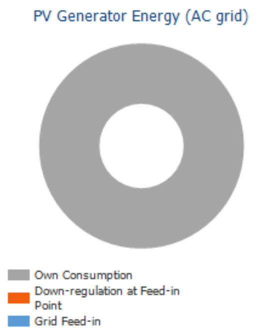
	Year 21	Year 22	Year 23	Year 24	Year 25
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 191.477,85	€ 193.340,72	€ 195.230,11	€ 197.144,10	€ 199.081,70
Annual Cash Flow	**€ 191.477,85**	**€ 193.340,72**	**€ 195.230,11**	**€ 197.144,10**	**€ 199.081,70**
Accrued Cash Flow (Cash Balance)	€ 2.093.068,35	€ 2.286.409,07	€ 2.481.639,17	€ 2.678.783,27	€ 2.877.864,97

Appendix D – Results parking roof installation

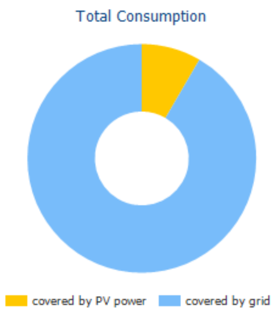
Appendix 7: Results PV*SOL parking roof installation



PV System		
PV Generator Output	2.200,00	kWp
Spec. Annual Yield	1.449,08	kWh/kWp
Performance Ratio (PR)	83,05	%
Yield Reduction due to Shading	0,0	%/Year
PV Generator Energy (AC grid)	3.191.675	kWh/Year
Own Consumption	3.191.675	kWh/Year
Down-regulation at Feed-in Point	0	kWh/Year
Grid Feed-in	0	kWh/Year
Own Power Consumption	100,0	%
CO_2 Emissions avoided	1.498.351	kg / year



Appliances		
Appliances	38.000.000	kWh/Year
Standby Consumption (Inverter)	3.694	kWh/Year
Total Consumption	38.003.694	kWh/Year
covered by PV power	3.191.675	kWh/Year
covered by grid	34.812.019	kWh/Year
Solar Fraction	8,4	%



Level of Self-sufficiency		
Total Consumption	38.003.694	kWh/Year
covered by grid	34.812.019	kWh/Year
Level of Self-sufficiency	8,4	%

Financial Analysis	
Internal Rate of Return (IRR)	21,12 %
Revenue or Savings	490367,2 €/Year
Accrued Cash Flow (Cash Balance)	9.864.596,85 €

Tech. Quality of the PV System	
PV Generator Energy (AC grid)	3.191.675 kWh/Year
Spec. Annual Yield	1.449,08 kWh/kWp
Performance Ratio (PR)	83,0 %

System integration			
Energy from Grid	34.812.019 kWh/Year	Grid Feed-in	0 kWh/Year

System Data		
Grid Feed-in in the first year (incl. module degradation)	0	kWh/Yea
PV Generator Output	2200	kWp
Start of Operation of the System	14/10/2021	
Assessment Period	25	Years
Interest on Capital	1	%
Economic Parameters		
Internal Rate of Return (IRR)	21,12	%
Accrued Cash Flow (Cash Balance)	9.864.596,85	€
Amortization Period	4,9	Years
Electricity Production Costs	0,0311	€/kWh
Payment Overview		
Specific Investment Costs	1.027,00	€/kWp
Investment Costs	2.259.400,00	€
One-off Payments	0,00	€
Incoming Subsidies	0,00	€
Annual Costs	0,00	€/Year
Other Revenue or Savings	0,00	€/Year
Remuneration and Savings		
Total Payment from Utility in First Year	0,00	€/Year
First year savings	490.367,17	€/Year
UPV (Example)		
Energy Price Tariff period 1	0,1853	€/kWh
Saving Tariff period 1	100.819,64	€/Year
Energy Price Tariff period 2	0,1729	€/kWh
Saving Tariff period 2	60.118,44	€/Year
Energy Price Tariff period 3	0,1585	€/kWh
Saving Tariff period 3	27.950,01	€/Year
Energy Price Tariff period 4	0,1513	€/kWh
Saving Tariff period 4	51.064,80	€/Year
Energy Price Tariff period 5	0,1488	€/kWh
Saving Tariff period 5	89.849,83	€/Year
Energy Price Tariff period 6	0,1482	€/kWh
Saving Tariff period 6	174.655,00	€/Year
Inflation Rate for Energy Price	2	%/Year

Global radiation - horizontal	**1.613,61**	**kWh/m²**	
Deviation from standard spectrum	-16,14	kWh/m²	-1,00 %
Ground Reflection (Albedo)	5,44	kWh/m²	0,34 %
Orientation and inclination of the module surface	140,76	kWh/m²	8,78 %
Module-independent shading	0,00	kWh/m²	0,00 %
Reflection on the Module Interface	-1,74	kWh/m²	-0,10 %
Global Radiation at the Module	**1.741,94**	**kWh/m²**	
	1.741,94	kWh/m²	
	x 10604,326	m²	
	= 18.472.104,73	kWh	
Global PV Radiation	**18.472.104,73**	**kWh**	
Soiling	-1.847.042,21	kWh	-10,00 %
STC Conversion (Rated Efficiency of Module 20,76 %)	-13.173.695,14	kWh	-79,24 %
Rated PV Energy	**3.451.367,38**	**kWh**	
Module-specific Partial Shading	0,00	kWh	0,00 %
Low-light performance	-1.627,66	kWh	-0,05 %
Deviation from the nominal module temperature	-138.368,57	kWh	-4,01 %
Diodes	0,00	kWh	0,00 %
Mismatch (Manufacturer Information)	-33.113,71	kWh	-1,00 %
Mismatch (Configuration/Shading)	0,00	kWh	0,00 %
PV Energy (DC) without inverter down-regulation	**3.278.257,43**	**kWh**	
Failing to reach the DC start output	-490,37	kWh	-0,01 %
Down-regulation on account of the MPP Voltage Range	-0,01	kWh	0,00 %
Down-regulation on account of the max. DC Current	0,00	kWh	0,00 %
Down-regulation on account of the max. DC Power	0,00	kWh	0,00 %
Down-regulation on account of the max. AC Power/cos phi	0,00	kWh	0,00 %
MPP Matching	-3.277,77	kWh	-0,10 %
PV energy (DC)	**3.274.489,29**	**kWh**	

Energy at the Inverter Input	**3.274.489,29**	**kWh**	
Input voltage deviates from rated voltage	-16.200,41	kWh	-0,49 %
DC/AC Conversion	-66.613,74	kWh	-2,04 %
Standby Consumption (Inverter)	-3.694,00	kWh	-0,12 %
Total Cable Losses	0,00	kWh	0,00 %
PV energy (AC) minus standby use	**3.187.981,14**	**kWh**	
PV Generator Energy (AC grid)	**3.191.675,14**	**kWh**	

	Year 1	Year 2	Year 3	Year 4	Year 5
Investments	-€ 2.259.400,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 472.998,39	€ 468.620,98	€ 456.826,07	€ 448.901,03	€ 443.917,03
Annual Cash Flow	**-€ 1.786.401,61**	**€ 468.620,98**	**€ 456.826,07**	**€ 448.901,03**	**€ 443.917,03**
Accrued Cash Flow (Cash Balance)	-€ 1.786.401,61	-€ 1.317.780,63	-€ 860.954,56	-€ 412.053,53	€ 31.863,50

	Year 6	Year 7	Year 8	Year 9	Year 10
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 441.171,01	€ 440.129,73	€ 440.390,78	€ 441.647,66	€ 443.670,31
Annual Cash Flow	**€ 441.171,01**	**€ 440.129,73**	**€ 440.390,78**	**€ 441.647,66**	**€ 443.670,31**
Accrued Cash Flow (Cash Balance)	€ 473.034,52	€ 913.164,25	€ 1.353.555,03	€ 1.795.202,69	€ 2.238.873,01

	Year 11	Year 12	Year 13	Year 14	Year 15
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 446.282,52	€ 449.352,79	€ 452.780,69	€ 456.490,14	€ 460.423,87
Annual Cash Flow	**€ 446.282,52**	**€ 449.352,79**	**€ 452.780,69**	**€ 456.490,14**	**€ 460.423,87**
Accrued Cash Flow (Cash Balance)	€ 2.685.155,52	€ 3.134.508,31	€ 3.587.288,99	€ 4.043.779,14	€ 4.504.203,01

	Year 16	Year 17	Year 18	Year 19	Year 20
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 464.538,53	€ 468.802,00	€ 473.188,76	€ 477.681,01	€ 482.264,49
Annual Cash Flow	**€ 464.538,53**	**€ 468.802,00**	**€ 473.188,76**	**€ 477.681,01**	**€ 482.264,49**
Accrued Cash Flow (Cash Balance)	€ 4.968.741,54	€ 5.437.543,54	€ 5.910.732,30	€ 6.388.413,31	€ 6.870.677,80

	Year 21	Year 22	Year 23	Year 24	Year 25
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 486.928,68	€ 491.665,98	€ 496.470,71	€ 501.338,00	€ 506.265,33
Annual Cash Flow	**€ 486.928,68**	**€ 491.665,98**	**€ 496.470,71**	**€ 501.338,00**	**€ 506.265,33**
Accrued Cash Flow (Cash Balance)	€ 7.357.606,48	€ 7.849.272,45	€ 8.345.743,16	€ 8.847.081,16	€ 9.353.346,49

Appendix 8: Results SAM for a conventional installation

System Advisor Model Report

Detailed Photovoltaic	2.2 DC MW Nameplate	39.48, -0.47
Commercial	$1.05/W Installed Cost	UTC +1

Performance Model

Modules	
Trina Solar TSM-500DE18M(II)	
Cell material	Mono-c-Si
Module area	2.34 m²
Module capacity	500.33 DC Watts
Quantity	4,395
Total capacity	2.2 DC MW
Total area	10,284 m²

Inverters	
SMA America: STP 33-US-41	
Unit capacity	33.300000 AC kW
Input voltage	330 - 800 VDC DC V
Quantity	40
Total capacity	1.33 AC MW
DC to AC Capacity Ratio	1.65
AC losses (%)	1.00

Array	
Strings	293
Modules per string	15
String Voc (DC V)	775.50
Tilt (deg from horizontal)	30.00
Azimuth (deg E of N)	200
Tracking	no
Backtracking	-
Self shading	no
Rotation limit (deg)	-
Shading	no
Snow	no
Soiling	yes
DC losses (%)	2.97

Performance Adjustments	
Availability/Curtailment	none
Degradation	none
Hourly or custom losses	none

Annual Results (in Year 1)	
GHI kWh/m²/day	4.73
POA kWh/m²/day	159.00
Net to inverter	4,041,000 DC kWh
Net to grid	3,377,000 AC kWh
Capacity factor	17.5
Performance ratio	0.77

Financial Model

Project Costs	
Total installed cost	$2,300,437
Salvage value	$0

Analysis Parameters	
Project life	30 years
Inflation rate	1.5%
Real discount rate	4%

Project Debt Parameters	
Debt fraction	0%
Amount	$0
Term	25 years
Rate	0%

Tax and Insurance Rates	
Federal income tax	0 %/year
State income tax	0 %/year
Sales tax (% of indirect cost basis)	0%
Insurance (% of installed cost)	0 %/year
Property tax (% of assessed val.)	0 %/year

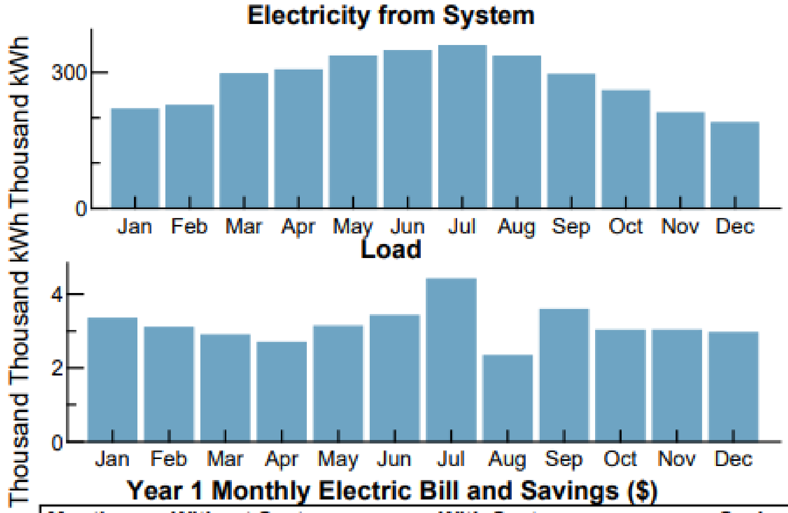
Incentives
None

Electricity Demand and Rate Summary
Annual peak demand 13,272 kW
Annual total demand 37,819,600 kWh
Generic Commercial
Monthly excess with kWh rollover
Annual rate escalation: 2%/year
Tiered TOU energy rates: 6 periods, 1 tier

Results	
Nominal LCOE	6.1 cents/kWh
Net present value	$8,319,200
Payback period	4.3 years

Detailed Photovoltaic | 2.2 DC MW Nameplate | 39.48, -0.47
Commercial | $1.05/W Installed Cost | UTC +1

Year 1 Monthly Generation and Load Summary



Year 1 Monthly Electric Bill and Savings ($)

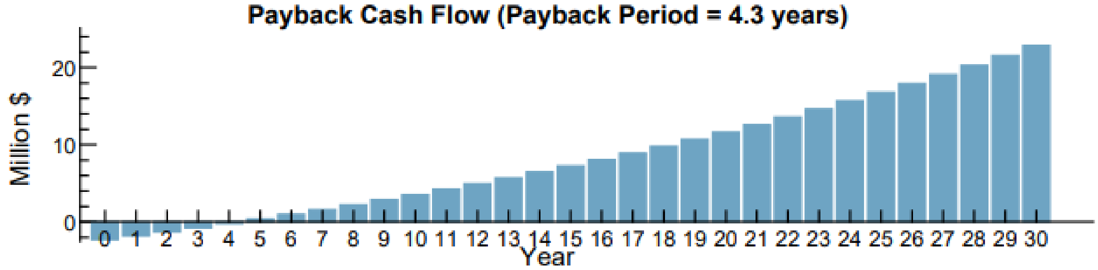
Month	Without System	With System	Savings
Jan	555,727	518,497	37,229
Feb	513,652	475,262	38,389
Mar	437,362	392,524	44,838
Apr	398,618	353,243	45,374
May	464,083	414,160	49,923
Jun	573,030	513,577	59,453
Jul	738,310	676,586	61,723
Aug	345,061	295,353	49,707
Sep	543,982	498,609	45,372
Oct	447,970	409,399	38,570
Nov	457,493	425,759	31,734
Dec	483,682	451,948	31,733
Annual	5,958,974	5,424,922	534,052

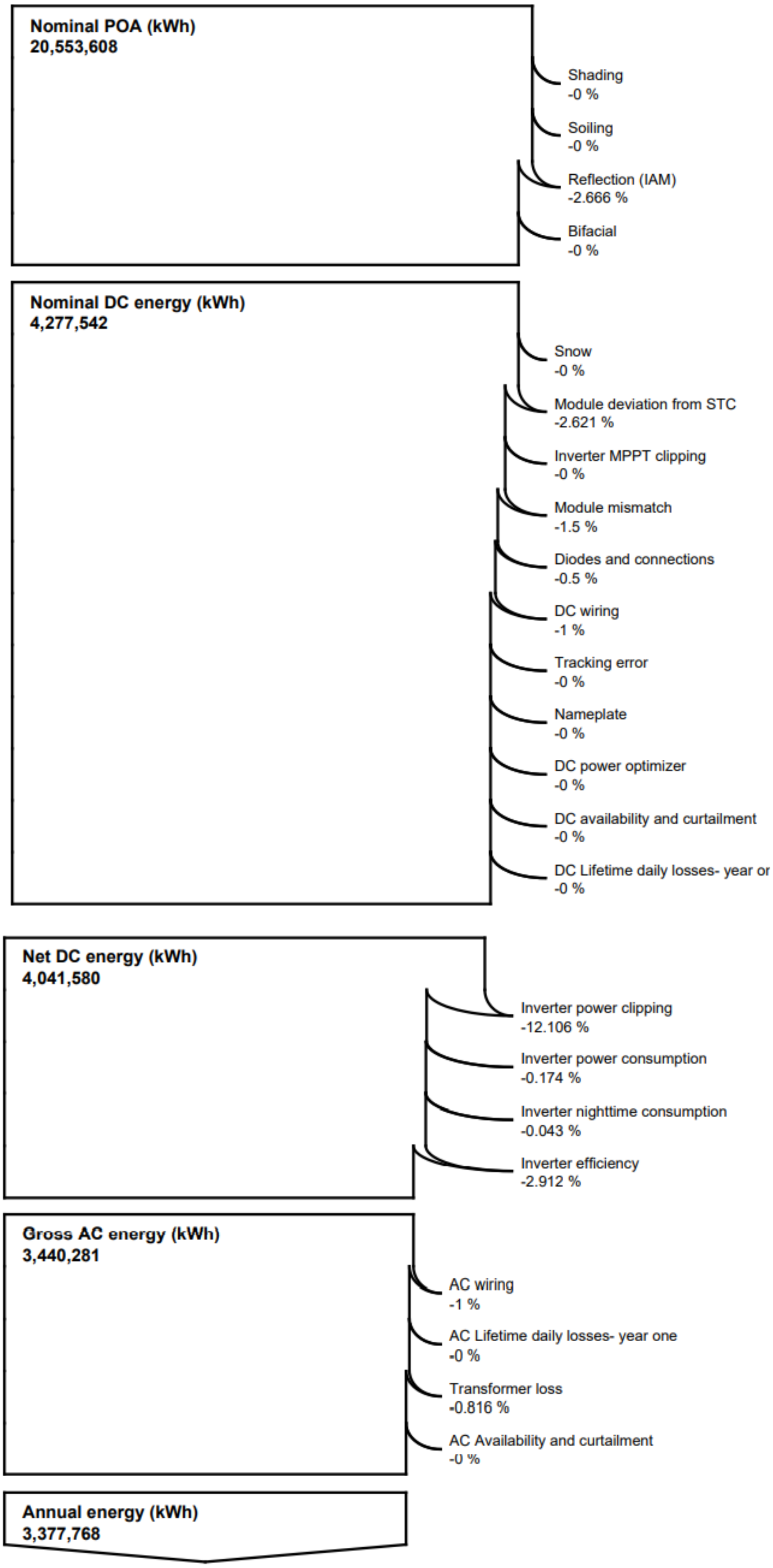
NPV Approximation using Annuities

Annuities, Capital Recovery Factor (CRF) = 0.0693		
Investment	$-159,300	Sum:
Expenses	$-40,700	$576,200
Savings	$0	NPV = Sum / CRF:
Energy value	$776,200	$8,319,000

Investment = Installed Cost - Debt Principal - IBI - CBI
Expenses = Operating Costs + Debt Payments
Savings = Tax Deductions + PBI
Energy value = Tax Adjusted Net Savings
Nominal discount rate = 5.56%

Payback Cash Flow (Payback Period = 4.3 years)



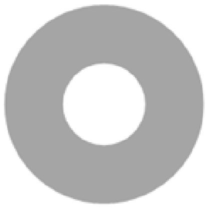

Nominal POA (kWh)
20,553,608
Shading
-0 %
Soiling
-0 %
Reflection (IAM)
-2.666 %
Bifacial
-0 %
Nominal DC energy (kWh)
4,277,542
Snow
-0 %
Module deviation from STC
-2.621 %
Inverter MPPT clipping
-0 %
Module mismatch
-1.5 %
Diodes and connections
-0.5 %
DC wiring
-1 %
Tracking error
-0 %
Nameplate
-0 %
DC power optimizer
-0 %
DC availability and curtailment
-0 %
DC Lifetime daily losses- year or
-0 %
Net DC energy (kWh)
4,041,580
Inverter power clipping
-12.106 %
Inverter power consumption
-0.174 %
Inverter nighttime consumption
-0.043 %
Inverter efficiency
-2.912 %
Gross AC energy (kWh)
3,440,281
AC wiring
-1 %
AC Lifetime daily losses- year one
-0 %
Transformer loss
-0.816 %
AC Availability and curtailment
-0 %
Annual energy (kWh)
3,377,768

Appendix E – Results building 8B,E,H PV-facade installation without north side

Appendix 9: Results PV*SOL Building 8B,E,H Facade installation without north side

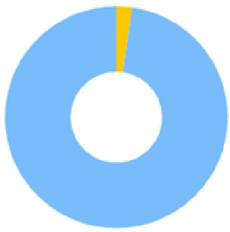
PV System		
PV Generator Output	1.055,00	kWp
Spec. Annual Yield	814,89	kWh/kWp
Performance Ratio (PR)	83,38	%
Yield Reduction due to Shading	7,7	%/Year
PV Generator Energy (AC grid)	860.344	kWh/Year
Own Consumption	860.344	kWh/Year
Down-regulation at Feed-in Point	0	kWh/Year
Grid Feed-in	0	kWh/Year
Own Power Consumption	100,0	%
CO_2 Emissions avoided	404.063	kg / year

PV Generator Energy (AC grid)



Appliances		
Appliances	38.000.000	kWh/Year
Standby Consumption (Inverter)	636	kWh/Year
Total Consumption	38.000.636	kWh/Year
covered by PV power	860.344	kWh/Year
covered by grid	37.140.292	kWh/Year
Solar Fraction	2,3	%

Total Consumption



Building 01-Facade South		
PV Generator Output	195,00	kWp
PV Generator Surface	939,93	m²
Global Radiation at the Module	1170,90	kWh/m²
Global Radiation on Module without reflection	1172,78	kWh/m²
Performance Ratio (PR)	69,14	%
PV Generator Energy (AC grid)	158233,94	kWh/Year
Spec. Annual Yield	811,46	kWh/kWp

Building 01-Facade West		
PV Generator Output	430,00	kWp
PV Generator Surface	2.072,66	m²
Global Radiation at the Module	797,38	kWh/m²
Global Radiation on Module without reflection	798,52	kWh/m²
Performance Ratio (PR)	87,06	%
PV Generator Energy (AC grid)	299108,44	kWh/Year
Spec. Annual Yield	695,60	kWh/kWp

Building 01-Facade East		
PV Generator Output	430,00	kWp
PV Generator Surface	2.072,66	m²
Global Radiation at the Module	1064,67	kWh/m²
Global Radiation on Module without reflection	1065,96	kWh/m²
Performance Ratio (PR)	87,86	%
PV Generator Energy (AC grid)	403001,66	kWh/Year
Spec. Annual Yield	937,21	kWh/kWp

Global radiation - horizontal	**1.613,61**	**kWh/m²**	
Deviation from standard spectrum	-16,14	kWh/m²	-1,00 %
Ground Reflection (Albedo)	159,75	kWh/m²	10,00 %
Orientation and inclination of the module surface	-774,54	kWh/m²	-44,08 %
Module-independent shading	-5,98	kWh/m²	-0,61 %
Reflection on the Module Interface	-1,34	kWh/m²	-0,14 %
Global Radiation at the Module	**975,36**	**kWh/m²**	
	975,36	kWh/m²	
	x 5085,256	m²	
	= 4.959.971,95	kWh	
Global PV Radiation	**4.959.971,95**	**kWh**	
Soiling	0,00	kWh	0,00 %
STC Conversion (Rated Efficiency of Module 20,76 %)	-3.930.280,46	kWh	-79,24 %
Rated PV Energy	**1.029.691,49**	**kWh**	
Module-specific Partial Shading	-62.733,57	kWh	-6,09 %
Low-light performance	-9.335,29	kWh	-0,97 %
Deviation from the nominal module temperature	-18.487,48	kWh	-1,93 %
Diodes	-1.749,97	kWh	-0,19 %
Mismatch (Manufacturer Information)	-18.747,70	kWh	-2,00 %
Mismatch (Configuration/Shading)	-7.459,66	kWh	-0,81 %
PV Energy (DC) without inverter down-regulation	**911.177,81**	**kWh**	
Failing to reach the DC start output	-287,57	kWh	-0,03 %
Down-regulation on account of the MPP Voltage Range	-164,22	kWh	-0,02 %
Down-regulation on account of the max. DC Current	0,00	kWh	0,00 %
Down-regulation on account of the max. DC Power	0,00	kWh	0,00 %
Down-regulation on account of the max. AC Power/cos phi	-3,39	kWh	0,00 %
MPP Matching	-112,89	kWh	-0,01 %
PV energy (DC)	**910.609,74**	**kWh**	

Energy at the Inverter Input	**910.609,74**	**kWh**	
Input voltage deviates from rated voltage	-713,37	kWh	-0,08 %
DC/AC Conversion	-22.943,75	kWh	-2,52 %
Standby Consumption (Inverter)	-635,61	kWh	-0,07 %
Total Cable Losses	-26.608,58	kWh	-3,00 %
PV energy (AC) minus standby use	**859.708,43**	**kWh**	
PV Generator Energy (AC grid)	**860.344,04**	**kWh**	

Financial Analysis

Internal Rate of Return (IRR)	11,89 %
Revenue or Savings	131916,1 €/Year
Accrued Cash Flow (Cash Balance)	2.208.122,80 €

Tech. Quality of the PV System

PV Generator Energy (AC grid)	860.344 kWh/Year
Spec. Annual Yield	814,89 kWh/kWp
Performance Ratio (PR)	83,4 %

System integration

Energy from Grid	37.140.292 kWh/Year	Grid Feed-in	0 kWh/Year

System Data

Grid Feed-in in the first year (incl. module degradation)	0	kWh/Year
PV Generator Output	1055	kWp
Start of Operation of the System	7/10/2021	
Assessment Period	25	Years
Interest on Capital	1	%

Economic Parameters

Internal Rate of Return (IRR)	11,89	%
Accrued Cash Flow (Cash Balance)	2.208.122,80	€
Amortization Period	8,7	Years
Electricity Production Costs	0,0538	€/kWh

Payment Overview

Specific Investment Costs	1.000,00	€/kWp
Investment Costs	1.055.000,00	€
One-off Payments	0,00	€
Incoming Subsidies	0,00	€
Annual Costs	0,00	€/Year
Other Revenue or Savings	0,00	€/Year

Remuneration and Savings

Total Payment from Utility in First Year	0,00	€/Year
First year savings	131.916,13	€/Year

UPV (Example)

Energy Price Tariff period 1	0,1853	€/kWh
Saving Tariff period 1	25.923,03	€/Year
Energy Price Tariff period 2	0,1729	€/kWh
Saving Tariff period 2	15.630,89	€/Year
Energy Price Tariff period 3	0,1585	€/kWh
Saving Tariff period 3	7.369,68	€/Year
Energy Price Tariff period 4	0,1513	€/kWh
Saving Tariff period 4	14.022,83	€/Year
Energy Price Tariff period 5	0,1488	€/kWh
Saving Tariff period 5	23.809,00	€/Year
Energy Price Tariff period 6	0,1482	€/kWh
Saving Tariff period 6	48.938,77	€/Year
Inflation Rate for Energy Price	2	%/Year

	Year 1	Year 2	Year 3	Year 4	Year 5
Investments	-€ 1.055.000,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 129.080,31	€ 126.063,58	€ 122.888,66	€ 120.755,23	€ 119.413,31
Annual Cash Flow	**-€ 925.919,69**	**€ 126.063,58**	**€ 122.888,66**	**€ 120.755,23**	**€ 119.413,31**
Accrued Cash Flow (Cash Balance)	-€ 925.919,69	-€ 799.856,11	-€ 676.967,45	-€ 556.212,22	-€ 436.798,91

	Year 6	Year 7	Year 8	Year 9	Year 10
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 118.673,70	€ 118.392,88	€ 118.462,55	€ 118.800,22	€ 119.343,97
Annual Cash Flow	**€ 118.673,70**	**€ 118.392,88**	**€ 118.462,55**	**€ 118.800,22**	**€ 119.343,97**
Accrued Cash Flow (Cash Balance)	-€ 318.125,21	-€ 199.732,34	-€ 81.269,79	€ 37.530,43	€ 156.874,40

	Year 11	Year 12	Year 13	Year 14	Year 15
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 120.046,39	€ 120.872,08	€ 121.794,02	€ 122.791,72	€ 123.849,78
Annual Cash Flow	**€ 120.046,39**	**€ 120.872,08**	**€ 121.794,02**	**€ 122.791,72**	**€ 123.849,78**
Accrued Cash Flow (Cash Balance)	€ 276.920,79	€ 397.792,88	€ 519.586,89	€ 642.378,62	€ 766.228,40

	Year 16	Year 17	Year 18	Year 19	Year 20
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 124.956,52	€ 126.103,31	€ 127.283,27	€ 128.491,61	€ 129.724,51
Annual Cash Flow	**€ 124.956,52**	**€ 126.103,31**	**€ 127.283,27**	**€ 128.491,61**	**€ 129.724,51**
Accrued Cash Flow (Cash Balance)	€ 891.184,92	€ 1.017.288,22	€ 1.144.571,49	€ 1.273.063,11	€ 1.402.787,61

	Year 21	Year 22	Year 23	Year 24	Year 25
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 130.979,11	€ 132.253,39	€ 133.545,81	€ 134.855,05	€ 136.180,45
Annual Cash Flow	**€ 130.979,11**	**€ 132.253,39**	**€ 133.545,81**	**€ 134.855,05**	**€ 136.180,45**
Accrued Cash Flow (Cash Balance)	€ 1.533.766,72	€ 1.666.020,11	€ 1.799.565,92	€ 1.934.420,97	€ 2.070.601,42

Appendix 10: Results SAM building 8B,E,H facade installation without north

System Advisor Model Report

Detailed Photovoltaic	1.1 DC MW Nameplate	39.48, -0.47
Commercial	$0.99/W Installed Cost	UTC +1

Performance Model

Modules	
Trina Solar TSM-500DE18M(II)	
Cell material	Mono-c-Si
Module area	2.34 m²
Module capacity	500.33 DC Watts
Quantity	2,100
Total capacity	1.05 DC MW
Total area	4,914 m²

Inverters	
SMA America: STP 33-US-41	
Unit capacity	33.300000 AC kW
Input voltage	330 - 800 VDC DC V
Quantity	9
Total capacity	299.7 AC kW
DC to AC Capacity Ratio	3.51
AC losses (%)	1.00

Three subarrays:	**1**	**2**	**4**
Strings	26	57	57
Modules per string	15	15	15
String Voc (DC V)	775.50	775.50	775.50
Tilt (deg from horizontal)	90.00	90.00	90.00
Azimuth (deg E of N)	200	110	290
Tracking	no	no	no
Backtracking	-	-	-
Self shading	no	no	no
Rotation limit (deg)	-	-	-
Shading	yes	yes	yes
Snow	no	no	no
Soiling	yes	yes	yes
DC losses (%)	2.97	2.97	2.97

Performance Adjustments	
Availability/Curtailment	none
Degradation	none
Hourly or custom losses	none

Annual Results (in Year 1)			
GHI kWh/m²/day	4.73	4.73	4.73
POA kWh/m²/day	99.00	88.00	64.00
Net to inverter	985,000 DC kWh		
Net to grid	878,000 AC kWh		
Capacity factor	9.5		
Performance ratio	0.79		

Financial Model

Project Costs	
Total installed cost	$1,045,076
Salvage value	$0

Analysis Parameters	
Project life	30 years
Inflation rate	1.5%
Real discount rate	4%

Project Debt Parameters	
Debt fraction	0%
Amount	$0
Term	25 years
Rate	0%

Tax and Insurance Rates	
Federal income tax	0 %/year
State income tax	0 %/year
Sales tax (% of indirect cost basis)	0%
Insurance (% of installed cost)	0 %/year
Property tax (% of assessed val.)	0 %/year

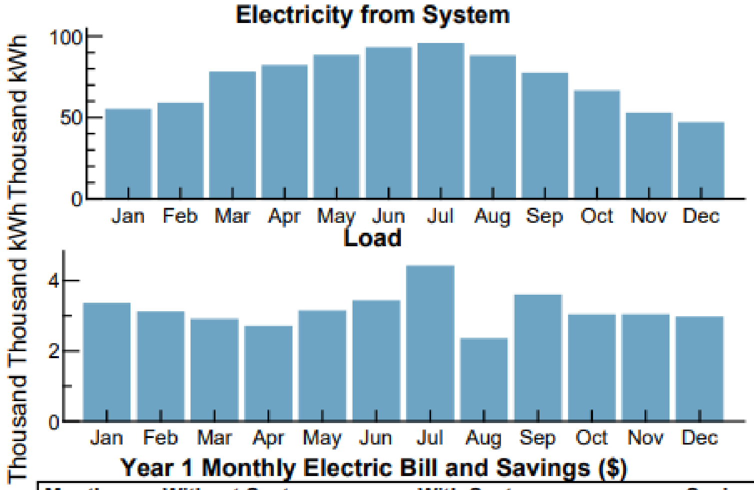
Incentives
None

Electricity Demand and Rate Summary
Annual peak demand 13,272 kW
Annual total demand 37,819,600 kWh
Generic Commercial
Monthly excess with kWh rollover
Annual rate escalation: 2%/year
Tiered TOU energy rates: 6 periods, 1 tier

Results	
Nominal LCOE	10.7 cents/kWh
Net present value	$1,577,000
Payback period	7.6 years

Detailed Photovoltaic	1.1 DC MW Nameplate	39.48, -0.47
Commercial	$0.99/W Installed Cost	UTC +1

Year 1 Monthly Generation and Load Summary



Year 1 Monthly Electric Bill and Savings ($)

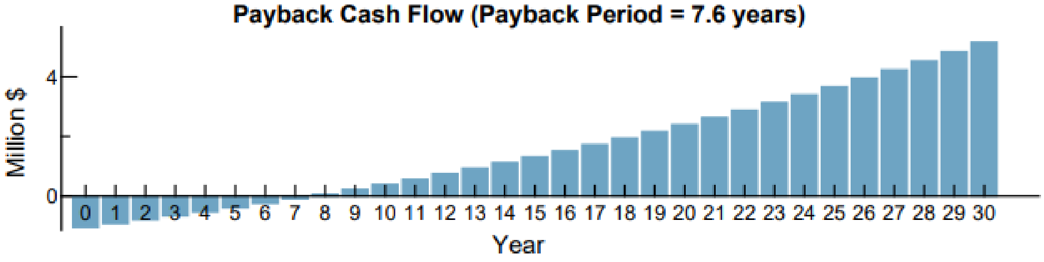
Month	Without System	With System	Savings
Jan	555,727	546,388	9,338
Feb	513,652	503,749	9,903
Mar	437,362	425,600	11,761
Apr	398,618	386,484	12,133
May	464,083	451,019	13,064
Jun	573,030	557,299	15,731
Jul	738,310	722,068	16,241
Aug	345,061	332,068	12,992
Sep	543,982	532,171	11,810
Oct	447,970	438,152	9,817
Nov	457,493	449,582	7,910
Dec	483,682	475,796	7,885
Annual	5,958,974	5,820,383	138,590

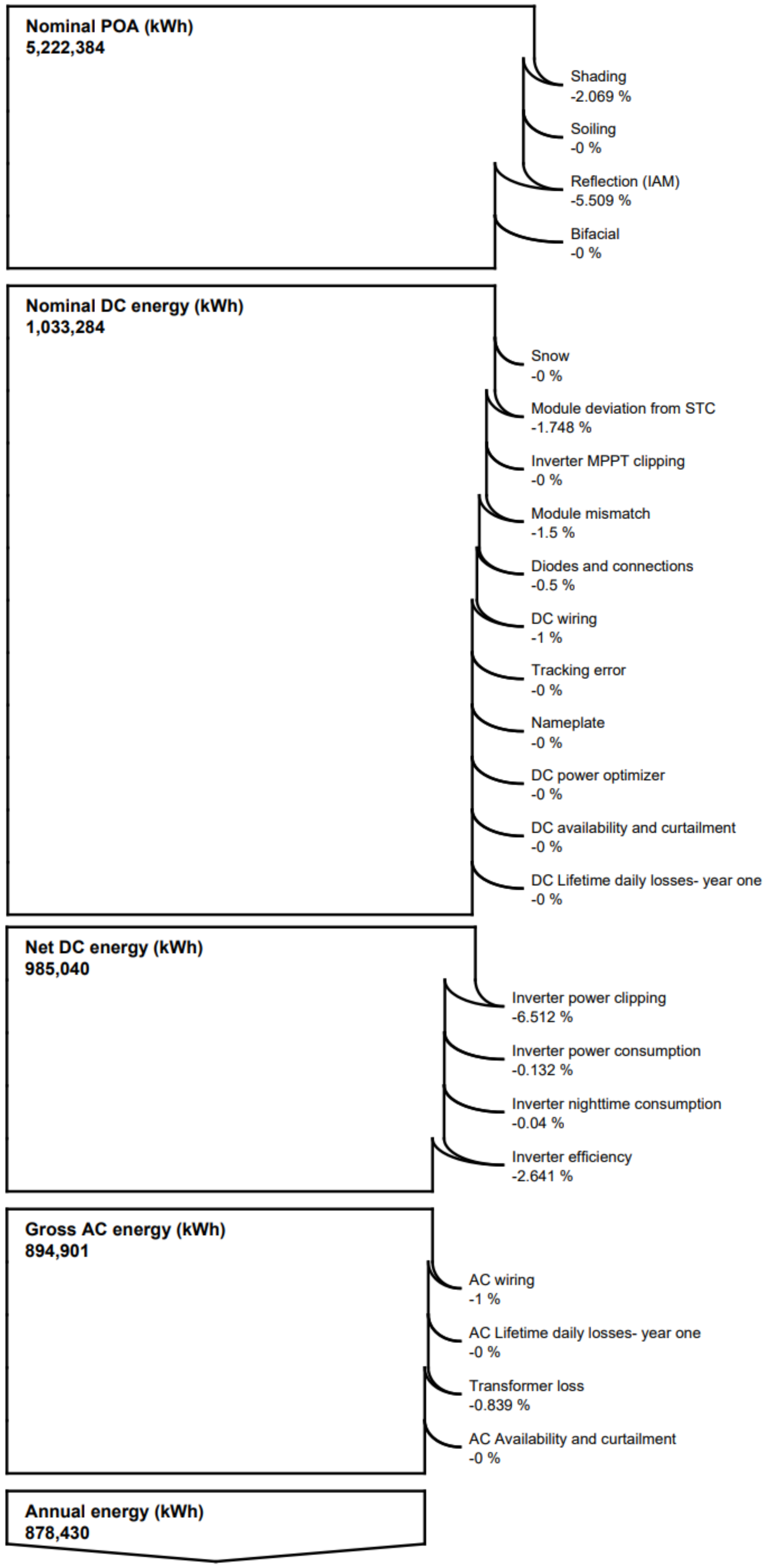
NPV Approximation using Annuities

Annuities, Capital Recovery Factor (CRF) = 0.0693		
Investment	$-72,300	Sum:
Expenses	$-18,400	$109,200
Savings	$0	NPV = Sum / CRF:
Energy value	$200,100	$1,577,000

Investment = Installed Cost - Debt Principal - IBI - CBI
Expenses = Operating Costs + Debt Payments
Savings = Tax Deductions + PBI
Energy value = Tax Adjusted Net Savings
Nominal discount rate = 5.56%

Payback Cash Flow (Payback Period = 7.6 years)

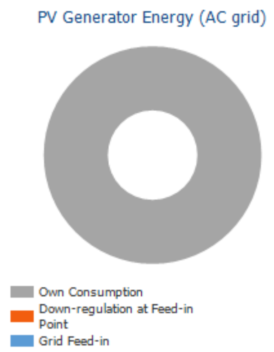



Nominal POA (kWh)
5,222,384
Shading
-2.069 %
Soiling
-0 %
Reflection (IAM)
-5.509 %
Bifacial
-0 %
Nominal DC energy (kWh)
1,033,284
Snow
-0 %
Module deviation from STC
-1.748 %
Inverter MPPT clipping
-0 %
Module mismatch
-1.5 %
Diodes and connections
-0.5 %
DC wiring
-1 %
Tracking error
-0 %
Nameplate
-0 %
DC power optimizer
-0 %
DC availability and curtailment
-0 %
DC Lifetime daily losses- year one
-0 %
Net DC energy (kWh)
985,040
Inverter power clipping
-6.512 %
Inverter power consumption
-0.132 %
Inverter nighttime consumption
-0.04 %
Inverter efficiency
-2.641 %
Gross AC energy (kWh)
894,901
AC wiring
-1 %
AC Lifetime daily losses- year one
-0 %
Transformer loss
-0.839 %
AC Availability and curtailment
-0 %
Annual energy (kWh)
878,430

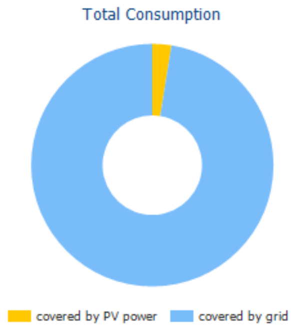
Appendix F – Results building 8B,E,H PV-facade installation without shadow

Appendix 11: Results PV*SOL building 8B,E,H facade installation without shadow

PV System		
PV Generator Output	1.250,00	kWp
Spec. Annual Yield	804,92	kWh/kWp
Performance Ratio (PR)	88,86	%
Yield Reduction due to Shading	0,9	%/Year
PV Generator Energy (AC grid)	1.006.908	kWh/Year
Own Consumption	1.006.908	kWh/Year
Down-regulation at Feed-in Point	0	kWh/Year
Grid Feed-in	0	kWh/Year
Own Power Consumption	100,0	%
CO_2 Emissions avoided	472.893	kg / year



Appliances		
Appliances	39.815.288	kWh/Year
Standby Consumption (Inverter)	752	kWh/Year
Total Consumption	39.816.040	kWh/Year
covered by PV power	1.006.908	kWh/Year
covered by grid	38.809.132	kWh/Year
Solar Fraction	2,5	%



Financial Analysis	
Internal Rate of Return (IRR)	11,73 %
Revenue or Savings	154414,4 €/Year
Accrued Cash Flow (Cash Balance)	2.569.681,95 €

Tech. Quality of the PV System	
PV Generator Energy (AC grid)	1.006.908 kWh/Year
Spec. Annual Yield	804,92 kWh/kWp
Performance Ratio (PR)	88,9 %

System integration			
Energy from Grid	38.809.132 kWh/Year	Grid Feed-in	0 kWh/Year

Building 01-Facade South		
PV Generator Output	195,00	kWp
PV Generator Surface	939,93	m²
Global Radiation at the Module	1203,23	kWh/m²
Global Radiation on Module without reflection	1205,15	kWh/m²
Performance Ratio (PR)	89,90	%
PV Generator Energy (AC grid)	211393,77	kWh/Year
Spec. Annual Yield	1084,07	kWh/kWp

Building 01-Facade West		
PV Generator Output	430,00	kWp
PV Generator Surface	2.072,66	m²
Global Radiation at the Module	797,38	kWh/m²
Global Radiation on Module without reflection	798,52	kWh/m²
Performance Ratio (PR)	87,11	%
PV Generator Energy (AC grid)	299304,82	kWh/Year
Spec. Annual Yield	696,06	kWh/kWp

Building 01-Facade North		
PV Generator Output	195,00	kWp
PV Generator Surface	939,93	m²
Global Radiation at the Module	485,12	kWh/m²
Global Radiation on Module without reflection	485,95	kWh/m²
Performance Ratio (PR)	88,09	%
PV Generator Energy (AC grid)	83541,43	kWh/Year
Spec. Annual Yield	428,42	kWh/kWp

Building 01-Facade East		
PV Generator Output	430,00	kWp
PV Generator Surface	2.072,66	m²
Global Radiation at the Module	1064,67	kWh/m²
Global Radiation on Module without reflection	1065,96	kWh/m²
Performance Ratio (PR)	89,97	%
PV Generator Energy (AC grid)	412667,87	kWh/Year
Spec. Annual Yield	959,69	kWh/kWp

Global radiation - horizontal	**1.613,61**	**kWh/m²**	
Deviation from standard spectrum	-16,14	kWh/m²	-1,00 %
Ground Reflection (Albedo)	159,75	kWh/m²	10,00 %
Orientation and inclination of the module surface	-852,03	kWh/m²	-48,49 %
Module-independent shading	0,00	kWh/m²	0,00 %
Reflection on the Module Interface	-1,26	kWh/m²	-0,14 %
Global Radiation at the Module	**903,93**	**kWh/m²**	
	903,93	kWh/m²	
	x 6025,185	m²	
	= 5.446.345,71	kWh	
Global PV Radiation	**5.446.345,71**	**kWh**	
Soiling	0,00	kWh	0,00 %
STC Conversion (Rated Efficiency of Module 20,76 %)	-4.315.682,90	kWh	-79,24 %
Rated PV Energy	**1.130.662,81**	**kWh**	
Module-specific Partial Shading	-8.971,84	kWh	-0,79 %
Low-light performance	-12.571,63	kWh	-1,12 %
Deviation from the nominal module temperature	-19.697,54	kWh	-1,78 %
Diodes	-499,93	kWh	-0,05 %
Mismatch (Manufacturer Information)	-21.778,44	kWh	-2,00 %
Mismatch (Configuration/Shading)	-602,64	kWh	-0,06 %
PV Energy (DC) without inverter down-regulation	**1.066.540,79**	**kWh**	
Failing to reach the DC start output	-331,58	kWh	-0,03 %
Down-regulation on account of the MPP Voltage Range	-38,97	kWh	0,00 %
Down-regulation on account of the max. DC Current	0,00	kWh	0,00 %
Down-regulation on account of the max. DC Power	0,00	kWh	0,00 %
Down-regulation on account of the max. AC Power/cos phi	-6,28	kWh	0,00 %
MPP Matching	-139,78	kWh	-0,01 %
PV energy (DC)	**1.066.024,17**	**kWh**	

Energy at the Inverter Input	**1.066.024,17**	**kWh**	
Input voltage deviates from rated voltage	-656,45	kWh	-0,06 %
DC/AC Conversion	-27.318,35	kWh	-2,56 %
Standby Consumption (Inverter)	-752,31	kWh	-0,07 %
Total Cable Losses	-31.141,48	kWh	-3,00 %
PV energy (AC) minus standby use	**1.006.155,58**	**kWh**	
PV Generator Energy (AC grid)	**1.006.907,89**	**kWh**	

System Data		
Grid Feed-in in the first year (incl. module degradation)	0	kWh/Year
PV Generator Output	1250	kWp
Start of Operation of the System	7/10/2021	
Assessment Period	25	Years
Interest on Capital	1	%

Economic Parameters		
Internal Rate of Return (IRR)	11,73	%
Accrued Cash Flow (Cash Balance)	2.569.681,95	€
Amortization Period	8,8	Years
Electricity Production Costs	0,0545	€/kWh

Payment Overview		
Specific Investment Costs	1.000,00	€/kWp
Investment Costs	1.250.000,00	€
One-off Payments	0,00	€
Incoming Subsidies	0,00	€
Annual Costs	0,00	€/Year
Other Revenue or Savings	0,00	€/Year

Remuneration and Savings		
Total Payment from Utility in First Year	0,00	€/Year
First year savings	154.414,38	€/Year
UPV (Example)		
Energy Price Tariff period 1	0,1853	€/kWh
Saving Tariff period 1	29.531,24	€/Year
Energy Price Tariff period 2	0,1729	€/kWh
Saving Tariff period 2	19.766,26	€/Year
Energy Price Tariff period 3	0,1585	€/kWh
Saving Tariff period 3	8.459,86	€/Year
Energy Price Tariff period 4	0,1513	€/kWh
Saving Tariff period 4	16.544,56	€/Year
Energy Price Tariff period 5	0,1488	€/kWh
Saving Tariff period 5	27.112,61	€/Year
Energy Price Tariff period 6	0,1482	€/kWh
Saving Tariff period 6	57.432,16	€/Year
Inflation Rate for Energy Price	2	%/Year

	Year 1	Year 2	Year 3	Year 4	Year 5
Investments	-€ 1.250.000,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 150.930,93	€ 147.565,65	€ 143.850,77	€ 141.354,65	€ 139.784,78
Annual Cash Flow	**-€ 1.099.069,07**	**€ 147.565,65**	**€ 143.850,77**	**€ 141.354,65**	**€ 139.784,78**
Accrued Cash Flow (Cash Balance)	-€ 1.099.069,07	-€ 951.503,42	-€ 807.652,65	-€ 666.298,00	-€ 526.513,23

	Year 6	Year 7	Year 8	Year 9	Year 10
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 138.919,73	€ 138.591,57	€ 138.673,56	€ 139.069,18	€ 139.705,96
Annual Cash Flow	**€ 138.919,73**	**€ 138.591,57**	**€ 138.673,56**	**€ 139.069,18**	**€ 139.705,96**
Accrued Cash Flow (Cash Balance)	-€ 387.593,50	-€ 249.001,93	-€ 110.328,36	€ 28.740,81	€ 168.446,78

	Year 11	Year 12	Year 13	Year 14	Year 15
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 140.528,42	€ 141.495,14	€ 142.574,48	€ 143.742,50	€ 144.981,15
Annual Cash Flow	**€ 140.528,42**	**€ 141.495,14**	**€ 142.574,48**	**€ 143.742,50**	**€ 144.981,15**
Accrued Cash Flow (Cash Balance)	€ 308.975,20	€ 450.470,33	€ 593.044,81	€ 736.787,31	€ 881.768,46

	Year 16	Year 17	Year 18	Year 19	Year 20
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 146.276,77	€ 147.619,26	€ 149.000,58	€ 150.415,11	€ 151.858,38
Annual Cash Flow	**€ 146.276,77**	**€ 147.619,26**	**€ 149.000,58**	**€ 150.415,11**	**€ 151.858,38**
Accrued Cash Flow (Cash Balance)	€ 1.028.045,23	€ 1.175.664,49	€ 1.324.665,07	€ 1.475.080,18	€ 1.626.938,56

	Year 21	Year 22	Year 23	Year 24	Year 25
Investments	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Electricity Savings	€ 153.327,06	€ 154.818,77	€ 156.331,71	€ 157.864,35	€ 159.415,89
Annual Cash Flow	**€ 153.327,06**	**€ 154.818,77**	**€ 156.331,71**	**€ 157.864,35**	**€ 159.415,89**
Accrued Cash Flow (Cash Balance)	€ 1.780.265,62	€ 1.935.084,39	€ 2.091.416,10	€ 2.249.280,45	€ 2.408.696,34

Appendix 12: Results SAM building 8B,E,H facade installation without shadow

System Advisor Model Report

Detailed Photovoltaic	1.2 DC MW Nameplate	39.48, -0.47
Commercial	$1.00/W Installed Cost	UTC +1

Performance Model

Modules	
Trina Solar TSM-500DE18M(II)	
Cell material	Mono-c-Si
Module area	2.34 m²
Module capacity	500.33 DC Watts
Quantity	2,490
Total capacity	1.25 DC MW
Total area	5,826 m²

Inverters	
SMA America: STP 33-US-41	
Unit capacity	33.300000 AC kW
Input voltage	330 - 800 VDC DC V
Quantity	13
Total capacity	432.9 AC kW
DC to AC Capacity Ratio	2.88
AC losses (%)	1.00

Four subarrays:	**1**	**2**	**3**	**4**
Strings	26	57	26	57
Modules per string	15	15	15	15
String Voc (DC V)	775.50	775.50	775.50	775.50
Tilt (deg from horizontal)	90.00	90.00	90.00	90.00
Azimuth (deg E of N)	20	110	200	290
Tracking	no	no	no	no
Backtracking	-	-	-	-
Self shading	no	no	no	no
Rotation limit (deg)	-	-	-	-
Shading	no	no	no	no
Snow	no	no	no	no
Soiling	yes	yes	yes	yes
DC losses (%)	2.97	2.97	2.97	2.97

Performance Adjustments	
Availability/Curtailment	none
Degradation	none
Hourly or custom losses	none

Annual Results (in Year 1)				
GHI kWh/m²/day	4.73	4.73	4.73	4.73
POA kWh/m²/day	40.00	89.00	105.00	64.00
Net to inverter	1,096,000 DC kWh			
Net to grid	1,049,000 AC kWh			
Capacity factor	9.6			
Performance ratio	0.86			

Financial Model

Project Costs	
Total installed cost	$1,251,621
Salvage value	$0

Analysis Parameters	
Project life	30 years
Inflation rate	1.5%
Real discount rate	4%

Project Debt Parameters	
Debt fraction	0%
Amount	$0
Term	25 years
Rate	0%

Tax and Insurance Rates	
Federal income tax	0 %/year
State income tax	0 %/year
Sales tax (% of indirect cost basis)	0%
Insurance (% of installed cost)	0 %/year
Property tax (% of assessed val.)	0 %/year

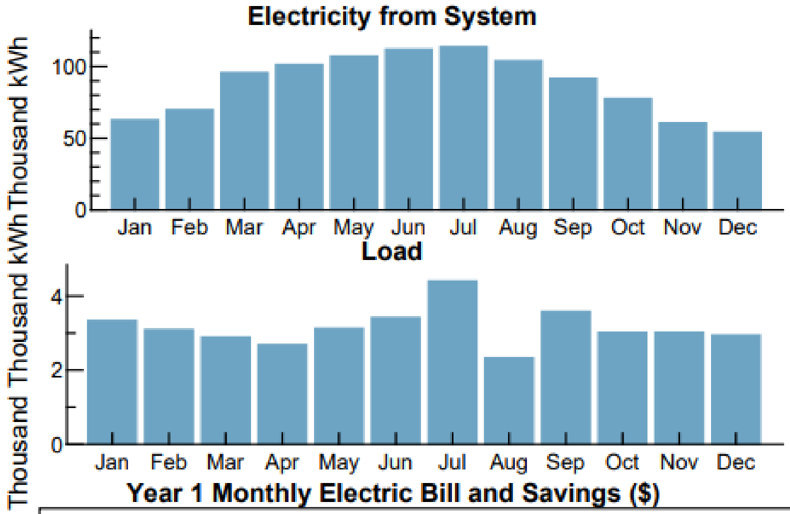
Incentives
None

Electricity Demand and Rate Summary
Annual peak demand 13,272 kW
Annual total demand 37,819,600 kWh
Generic Commercial
Monthly excess with kWh rollover
Annual rate escalation: 2%/year
Tiered TOU energy rates: 6 periods, 1 tier

Results	
Nominal LCOE	10.9 cents/kWh
Net present value	$1,796,400
Payback period	7.7 years

Detailed Photovoltaic	1.2 DC MW Nameplate	39.48, -0.47
Commercial	$1.00/W Installed Cost	UTC +1

Year 1 Monthly Generation and Load Summary



Year 1 Monthly Electric Bill and Savings ($)

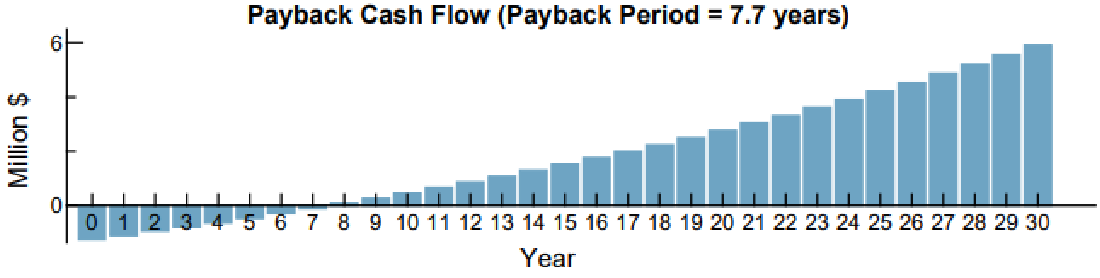
Month	Without System	With System	Savings
Jan	555,727	545,016	10,710
Feb	513,652	501,807	11,845
Mar	437,362	422,892	14,469
Apr	398,618	383,576	15,042
May	464,083	448,165	15,918
Jun	573,030	554,050	18,980
Jul	738,310	718,944	19,365
Aug	345,061	329,665	15,395
Sep	543,982	529,952	14,029
Oct	447,970	436,457	11,513
Nov	457,493	448,349	9,143
Dec	483,682	474,578	9,103
Annual	5,958,974	5,793,456	165,517

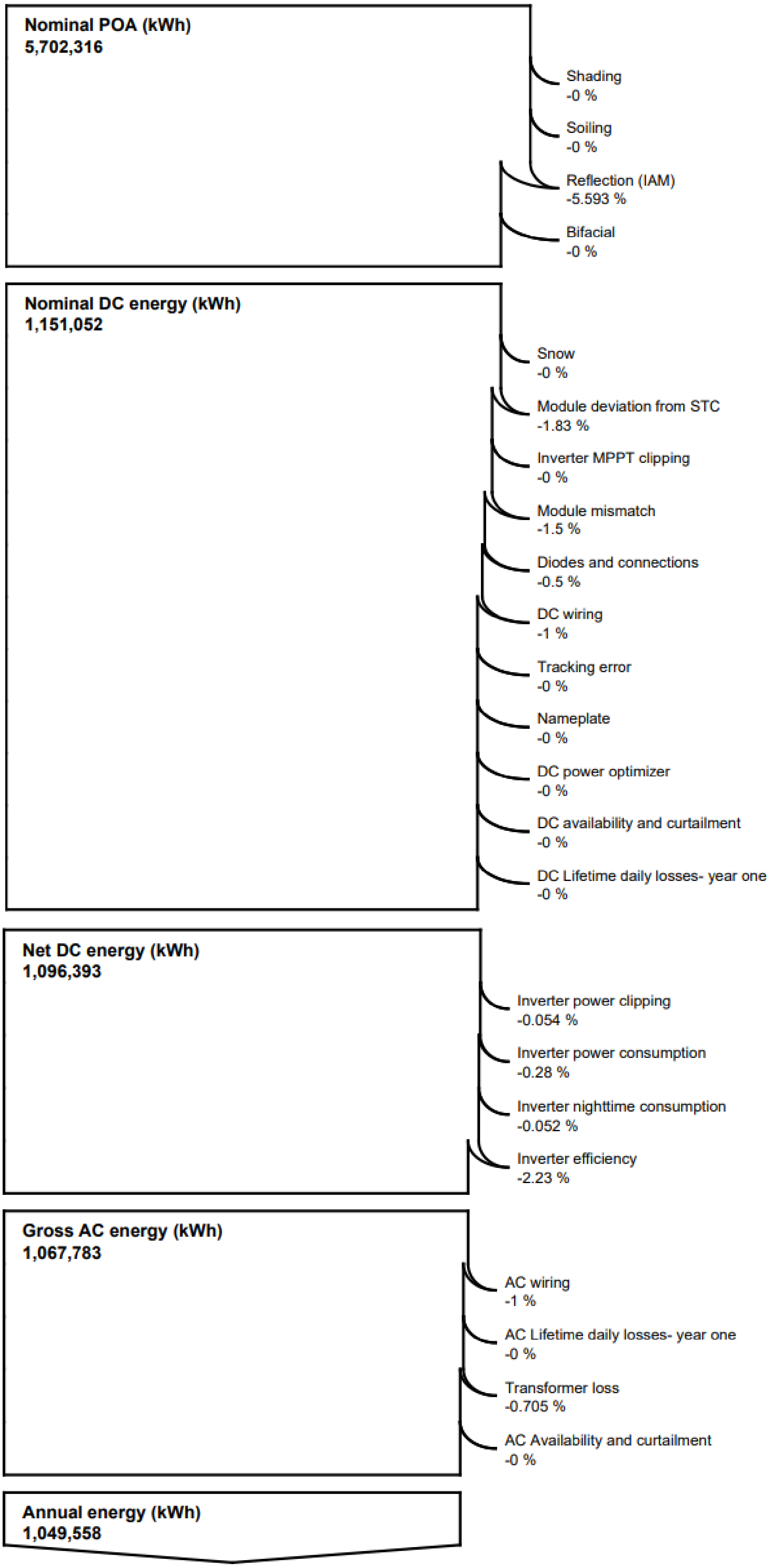
NPV Approximation using Annuities

Annuities, Capital Recovery Factor (CRF) = 0.0693		
Investment	$-86,600	Sum:
Expenses	$-21,900	$124,400
Savings	$0	NPV = Sum / CRF:
Energy value	$233,100	$1,796,000

Investment = Installed Cost - Debt Principal - IBI - CBI
Expenses = Operating Costs + Debt Payments
Savings = Tax Deductions + PBI
Energy value = Tax Adjusted Net Savings
Nominal discount rate = 5.56%

Payback Cash Flow (Payback Period = 7.7 years)




Nominal POA (kWh)
5,702,316
Shading
-0 %
Soiling
-0 %
Reflection (IAM)
-5.593 %
Bifacial
-0 %
Nominal DC energy (kWh)
1,151,052
Snow
-0 %
Module deviation from STC
-1.83 %
Inverter MPPT clipping
-0 %
Module mismatch
-1.5 %
Diodes and connections
-0.5 %
DC wiring
-1 %
Tracking error
-0 %
Nameplate
-0 %
DC power optimizer
-0 %
DC availability and curtailment
-0 %
DC Lifetime daily losses- year one
-0 %
Net DC energy (kWh)
1,096,393
Inverter power clipping
-0.054 %
Inverter power consumption
-0.28 %
Inverter nighttime consumption
-0.052 %
Inverter efficiency
-2.23 %
Gross AC energy (kWh)
1,067,783
AC wiring
-1 %
AC Lifetime daily losses- year one
-0 %
Transformer loss
-0.705 %
AC Availability and curtailment
-0 %
Annual energy (kWh)
1,049,558

Appendix G – The average annual geographical irradiation potential

Appendix 13: The average annual geographical irradiation potential [14]

No	Country	Capital	Average annual radiation (kWh/sq.m.)				
			Roof	South	East	West	North
1	Austria	Vienna	1225	1004	702	736	294
2	Belgium	Brussels	1073	902	649	656	295
3	Bulgaria	Sofia	1352	1042	797	743	332
4	Croatia	Zagreb	1312	1031	734	773	301
5	Cyprus	Nikosia	1928	1330	1044	1040	348
6	Czechia	Prague	1132	935	672	680	293
7	Denmark	Copenhagen	1051	926	634	664	271
8	Estonia	Tallinn	932	830	571	601	252
9	Finland	Helsinki	926	836	552	600	240
10	France	Paris	1174	975	712	667	302
11	Germany	Berlin	1079	922	661	652	288
12	Greece	Athens	1819	1286	990	997	338
13	Hungary	Budapest	1309	1069	756	762	302
14	Ireland	Dublin	975	862	613	597	291
15	Italy	Rome	1640	1262	937	846	309
16	Latvia	Riga	980	858	601	616	265
17	Lithuania	Vilnius	986	829	598	596	270
18	Luxembourg	Luxemburg	1121	900	677	681	300
19	Malta	Valleta	1875	1281	986	1056	341
20	Netherlands	Amsterdam	1065	902	636	675	291
21	Poland	Warsaw	1087	912	658	654	281
22	Portugal	Lisbon	1751	1277	953	1029	339
23	Romania	Bucharest	1406	1071	761	805	305
24	Slovakia	Bratislava	1253	1018	720	735	291
25	Slovenia	Ljubljana	1249	958	613	752	292
26	Spain	Madrid	1788	1401	1035	1015	321
27	Sweden	Stockholm	961	886	608	632	263
28	UK	London	1046	900	645	639	300
29	Norway	Oslo	911	865	568	594	245
30	Switzerland	Bern	1252	1045	754	735	302

Appendix H – Quotation Endesa for 2021

Appendix 14: Quotation Endesa for 2021

CONSUMO PREVISTO 2021 kWh							
SUMINISTRO	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**TOTAL**
Vera	5.175.000	5.200.000	3.150.000	4.425.000	5.625.000	14.425.000	**38.000.000**
Gandía 1 La Rábida	194.000	186.000	102.000	130.000	160.000	278.000	**1.050.000**
Gandía Biblioteca	78.000	72.000	35.000	45.000	60.000	120.000	**410.000**
Carbonell	195.000	295.000	140.000				**630.000**
Ferrandiz	65.000	95.000	50.000				**210.000**
Viaducte	12.500	14.500	6.000				**33.000**
Complejo Deportivo	115.000	180.000	70.000				**365.000**
Molino de Vera	13.250	37.500	23.250				**74.000**
Gandía Deportes	5.100	1.080	20				**6.200**
Portal Nuevo	0						**0**

Tarifa 6.1	**Potencia contratada Pci (kW)**	**Termino Potencia Tpi (€/kW)**	**Consumo Energía Qi (kWh)**	**Precio OMIP**
P1	11.830	39,139427	5.447.000	4,205
P2	11.830	19,586654	5.458.000	
P3	11.830	14,334178	3.287.000	
P4	11.830	14,334178	4.600.000	
P5	11.830	14,334178	5.845.000	
P6	11.830	6,540177	14.823.000	
TOTAL			39.460.000	

ENDESA	**Tarifa 6.1**	Ai (c€/kWh)	Bi	Pm (€/kWh)
	P1	3,6897	1,088	0,098398
	P2	2,6556	1,094	
	P3	1,6449	1,082	
	P4	1,0706	1,0830	
	P5	0,8979	1,08	
	P6	0,7023	1,095	
	Tarifa 3.1	Término Energía TQi (€/kWh)	Total (€)	Pm (€/kWh)
	P1	0,083069	67.693,32	0,133174
	P2	0,076561	66.644,32	
	P3	0,056103	22.512,93	
	Tarifa 3.0A	Término Energía TQi (€/kWh)	Total (€)	Pm (€/kWh)
	Punta	0,094056	3.265,48	0,121265
	Llano	0,081343	4.061,94	
	Valle	0,05626	1.924,99	
	Tarifa 2.0A	Término Energía TQi (€/kWh)	Total (€)	Pm (€/kWh)
	P1	0,111456	83,70	0
	Pm final (€/kWh)			**0,099499**

Appendix I – Quotation Formulas

Appendix 15: Quotation formulas

OFERTA ECONÓMICA Precio indexado al mercado OMIE	$Am=\left(\frac{\Sigma(Ai * Qi)}{\Sigma Qi}\right)$ $Bm=\left(\frac{\Sigma(Bi * Qi)}{\Sigma Qi}\right)$ TQm=(Am+Bm*OMIP)/100 $Pm\ 6.1=\left(\frac{(\Sigma(Pci * TPi)+(\Sigma Qi * TQm))}{\Sigma Qi}\right)*1{,}051127$									
Tarifa 6.1	**POTENCIA CONTRATADA Pci (kW)**	**TERMINO POTENCIA TPi (€/kW)**	**CONSUMO ENERGÍA Qi (kWH)**	**PRECIO OMIP (cts€/kWh)**	**Ai (cts€/kWh)**	**Bi**	**Am**	**Bm**	**TERMINO ENERGÍA TQm €/kWh**	**Pm 6.1 €/kWh**
P1	11.830	39,139427	5.447.000	4,205						
P2	11.830	19,586654	5.458.000							
P3	11.830	14,334178	3.287.000							
P4	11.830	14,334178	4.600.000							
P5	11.830	14,334178	5.845.000							
P6	11.830	6,540177	14.823.000							
TOTAL	**-**	**-**	**39.460.000 Q(6.1)**			**-**				

Appendix J – Data sheets

Appendix 16: SMA SUNNY TRIPOWER CORE1 STP 50-40

SUNNY TRIPOWER CORE1
STP 50-40

Cost-Effective
- Floor-mounted device easy to install
- No DC fuses required
- Integrated DC disconnector

Highly Integrated
- Integrated Wi-Fi access with any mobile device
- 12 direct string inputs reduce labor and material costs
- AC/DC overvoltage protection (optional)

Fastest Installation
- Fast grid connection due to easy inverter configuration and commissioning
- Completely accessible connection areas

Maximum Yields
- Up to 150% DC:AC ratio
- Six independent MPP trackers guarantee optimal energy production for every use, even in shading

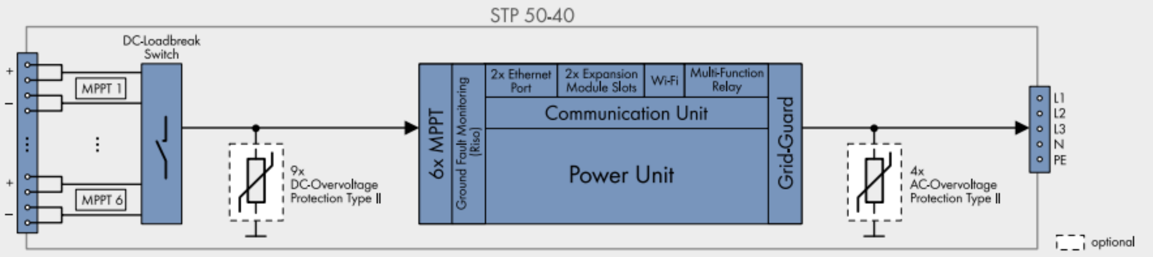
SUNNY TRIPOWER CORE1

Stands on its own

The Sunny Tripower CORE1 is the world's first free-standing string inverter for decentralized rooftop and ground-based PV systems as well as covered parking spaces. The CORE1 is the third generation in the successful Sunny Tripower product family and is revolutionizing the world of commercial inverters with its innovative design. SMA engineers developed an inverter that combines a unique design with an innovative installation method to significantly reduce installation time and provide all target groups with a maximum return on investment.

From delivery and installation to operation, the Sunny Tripower CORE1 generates widespread savings in logistics, labor, materials and services. Commercial PV installations are now quicker and easier to complete than ever before.

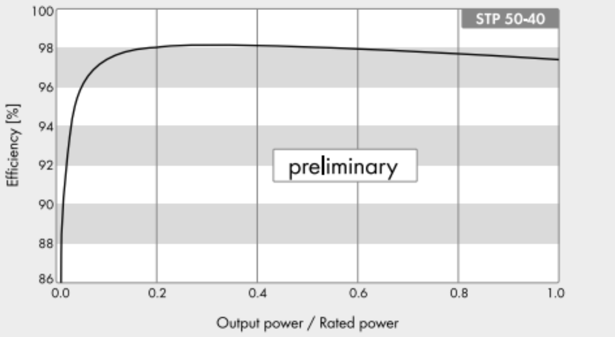
BLOCK DIAGRAM



Technical Data (preliminary)	Sunny Tripower CORE1
Input (DC)	
Max. DC power (at cos φ = 1) / DC rated power	51000 W / 51000 W
Max. input voltage	1000 V
MPP voltage range / rated input voltage	150 V to 1000 V / 500 V to 800 V
Min. input voltage / start input voltage	150 V / 188 V
Max. operating input current / per MPPT	120 A / 20 A
Max. short circuit current per MPPT / per string input	30A / 30A
Number of independent MPPT inputs / strings per MPP input	6 / 2
Output (AC)	
Rated power (at 230 V, 50 Hz)	50000 W
Max. apparent AC power	50000 VA
AC nominal voltage	3 / N / PE; 220 V / 380 V 3 / N / PE; 230 V / 400 V 3 / N / PE; 240 V / 415 V
AC voltage range	180 V to 280 V
AC grid frequency / range	50 Hz / 44 Hz to 55 Hz 60 Hz / 54 Hz to 65 Hz
Rated power frequency / rated grid voltage	50 Hz / 230 V
Max. output current / Rated output current	72.5 A / 72.5 A
Output phases / line connections	3 / 3
Power factor at rated power / Adjustable displacement power factor	1 / 0.0 leading ... 0.0 lagging
THD	3%
Protective devices	
Input-side disconnection device	●
Ground fault monitoring / grid monitoring	● / ●
DC reverse polarity protection / AC short-circuit current capability / galvanically isolated	● / ● / –
All-pole sensitive residual-current monitoring unit	●
Protection class (according to IEC 62109-1) / overvoltage category (according to IEC 62109-1)	I / AC: III; DC: II
AC/DC surge arrester (Type II)	○ / ○

Technical Data (preliminary)	Sunny Tripower CORE1
Efficiency	
Max. efficiency / European efficiency	>98.0% / >98.0%
General data	
Dimensions (W/H/D)	621 mm / 733 mm / 569 mm (24.4 in / 28.8 in / 22.4 in)
Weight	82 kg (180 lb)
Operating temperature range	-25°C to +60°C (-13°F to +140°F)
Noise emission (typical)	<60 dB(A)
Self-consumption (at night)	<5 W
Topology / Cooling concept	Transformerless / OptiCool
Degree of protection (as per IEC 60529)	IP65
Climatic category (according to IEC 60721-3-4)	4K4H
Max. permissible value for relative humidity (non-condensing)	100%
Features / functions / accessories	
DC connection / AC connection	SUNCLIX / screw terminal
LED indicators (status / fault / communication)	●
Interface: Ethernet / WLAN / RS485	● (2 ports) / ● / ○
Data interface: SMA Modbus / SunSpec Modbus / Speedwire, Webconnect	● / ● / ●
Multi-Function relay / Expansion Module Slots	● / ● (2 ports)
OptiTrac Global Peak / Integrated Plant Control / Q on Demand 24/7	● / ● / ●
Off-grid capable / SMA Fuel Save Controller compatible	● / ●
Guarantee: 5/10/15/20 years	● / ○ / ○ / ○
Certificates and permits (more available on request) * Does not apply to all national appendices of EN 50438	ANRE 30, AS 4777, BDEW 2008, C10/11:2012, CE, CEI 0-16, CEI 0-21, EN 50438:2013*, G59/3, IEC 60068-2-x, IEC 61727, IEC 62109-1/2, IEC 62116, MEA 2013, NBR 16149, NEN EN 50438, NRS 091-2-1, PEA 2013, PPC, RD 1699/413, RD 661/2007, Res. n°7:2013, SI4777, TOR D4, TR 3.2.2, UTE C15-712-1, VDE 0126-1-1, VDE-ARN 4105, VFR 2014, P.O.12.3, NTCO-NTCyS, GC 8.9H, PR20, DEWA
● Standard features ○ Optional – Not available	
Data at nominal conditions - preliminary version: 11/2016	
Type designation	STP 50-40

Efficiency Curve



Assessories

SMA Sensor Module MD.SEN-US-40

SMA IO-Module MD.IO-40

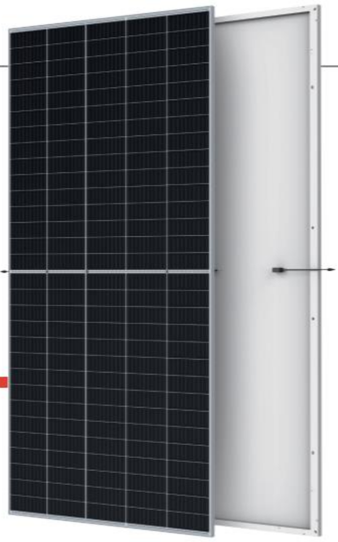
SMA RS485 Module MD.RS485-US-40

Antenna Extension Kit EXTANT-US-40

AC Surge Protection Module Kit AC_SPD_Kit1-10
DC Surge Protection Module Kit DC_SPD_Kit4-10

Appendix 17:TSM-DE18M(II) datasheet

Mono Multi Solutions



THE Vertex

BACKSHEET MONOCRYSTALLINE MODULE

500W+
MAXIMUM POWER OUTPUT

21.1%
MAXIMUM EFFICIENCY

0~+5W
POSITIVE POWER TOLERANCE

PRODUCTS	POWER RANGE
TSM-DE18M(II)	480-505W

High customer value

- Lower LCOE (Levelized Cost Of Energy), reduced BOS (Balance Of System) cost, shorter payback time
- Lower guaranteed first year and annual degradation
- Designed for compatibility with existing mainstream system components

High power up to 505W

- Large area cells based on 210mm silicon wafers and 1/3-cut cell technology
- Up to 21.1% module efficiency with high density interconnect technology
- Multi-busbar technology for better light trapping effect, lower series resistance and improved current collection

High reliability

- Minimized micro-cracks with innovative non-destructive cutting technology
- Ensured PID resistance through cell process and module material control
- Resistant to harsh environments such as salt, ammonia, sand, high temperature and high humidity areas
- Mechanical performance up to 5400 Pa positive load and 2400 Pa negative load

High energy yield

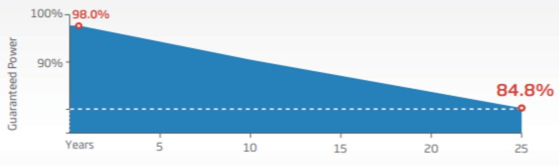
- Excellent IAM (Incident Angle Modifier) and low irradiation performance, validated by 3rd party certifications
- The unique design provides optimized energy production under inter-row shading conditions
- Lower temperature coefficient (-0.36%) and operating temperature

Founded in 1997, Trina Solar is the world's leading total solution provider for solar energy. With local presence around the globe, Trina Solar is able to provide exceptional service to each customer in each market and deliver our innovative, reliable products with the backing of Trina as a strong, bankable brand. Trina Solar now distributes its PV products to over 100 countries all over the world. We are committed to building strategic, mutually beneficial collaborations with installers, developers, distributors and other partners in driving smart energy together.

Comprehensive Products and System Certificates

IEC61215/IEC61730/IEC61701/IEC62716
ISO 9001: Quality Management System
ISO 14001: Environmental Management System
ISO14064: Greenhouse Gases Emissions Verification
ISO45001: Occupational Health and Safety Management System

Trina Solar's VERTEX Backsheet Performance Warranty

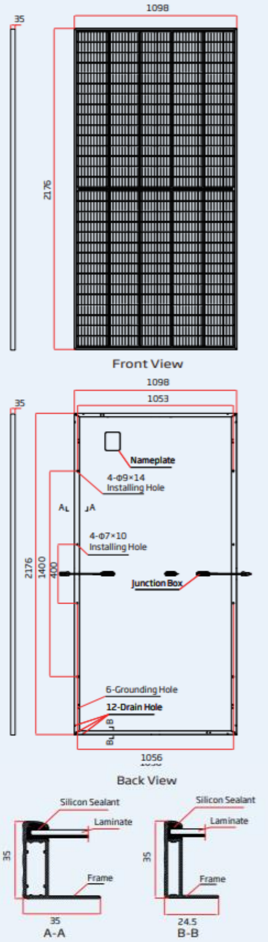


Trinasolar

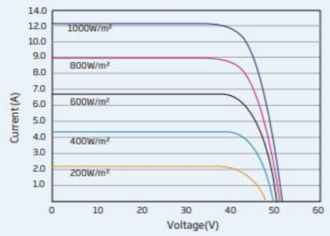
Vertex

BACKSHEET MONOCRYSTALLINE MODULE

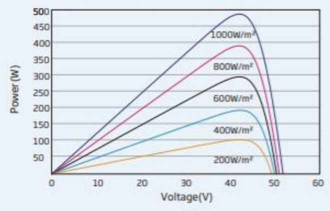
DIMENSIONS OF PV MODULE(mm)



I-V CURVES OF PV MODULE(490 W)



P-V CURVES OF PV MODULE(490W)



ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)*	480	485	490	495	500	505
Power Tolerance-P_{MAX} (W)	0 ~ +5					
Maximum Power Voltage-V_{MPP} (V)	42.0	42.2	42.4	42.6	42.8	43.0
Maximum Power Current-I_{MPP} (A)	11.42	11.49	11.56	11.63	11.69	11.75
Open Circuit Voltage-V_{OC} (V)	50.8	51.1	51.3	51.5	51.7	51.9
Short Circuit Current-I_{SC} (A)	11.99	12.07	12.14	12.21	12.28	12.35
Module Efficiency η_m (%)	20.1	20.3	20.5	20.7	20.9	21.1

STC: Irradiance 1000W/m², Cell Temperature 25°C, Air Mass AM1.5.
*Measuring tolerance: ±3%.

ELECTRICAL DATA (NMOT)

Maximum Power-P_{MAX} (Wp)	363	367	371	375	379	382
Maximum Power Voltage-V_{MPP} (V)	39.6	39.8	40.0	40.2	40.4	40.6
Maximum Power Current-I_{MPP} (A)	9.15	9.20	9.26	9.32	9.37	9.43
Open Circuit Voltage-V_{OC} (V)	48.0	48.2	48.4	48.6	48.8	49.0
Short Circuit Current-I_{SC} (A)	9.65	9.72	9.77	9.83	9.89	9.94

NMOT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.

MECHANICAL DATA

Solar Cells	Monocrystalline
Cell Orientation	150 cells
Module Dimensions	2176 ×1098× 35 mm (85.67 × 43.23 × 1.38 inches)
Weight	26.3 kg (58.0 lb)
Glass	3.2 mm (0.13 inches), High Transmission, AR Coated Heat Strengthened Glass
Encapsulant Material	EVA
Backsheet	White
Frame	35 mm (1.38 inches) Anodized Aluminium Alloy
J-Box	IP 68 rated
Cables	Photovoltaic Technology Cable 4.0mm² (0.006 inches²), Portrait: N 280mm/P 280mm(11.02/11.02inches) Landscape: N 1400 mm /P 1400 mm (55.12/55.12 inches)
Connector	MC4 EVO2 / TS4*

*Please refer to regional datasheet for specified connector.

TEMPERATURE RATINGS

NMOT (Nominal Module Operating Temperature)	41℃ (±3℃)
Temperature Coefficient of P_{MAX}	- 0.36%/℃
Temperature Coefficient of V_{OC}	- 0.26%/℃
Temperature Coefficient of I_{SC}	0.04%/℃

MAXIMUMRATINGS

Operational Temperature	-40~+85℃
Maximum System Voltage	1500V DC (IEC)
Max Series Fuse Rating	20A

(Do not connect Fuse in Combiner Box with two or more strings in parallel connection)

WARRANTY

12 year Product Workmanship Warranty
25 year Power Warranty
2% first year degradation
0.55% Annual Power Attenuation

(Please refer to product warranty for details)

PACKAGING CONFIGUREATION

Modules per box: 30 pieces
Modules per 40' container: 600 pieces